Enabling Autonomy in Aircraft Towing Operations

A case study utilizing the towing driver's perspective at KLM Royal Dutch Airlines

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Acknowledgements

Dear Reader

This Graduation Project is the culmination of a two-year journey as a student of Integrated Product Design at the Faculty of Industrial Design Engineering at Delft University of Technology. As an engineer, it was a truly insightful experience studying design and working in aviation for this project reignited my interest in the field. The project allowed me to combine my interests in aviation with my design and engineering background, providing learnings that will inspire my work in the coming years.

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This thesis would not have been possible without the support of my family and friends. Their words of encouragement and relentless optimism in my abilities served as motivation throughout the project. This project would not be where it is without them.

I hope this research serves as a benchmark, not only for KLM's automation projects in the future, but also for other companies to employ user-centered methods, integrating the inputs and feedback of the human workforce meant to collaborate with automation throughout the technology integration process. The role of the human in human-machine collaboration is still relevant and must be considered.

"Ultimately, it is not going to be about man versus machine. It is going to be about man with machines".
– Satya Nadella, CEO, Microsoft

Aayush Bhat
July, 2025

Abbreviations

CDM	Critical Decision Method
CDE	Critical Decision Experiment
DP	Decision Point
HMC	Human Machine Collaboration
HMI	Human Machine Interaction
LoA	Level of Autonomy
LiDAR	Light Detection and Ranging
MRO	Maintenance, Repair and Overhaul
PSW	Parasuraman, Sheridan, and Wickens
RAM	Rational Agent Model
RC	Remote Controlled
TA	Think Aloud

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Executive Summary

The post-pandemic period was a critical point for the aviation industry; the shortage of workforce meant difficulties in keeping up with tight aircraft maintenance schedules. To deal with this, KLM Royal Dutch Airlines designed the Back-on-Track program, which emphasized introducing automation as a long-term goal to deal with labour shortages. While there is an attempt to gradually introduce autonomous technologies into the workflow, the opinions and inputs of the employees meant to collaborate with said technologies are not often considered. This gives the impression of a technology push, persuading the employees to collaborate with them. That is where this project comes in; it focuses on technological pull, using the employees' feedback as input in introducing an autonomous system.

This project is performed at the MRO Lab and aims to aid the aircraft towing operations at KLM's Hangar 12. KLM uses a remote-controlled towing vehicle called the Mototok to tow an aircraft into and out of the hangar for maintenance. The MRO Lab intends to make this towing process more autonomous, making this project their first attempt to do so.

The project starts with establishing a main research question and sub-research questions, followed by understanding the towing process, specifically its phases, its people, and the interactions occurring between them. To visualize the towing process, a scaled-down, 3D printed version of the setup was created with all towing-relevant infrastructure. An experimental interview arranged with two Mototok drivers helped visualize the towing procedure through the setup, resulting in the development of a process map, containing every step of the towing process, and an interaction map, linking every interaction between operators with the process map.

The first novel aspect of this thesis is a custom framework developed to identify that the safety verification role of the walkers is an ideal starting point to introduce autonomy. This required structuring the flow of information through the Rational Agent Model and breaking the process into functional clusters, followed by the consideration of key inputs from a safety and compliance perspective. Research indicated that the Rational Agent Model matched closely with the Parasuraman, Sheridan, and Wickens framework, which also provides a scale for autonomous system levels. Using its scale as a reference, a Level 2 autonomous system was chosen to replace the safety verification role of the walkers.

Before using the technology in towing, it must be tested. A system-level test was chosen over a product-level test to ensure the autonomy can be evaluated in a context-specific manner. Since the information perceived by the autonomous system would directly impact the decision-making of the drivers, this decision-making was chosen as the test area for the system. However, it was decided to first test the decision-making with the walkers, so that the natural decision-making behaviour could be revealed, along with more specific factors that could be used to test the decision-making of the drivers.

The Critical Decision Method was used to set up the decision-making experiment, which involved an experiment followed by an interview with the driver. The test was based on the driver's decision-making under certain worst-case scenarios, which they are not trained for, but could occur in towing conditions. A specific situation of the driver receiving multiple inputs was incorporated into the experiment to further understand worst-case decision-making. The scaled-down setup involved simulating the driver and walker's vision via cameras to maintain a more realistic vision of the towing environment. Results from the scaled-down experiments revealed a decision-making model.

The interview revealed that the driver's ability to make decisions was heavily reliant on his trust in the walker's inputs. Thus, the challenge for the perception system test would be to understand if the driver trusts the inputs provided. Guidelines were provided to design this test while addressing any possible limitations.

Finally, the project is concluded and reflected on by answering the main research question and discussing its implications for academia and KLM. The next possible steps to take this project forward are also discussed.

Section 1.

Discover

This section starts with a broad exploration of automation in the aviation industry and the factors that play a role in successful automation implementation. This helps set up a research gap. It then introduces KLM's project brief and the reason behind the challenge set forth. A design approach is established for the project, following which the literature survey and KLM's contextual analysis help develop research questions to be answered to understand the towing process. Finally, a practical research opportunity is also identified which helps build the case for the project brief, and how the results of the thesis would add value for the client.

Chapter 1. Context Exploration
Chapter 2. Project Introduction
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Chapter 1.
Context Exploration

This chapter defines the latest progress in the aviation industry through the lens of user-centered automation and the importance of human-machine collaboration in the workplace. The chapter ends with a theoretical research gap that will be addressed by this study.

1.1 Automation in Aviation

The advances in technology observed over the recent years have been the driving factor in propagating the idea of Industry 4.0. Within the new era of industrialization, innovations in the field of digitized technologies have been coupled to create value through automation (refer to Figure 1), which is one of the targets of the Industry 4.0 movement (Ghobakhloo, 2020). With nations moving towards more sustainable practices following the Sustainable Development Goals (SDGs) (Stafford-Smith et al., 2017), automation has come to play a key role in the transition towards the efficient use of resources. This is evident in many sectors, for instance, offering automated technologies as an aid to sustainable construction practices (Pan et al., 2018), frameworks such as 'AI4GoodTourism' for the advent of intelligent automation to promote environment-friendly viewpoints in tourism (Majid et al., 2023), developing automated vehicles to conserve and redirect human effort towards more functional purposes (Bathla et al., 2022), etc.

Within the scope of industrial processes, automation aims to improve efficiency and accuracy under a limited set of resources (Galaz et al., 2021). This idea is heavily utilized in the transportation sector, particularly in aviation. Aviation can be considered a broader term encompassing the relationship between multiple stakeholders: airports, airlines, the Government, external clients who provide services such as catering and ground staff, etc. The implementation of automated technology requires each stakeholder to take active steps towards its adoption (Hendra et al., 2024).

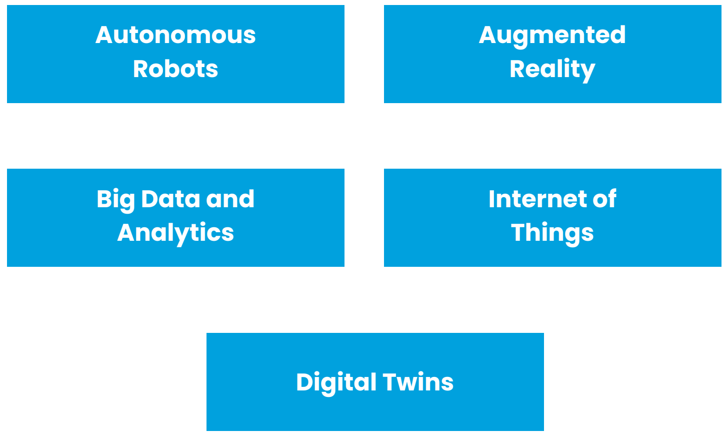


Figure 1. Technologies in Industry 4.0 (Ghobakhloo, 2020)

The aviation sector has witnessed multiple examples of cohesive, governance-led implementation of automated technologies. Most automated systems have been used within the cockpit to assist pilots through the many operations that need to be performed. Some examples include the use of automatic flight control systems (AFCS) take over, to some degree, the flying of the aircraft which lowers the cognitive workload of the pilots (Sadraey, 2020), and flight-management systems enable optimized route planning and navigation (Walter, 2001). Over the past few decades, research and technological implementation of automated systems for on-ground services have also sharply risen, such as automated baggage-handling systems (see Figure 2) (Rijsenbrij & Ottjes, 2007, Aurrigo, 2025) and automated self-check-in kiosks in airports (Abdelaziz et al., 2010), to name a few. Most on-ground automated operations can capably replace repetitive manual tasks and thus require research on the collaborative approach for human-automated machine systems. While these automated systems exist, their initial implementation requires effort, not only through scientific research and testing but also through a systematic and informed approach to involving all stakeholders during the process.

The possibility of allowing automated systems to intervene in in-flight and on-ground operations has benefited airlines' economic standpoint; companies have started approaching automation as a sustainable and realistic feature of the workplace and continue to find ways to strike the right balance between human-led and machine-led tasks.

Figure 2. Aurrigo's autonomous baggage handling vehicle at Schiphol Airport (Aurrigo, 2025)

1.2 Industry 4.0 to Industry 5.0

The Level of Autonomy (LoA) (Vagia et al., 2016) is often a deciding factor in understanding the manner and quality of its implementation. The LoA is a taxonomy that determines the level to which a system can take over tasks and perform them independently. For example, while developing a manufacturing strategy, the LoA is determined by how the task is generally conducted, and more importantly, the degree of interaction between the operator and the system (Lindström & Winroth, 2010).

The realization of the importance of Human-Machine Collaboration (HMC) has guided the transition towards Industry 5.0, which, in addition to prioritizing a technology-centric approach, also focuses on a human-centric outlook in the workplace when it comes to defining the role of automated systems (Xu et al., 2021). Introducing automated systems can influence the nature of a workplace, for instance, in its design and arrangement for the physical and cognitive well-being of the individuals, as well as the organizational well-being of the institution (Antonaci et al., 2024). While the underlying technology can guarantee the technical performance of an automated system, an effort to understand its impact on a human workplace is just as important. The taxonomy of LoAs plays a vital role in understanding the nature of this impact. With varying LoAs, the interaction between an autonomous system and the human operator varies, and the roles undertaken by each change. Inspired by SAE's automation taxonomy, a case study takes inspiration to derive the autonomous levels in aircraft systems, which are assistance, partial automation, highly automated, fully automated, and autonomous (in order) (Anderson et al., 2018).

For instance, for in-flight tasks based on navigation, communication, system management, and command decisions, the general theme is a higher observable HMC within the first three levels, beyond which the pilot has only an observational or monitoring role, with the system doing most of the reasoning work.

As a workplace transitions towards collaborative human-machine environments, its impact on working individuals must be understood. This benefits the transition towards a transparent and partnered workplace, which eventually builds trust (Saadati et al., 2021), and influences whether the technology would be successfully adopted. One of how this impact can be viewed is by visualizing the new interaction between the human and the introduced machine, and the acceptance/change in work-related roles. Examples of on-ground operations can help understand this perspective better. Airlines are required to perform pre-flight inspections to ensure the safety of the aircraft, for which most companies are now shifting towards autonomous approaches. The use of Unmanned Aerial Vehicles (UAVs) in a pre-flight inspection process reduces the human effort to perform these detailed operations manually, while also reducing errors due to human influence (Novák et al., 2021). Since the UAVs are not fully autonomous yet in this case, the operator still has a role to play in the process. This role could range from planning and setup of the operation, controlling the drone, etc, to monitoring and intervention, all defined by the LoA of the system.

In a similar approach, Airbus has developed an advanced inspection drone to inspect the aircraft fuselage within 30 minutes by operators without drone flying qualifications (Olaganathan, 2024). Similarly, the mode of interaction between the operator and the system needs to be defined, which may influence the work roles of both the machine and the operator.

1.3 Human-Machine Collaboration

While automated systems provide technological benefits, it becomes equally important to take into account the organizational aspect of their autonomy; specifically, the introduction of autonomous systems means an obvious impact on manual operations, and by extension, on the employees of the workplace. Thus, it is important to assess the factors that define a healthy co-working relationship between humans and autonomous agents. A productive workplace is governed by certain criteria explored in the following segments, which define the quality of the relationship that develops between humans and machines. Figure 3 summarises how these factors vary between Industry 4.0 and Industry 5.0.

Comparitive Factors	Industry 4.0 Technology-Centric	→	Industry 5.0 Human-Centric
Human Role	Supervisory/Monitory		Active Collaborator
Trust & Transparency	Based on technological reliability & performance		Built through transparent interaction
Communication	One-way: Machine informs human of status/actions		Continuous dialogue and feedback
Task Allocation	Machine attempts to replace human tasks entirely		Based on strengths of the human and the machine
Error Management	Machine driven with human intervention as backup		Collaborative problem solving
Philosophy	"How can technology replace human tasks?"		"How can humans & machines work together"

Figure 3. HMC factors across Industry 4.0 & Industry 5.0

1.3.1 Trust, Transparency, and Confidence

The transparency (Lee & Moray, 1992) of an automated system in relaying its activities to the user builds trust. A user generally trusts a technology when they can receive accurate information and communicate with it accordingly. The definition of transparency varies with the context, and identifying what information needs to be provided to maintain transparency significantly impacts the user experience of the operator in the process, and ensures a protected workspace (Tatasciore et al., 2024). This becomes extremely important in aviation, where safety is of paramount importance.

While studies indicate that increased transparency improves trust between a system and its operator, there have also been cases where increased transparency has resulted in a bias toward the automated system's output (Tatasciore & Loft, 2024). This could lead to operators neglecting errors and trusting the system's result without validation (Carragher, 2024). This 'complacency' factor has been previously identified in cases where operators fail to observe deviations from regular operations due to high trust in the automated system (Moray & Inagaki, 1999). Generally, systems providing low confidence results resulted in the users neglecting that advice (Moray & Inagaki, 1999). Users receiving confidence information about the system have also been shown to been less prone to automation bias. However, theory has indicated that there is no correlation between the confidence of an automated system and its transparency (Tatasciore & Loft, 2024).

1.3.2 Communication

Human-machine interaction (HMI) defines the nature and quality of the collaborative effort between the user and the machine (Hoc, 2000). To align the system's goals with the user's, both must have a common understanding of the shared environment, tasks, and goals. The means of HMI dictate how similar their communication standards are, the quality of feedback, and thereby how well the two understand each other.

The mode of communication may vary in the human-to-robot direction and vice versa. Both communication directions have undergone in-depth development, ranging from haptics, natural language, expressions, etc, to augmented reality and multimodal systems (Ajoudani et al., 2018).

The timing of this communication matters in the context of the work being performed; in time-dependent tasks, the robot's actions, i.e., communication in this case, would take precedence in the context, leading to possible interference with the user's activities. This could impact trust in the long term. Thus, communication must take into account the urgency/relevance of the task while perceiving (Boos et al., 2020) the user's environment. Consequently, humans must be trained in ways of effective interaction in an automated environment.

1.3.3 Task allocation

When automation starts taking over manual labor, the tasks taken up by humans in the process change. The new allocation of functions must conform to the manual and autonomous segments' capabilities in the process, as well as the interaction between the two (Pritchett et al., 2014).

Usually, automation is introduced for one of three reasons: high task complexity (McBride et al., 2014), frequency (Isaza & Cepa, 2024), and volume (Sharp et al., 2021). Each case usually benefits the human in the loop in ways such as reduced physical and cognitive strain, ability to perform alternative tasks, and improved safety. Assuming a complementary relationship between the human and the machine (considering the aforementioned factors like trust and communication), the role of the human usually shifts up the value chain, generally from execution to administration and problem-solving from a broader, process perspective. It is important to note that automation does not necessarily reduce the workload of humans. In several cases, stop-gap labor, which refers to the human managing the errors in the results of the automated system, also contributes to their workload, which is often neglected (Lee et al., 2025).

An important consideration while defining the task allocation for a process is understanding the extent to which tasks might be performed outside the boundary conditions/defined and trained conditions. Usually, when a human is exposed to critical conditions that require actions outside the defined protocols (Roth et al., 2019), critical thinking and the ability to adapt and make decisions ensure the task is completed. However, automated systems are usually not as effective in such situations, unless rigorously trained for every contingency. Thus, task allocation to automated systems must have an underlying understanding of the extent and frequency to which a process is executed outside nominal conditions.

A well-distributed task factors in the ability, authority, and responsibility criteria for a process (Flemisch et al., 2012). While the execution of a task is usually dependent on the ability of the human/machine to complete it, the authority to take control of the process depends not just on the ability to perform a task, but also on experience in execution, training, and frequency of the occurrence of the worst-case scenario. Considering both humans and machines are equally capable of performing a task under nominal conditions, the difference often comes up under worst-case scenarios where humans have greater experience in dealing with the situation, giving them authority. The variation in authority is thereby a dynamic process. The responsibility of the execution generally lies with the human, even in the middle-high LoAs. The phenomenon, known as the accountability gap (Simmler, 2024), persists due to the human supervision roles and because moral responsibility usually defaults to them.

1.4 Literature Research Gap

The aviation industry has witnessed several automated projects within the last few decades. While some have been implemented within daily operations, such as the aircraft autopilot system, and have achieved high implementation efficiency, others are still under development. The heavily regulated and safety-oriented environments require extensive technological and contextual testing to ensure the system fits in the workplace (Helle, Schamai, & Strobel, 2016). As a result, autonomous projects often remain conceptual in aviation contexts. This study will attempt to break past the conceptual barrier, combining automation theory and practical, contextual information to make progress towards realizing a more autonomous towing vehicle.

While the impact of automated systems on human-led work environments has been studied in detail (Filippi, Bannò, & Trento, 2023), little emphasis is given to how an autonomous system must be chosen for a particular context. Through literature review, no particular framework was found that could provide guidelines towards taking theoretical information and practical factors into consideration to inform the choice of an autonomous system. Since practical information is very specific to different contexts, this could explain why studies have not previously addressed this gap. These practical factors also represent the input and method of working of the humans meant to use the technology, which is often not considered while choosing an autonomous system and will be addressed through this study.

Moreover, research has indicated that practical environments like aviation often introduce automation in incremental LoAs, to test each level in specific contexts before applying the highest level (Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1992). However, research does not provide a framework to make this choice of LoA, which is a gap that will also be addressed in this study.

Chapter 2.
Project Introduction

This chapter introduces the project from KLM's perspective. It sets up the project scope and stakeholders, and introduces the approach followed for the design process. Finally, research questions for the project are introduced.

2.1 Aviation in the Post-Pandemic Period

The COVID-19 period marked a significant turning point for industries around the globe. Due to the exposed vulnerabilities in global supply chain networks, companies were required to adapt quickly by modifying operational strategies, transforming digitally, and reshaping workforce dynamics. While some industries managed to subdue the subsequent economic impact through the abovementioned measures, others took longer to recover, leading to more significant financial implications over the years. For instance, industries whose day-to-day operations were dependent on their physical workforces, such as construction and manufacturing, found it highly challenging to maintain their operational output, due to absenteeism (Nowak et al., 2023), and preventing equipment from being idle. On the other hand, the IT services industry coped better by building remote working digital infrastructures and allowing its employees to work remotely, thus maintaining a better working output.

The aviation industry was among the hardest hit by the pandemic, due to the disrupted global air travel that led to huge financial losses (Jaap Bouwer, 2022). Despite operational involvement during the pandemic to supply medical cargo and personnel (Nhamo et al., 2020a), it failed to overcome the revenue losses inflicted throughout the aviation supply chain. Some airports restructured to facilitate the delivery of essential supplies but failed to raise adequate revenue, further affecting jobs (Nhamo et al., 2020b). In addition to facing aircraft order cancellations, manufacturers were forced to cut a large number of jobs (Woo et al., 2021). Ground handling and catering companies, which were dependent on the passenger volumes, also faced the possibility of business closures. The pandemic especially impacted the European aviation market since it hosted some of the most globally connected airports. (Su et al., 2023). One of these airports was the Amsterdam Airport Schiphol, the home hub of the KLM Royal Dutch Airlines.

Airlines were one of the most impacted stakeholders of the aviation market (Szczygielski et al., 2022). As the rate of tourism dropped, so did travel. The International Air Transport Association (IATA) estimated a $252 billion revenue loss by the airline industry, with millions losing their jobs (Kolahchi et al., 2021). To offset these negative impacts of the pandemic, several airlines took strategic measures to survive and build stability.

> “The pandemic wreaked financial devastation across the aviation value chain, most notably for airlines. All subsectors reported massive losses in 2020, except for freight forwarders and cargo airlines.”

Source: Jaap Bouwer, 2022 (McKinsey & Company)

2.2 KLM’s strategic response

2.2.1 The immediate reaction

The pandemic had a profound impact on KLM Royal Dutch Airlines in terms of operational and financial challenges. Due to the outbreak, KLM initially reduced the number of flights it operated, leading to significant financial losses. The uncertain situation led to KLM being forced to reduce its workforce by around 15 percent in 2021 to reduce operational costs.

2.2.2 The current scenario

As of 2024, KLM has recovered from its poor financial position during the peak of the pandemic. Despite high operating profits, the figures are still lower than those observed in 2023. This is primarily due to the layoffs during the pandemic, which resulted in productivity losses due to a shortage of staff. Another factor contributing to the decline in productivity is the aging employee population at KLM, particularly those who contribute to manual labor within the company.

The Back-on-Track program is the latest plan devised by KLM (KLM, 2024), which, while protecting jobs across the company as much as possible, will seek to continue investments that contribute to sustainable operations while postponing investments that don’t (see Figure 4). One of the measures within this plan is to bring about a 5 percent increase in labor productivity at the very least, through automation and mechanization. This would mean offsetting the shortage of manual labor with on-ground autonomous operations to achieve a more productive workforce. At the same time, KLM is attempting to gradually introduce automation projects, so that the manual workforce is not impacted all at once. While KLM recognizes the initial economic and infrastructural investment required to accommodate these new operations, it believes that laying the early foundations is a certain way of securing a profitable future.

This project falls within this innovation strategy at KLM E&M. Aligning itself with KLM’s broader strategy, KLM Engineering and Maintenance (KLM E&M) developed its innovation strategy to develop an ecosystem driven by data and autonomous operations. The ambition was to create a long-term vision of innovation, with automation as a key focus area, and execute potential concepts on operational levels.

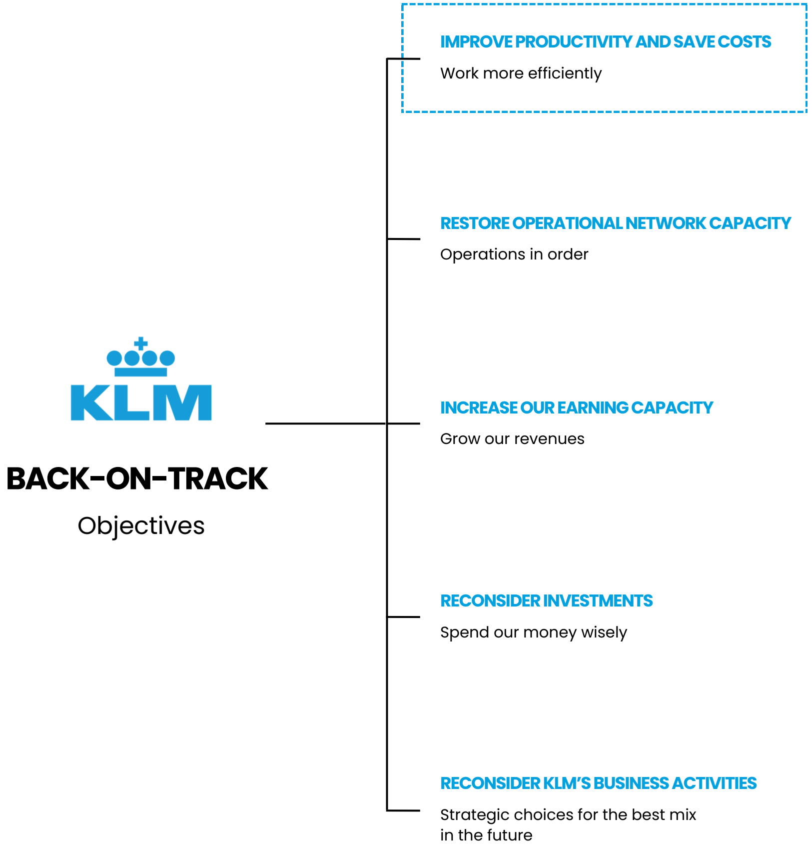


Figure 4. KLM’s objectives for the Back-on-Track program

2.3 Project Brief and Scope

As part of its autonomous operations development project, KLM envisions a future with more autonomous ground operations. Since a majority of the KLM workforce is responsible for on-ground operations in aircraft maintenance hangars, this is where the staff shortage has hit the hardest, and where autonomy would be most beneficial. The project is undertaken by the Maintenance, Repair, and Overhaul (MRO) Lab, which focuses on innovation and continuous improvement projects.

This project is one of several ongoing autonomous operations projects at the maintenance hangars and focuses specifically on the autonomous movement of an aircraft from the hangar to the parking area. The process, called towing, currently utilizes a diesel-powered tow truck driven manually by an operator to push/pull the aircraft after making a physical connection between the nose-landing gear and itself.

In collaboration with Mototok, a company that manufactures electric tow tugs, KLM has introduced a fleet of remote-controlled tugs as a first step toward its innovation strategy. While the Mototok tug (hereby referred to as the Mototok) provides various operational and environmental benefits compared with its current competitor truck, it is still a highly manual truck requiring a fair amount of user control. KLM views the Mototok as the successor of the current truck, but with a long-term objective of developing a fully autonomous Mototok. Achieving this vision requires incrementally increasing the autonomous level of the tug.

The project is divided into two areas of expertise: a Systems Engineering segment focusing on the hardware and software requirements of developing the autonomous Mototok, and an Operational segment focusing on understanding the operational aspects of towing, i.e., how and where autonomy can be introduced and tested in the towing process. This thesis focuses primarily on the second expertise area, while some insights from the former will be used to finalize boundary conditions.

2.4 Stakeholders

The project is a collaborative effort between the primary researcher (i.e., myself), the client KLM Royal Dutch Airlines, and the educational institute Delft University of Technology. At KLM, the main stakeholders are the Project Manager at the MRO Lab, the operators involved in the towing process, and the safety and regulations department. At the university, the project is guided by the supervisory team consisting of a Project Chair and a Project Mentor. External stakeholders include private companies that work in autonomous development, including the one currently under contract with KLM for its provision of the towing vehicle, and others that may provide technological additions to increase the autonomy of the process.

2.5 Challenge

The incremental process of increasing the autonomy of the towing process requires identifying the area and the level at which the autonomy can be introduced. This requires first understanding the towing operation; the steps involved, the operators involved, and the interaction between them. The complex flow of information requires a systematic arrangement so that opportunities for autonomy can be identified. KLM's context provides the information to be structured, and existing knowledge from literature provides a reference to how this knowledge can be structured.

Any technology introduced into a safety-driven workflow requires concrete testing (Schiphol, 2021). The intention of testing the autonomous technology introduced at the specified level and within a particular aspect of the towing process at KLM is to determine whether the technology is capable of performing the desired function at a contextual level. To do so, it becomes necessary to understand what must be tested in the first place. The operators involved in the towing process would be one of the primary stakeholders impacted by the autonomous technology, making it critical to assess the nature of this impact. If the technology replaces the roles of some operators involved in the towing, the impact on the rest of the operators still involved must be understood. This approach will be followed for the project, where, particularly, the role of the driver of the Mototok will be studied, and the consequent factors to be tested to assess the impact on the driver will be determined.

2.6 Approach

The conventional double-diamond method (see Figure 5) is used as the structure for the project, as it is often found in human-centered design processes (Melles et al., 2021). The process of developing an autonomous vehicle is procedural, requiring an experimental approach and verification after increasing the autonomy at every stage of development (Su & Wang, 2021). This project will visualize the user interaction and experience of driving the Mototok after its autonomous capabilities have been enhanced to some defined degree, leading the project towards a more enhanced autonomy stage. The process of defining all the stages through which autonomy should progress, however, is not within the scope of this project. This will be led by an experimental approach, requiring feedback from the operators within that stage. The results will contribute towards furthering the autonomous development of the tug by prioritizing the understanding of operator input as a significant requirement in the development process.

2.7 Research Questions

Based on the project brief and the literature review, the main question that needs to be answered is:

What process can be followed to introduce an autonomous technology into the Mototok towing workflow?

The research sub-questions are:

1. When is a towing operation considered successful? What factors influence the success of the towing?

2. How can the towing process be visualized if a real-time towing operation cannot be performed?

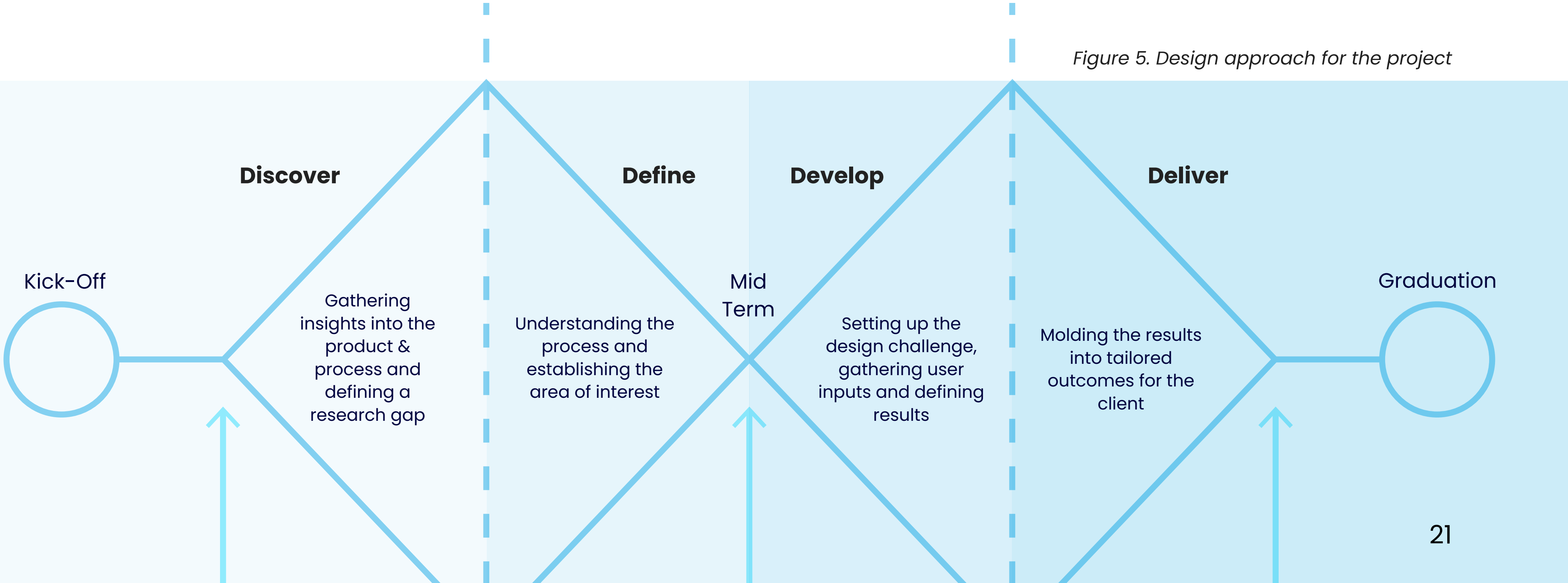
3. What methodology can be utilized to derive a level of autonomy for the towing process?

4. How can the impact of autonomy on the towing be assessed?

5. Should the testing be done in training-like scenarios? Are there more scenarios that might be relevant to test the decision-making of the driver?

6. How can the gap created by the limitations of the experiment be addressed if the experiment were performed under real towing conditions?

Figure 5. Design approach for the project



Chapter 3.

The Case at KLM

This chapter focuses on KLM’s post-pandemic challenges and its approach towards resolving them. It also sets the scene for KLM's collaborative efforts to offset productivity issues and presents a practical research opportunity for this project.

3.1 About KLM Royal Dutch Airlines

KLM Royal Dutch Airlines, established on October 7, 1919, is the official flag carrier of the Netherlands and holds the distinction of being the world's oldest airline still operating under its original name. It is a subsidiary of the Air France-KLM Group, formed through a merger between Air France and KLM in 2004, to strengthen its position within the aviation industry, expand its network, and achieve global connectivity. Air France, KLM, and Transavia are the three main brands within this group, which boast a fleet of 551 aircrafts and services to up to 300 destinations across 125 countries.

To compete against global airline groups that were part of two existing alliances (namely, Star Alliance and Oneworld), KLM became one of the founding members of the SkyTeam Alliance in June 2000. With 19 SkyTeam members within the alliance, KLM has expanded its operational connectivity to more than 170 countries, by offering its passengers services such as seamless check-in and flight transfer options, loyalty program benefits, and shared airport lounges. With its main hub at the Amsterdam Schiphol Airport, KLM has achieved increased passenger traffic through connections between SkyTeam members, thus strengthening its position as not only a major European carrier but also an international transit point.

The post-pandemic years have been challenging for the company; high operational costs and staff shortages have been the main disruptors to KLM’s profitability as of October 2024. Despite challenges in operational feasibility, KLM continues to place faith in its long-term development targets through various initiatives. Their strategy battles against rising costs and staff shortages by leveraging technology to spearhead improving labor productivity, which ultimately streamlines processes. The Back-on-Track program defines a set of measures that will be followed to achieve the same, one of them describing automation as the means to increase labor productivity by at least 5 percent. Similar initiatives promoting sustainability have eventually also contributed to total carbon neutrality and noise emission targets.

3.2 Technology to achieve Productivity

Under the guidelines of the Back-on-Track program, KLM is taking steps to resolve cost and productivity concerns. Apart from the revenue lost due to non-operational flights during the pandemic, the significant layoffs impacted operational feasibility in the post-pandemic period, furthering the revenue decline. The program defines the roadmap for KLM’s profitability target towards the end of 2025.

Technology has been a driving factor in KLM’s progress. Despite profitability challenges, KLM continues to believe that investing in radical innovation and technology is the way to ensure the fulfillment of its strategies while staying competitive in the aviation market. While KLM has been actively making changes throughout its operations to stay on track toward achieving said targets, noticeable changes can be observed in on-ground facilities. TaxiBot, a hybrid towing vehicle under development at KLM (in collaboration with the Royal Schiphol Group) boasts reduced fuel consumption by allowing the aircraft to be towed from the gate to the runway without the need to start the engines (Beumer, 2024). The self-driving, electric Ohmio Shuttles have also undergone trials, aiming to transfer cabin crew from the aircraft to the terminal and vice versa, reducing the need for an operator and providing emission-free transport. Both projects required intensive research and communicative efforts within KLM and across the stakeholders associated with the project.

3.3 The role of automation at KLM

In line with KLM's broad 2030 target of improving operational efficiency, KLM Engineering and Maintenance (KLM E&M) developed an innovation strategy to incorporate automation within different workflows. E&M believes that automation will bring in not only efficiency and quality through a "first-time-right" approach, which helps balance costs and revenues, but also have an impact on the optimal working conditions for the operators but reducing physically/cognitively demanding tasks. The strategy laid down innovation as a long-term vision, achievable through joint efforts between departments.

01 Predictive Maintenance

a suite of predictive maintenance solutions designed to enhance aircraft maintenance operations.

02 Digitalization

digital solutions such as virtual reality and online applications for technical training and cabin checks.

03 Robotics

facilitate drone inspections, cobots for part inspection and repairs, and 3D printing. This project falls within this expertise area.

Figure 6. MRO Lab's expertise areas

3.4 The MRO Lab

3.4.1 About the Department

This project will be conducted at the Maintenance, Repair, and Overhaul (MRO) Lab, which operates under KLM E&M and serves as a dedicated program to foster innovation, particularly for the challenges of aircraft maintenance. Driven by employee-led innovations and continuous improvement platforms, the MRO Lab serves as a problem-solving ecosystem driven by the idea of creating and inheriting existing market solutions, or collaborating with startups, universities, and manufacturers to generate innovative solutions to specific problems. The Lab focuses not only on developing cutting-edge solutions to KLM-specific problems (see Figure 6) but also creates and maintains contacts with external partners to incorporate solutions that may solve new problems within the company.

The MRO Lab brings solutions into the workplace in one of three ways:

a) Fully internally, whereby the entire solution is developed in-house.
b) Collaboratively, whereby the Lab partners with an external client to further their technology and implement it as per KLM-specific requirements.
c) Fully externally, whereby the external solution is incorporated as is into the workplace.

3.4.2 Project context at the MRO Lab

The process of aircraft towing at KLM has always been manually performed. Trained and certified drivers operate diesel-powered tow trucks (now also transitioning to electric) during day and evening shifts, usually from the Schiphol Airport area to the Maintenance Hangars. The drivers, licensed by Schiphol to drive for KLM, require extensive training and certification. At the moment, these towing trucks provide pushback services at the Airport and towing services at the Hangars to tow aircrafts from KLM's parking areas to the airport terminal. However, a towing request takes time to be executed, since pushback/towing at the airport is always prioritized.

The towing environment at KLM had two main concerns:

a) The towing department worked only during day and evening shifts. This meant that any maintenance procedures, which required aircrafts to be moved from the parking stand to the hangar (cabin repair, inspections, etc) or from inside the hangar to the parking stand (idle engine runs) could not be performed during night shifts.

b) The process of becoming a tow truck driver for KLM required extensive training and a good understanding of safety and regulations. The time-consuming nature of the procedure made it difficult for operators working in hangars to participate in the training program.

To resolve these problems, the Operational Leads at Hangar 11 and 12 at KLM incorporated a new towing vehicle, which was easy to learn and operate, and allowed KLM operators to tow the aircraft within company boundaries during night shifts. This proved to be significant to KLM's process efficiency and gave the operators greater control over completing their maintenance tasks.

Figure 7. Mototok Spacer 8600 at KLM's H12

3.5 The KLM x Mototok Collaboration

This project focuses on the collaborative manner of solution implementation with Mototok, a German company that manufactures electric towing vehicles. With extensive experience (20+ years) in the towing industry and partnerships with leading airlines like British Airways, the Mototok has become a reliable alternative to current tow trucks, solving complex towing problems. KLM currently leases the Mototok Spacer 8600, a towbar-less tug capable of towing and pushback operations for narrowbody aircraft(see Figure 7).

Apart from some obvious technological benefits through efficient aircraft parking in hangars, better process overview, and noise and pollutant emission benefits, the device can be operated using a remote control. This allows the operator to maneuver the aircraft without physically driving the towing truck, eliminating the need for extensive certifications required to drive the existing tow trucks. (see Figure 8).

Figure 8. Trained Mototok driver performing a pushback (Mototok, 2025)

The training and certification process for driving a Mototok is simple; a 2-day training procedure imparts sufficient theoretical knowledge of the device's capabilities and safety requirements, along with practical training using the Mototok and an aircraft. This makes it easier and encouraging for operators to become licensed towing drivers. Owing to the simplicity of use and internal control over the towing process, KLM has been able to use the Mototok for the towing processes during the night shifts.

3.6 Practical research opportunity

Throughout multiple projects at the MRO Lab, the approach has always been focused on technological integration, i.e., how well a technology can be developed or how well an existing technology can be integrated into the workplace. Most of these solutions are approached from a final-problem solving perspective, without taking into account how it may impact the people supposed to work with the solution. As a result, more often than not, technologies are not readily accepted, due to their absence from some decision-making processes while choosing or developing a technology.

This project provides an ideal opportunity to follow a user-centered approach to developing an autonomous towing system. By keeping the operators in the loop throughout the information collection, technological integration, and testing phases, real-time improvements can be made, which eventually aid the very people who need to use it.

Section 2.
Define

This section aims to narrow down to the specific area and level at which autonomy should be introduced in the towing process. Through an experiment with the Mototok's drivers, a process and interaction map is developed which helps understand the flow of information throughout the towing. A custom framework is developed based on contextual information, which helps decide the target area of autonomy. An established autonomy framework describing levels of automation is then overlapped with the information processing in the towing context, which, with the help of safety and regulations at H12, helps determine the next level of autonomy. Finally, the impact of autonomy of the driver is chosen as the specific testing target.

Chapter 4. The Towing Process
Chapter 5. The Next Level of Autonomy
Chapter 6. The Impact of Autonomy

Chapter 4.
The Towing Process

This section introduces the context of towing at KLM, the infrastructure built for towing, the phases in the towing process, and the interaction between different towing operators throughout the process. The data was collected through KLM's news repositories, conversations with the maintenance operators at the Hangars, and experimental interviews with Mototok drivers. The section sets up all the information required to determine the LoA in the next Chapter.

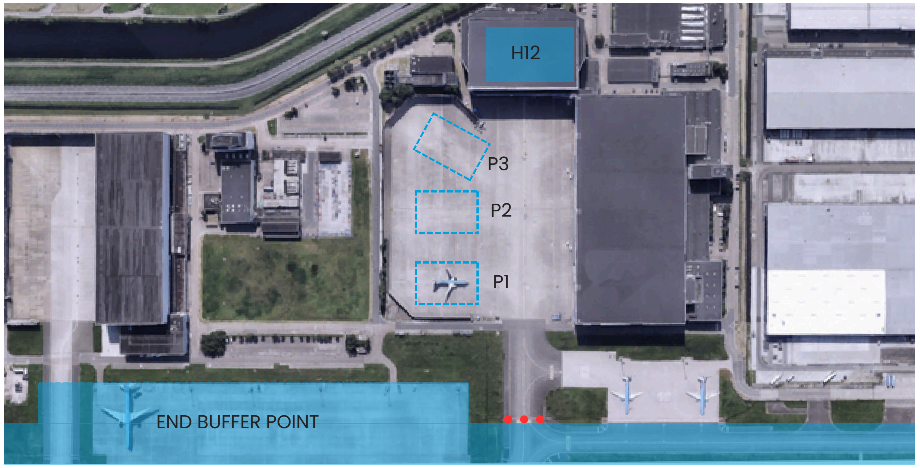
4.1 The current Towing Environment

This project focuses on the towing operations performed at KLM E&M's Hangar 12 (H12) (see Figure 9a). While towing is generally performed across all Hangars (H11, H14), H12 is chosen specifically for this case since the Mototok is currently only used to tow vehicles in this Hangar. A reason behind this could be the larger Hangar space or the fact that aircrafts at H12 usually come in for line maintenance (routine and day-to-day checks), which is quicker to execute (17-24 hours on average).

H12 was originally built to accommodate two B-747 aircrafts at the same time. However, the hangar also currently accommodates narrow-body aircrafts, such as the latest fleet of A321 Neos, the B-737s and A320s. Complete occupancy is usually never observed. Outside the hangar is a parking area with three parking stands, P1, P2, and P3 (see Figure 9b). Beyond the parking area lies the airside, which is marked by a red line. Schiphol regulates the area beyond this line, and all KLM internal processes must be stopped before this line. This marks the moving limit for the KLM internal towing operations. When a KLM aircraft requires maintenance, KLM's towing department at the Airport collects the aircraft (either directly from terminals or buffer points) and drops it off at one of three locations (based on area availability): directly at H12, at one of the parking stands or an end-buffer point adjacent to the airside marking.

KLM differentiates between the towing and pushback process; pushback refers to the towing vehicle's reverse movement to push the aircraft back, whereas the towing process refers to pulling an aircraft in the direction of the towing vehicle's forward movement. Towing is generally considered an easier or preferable movement to pushback, due to greater control over the straight-line movement.

(a)



(b)

Figure 9. Hangar 12 (a) Front-view, and (b) Top-view

Due to the boundary restrictions, the towing process using the Mototok is limited to the parking area. Towing using the Mototok is limited to two scenarios. First, if the aircraft parked by the towing department in the parking area needs to be moved into the hangar for maintenance, and second, if the aircraft needs to be moved from the hangar to a parking stand for an idle engine run. As mentioned earlier, the towing department works only during day and evening shifts, due to which the Mototok is used only during the night shifts. An informal agreement between H11 and H12 dictates that the parking area outside H12 will remain empty to park narrowbody aircrafts for early deliveries to the Airport. An important consideration is that the Mototok model currently in use is compatible only with narrow-body aircraft towing.

Figure 10. Tail docks at H12

4.2 Inside the Hangar

H12 is divided into two floors; the ground floor is the hangar platform where the aircrafts are accommodated, and the floor above comprises meeting and break rooms for operators. The floor above is accessible only by stairs.

Towing inside H12 is a restrictive process due to the constraints on movement and the tighter spaces. For the safe movement of personnel and aircrafts, the Hangar is divided into zones. The green walkways around the Hangar are for operators to walk on, particularly those not involved in any maintenance or towing process on the hangar platform. The end walls of the Hangar have two tail docks to accommodate aircrafts that are parked tail-first (see Figure 10). H12 has a parking area for the Mototok and other ground vehicles. The hangar has 5 towing lines, one across the center of the hangar and two on each side. Each towing line has several marked end points to indicate the furthest position the aircraft's nose/tail can be on. This is done to accommodate different aircraft types on the lines. The lines right next to the center follow the path to the tail docks. Figure 11 depicts the schematic layout of H12's interior from a top view.

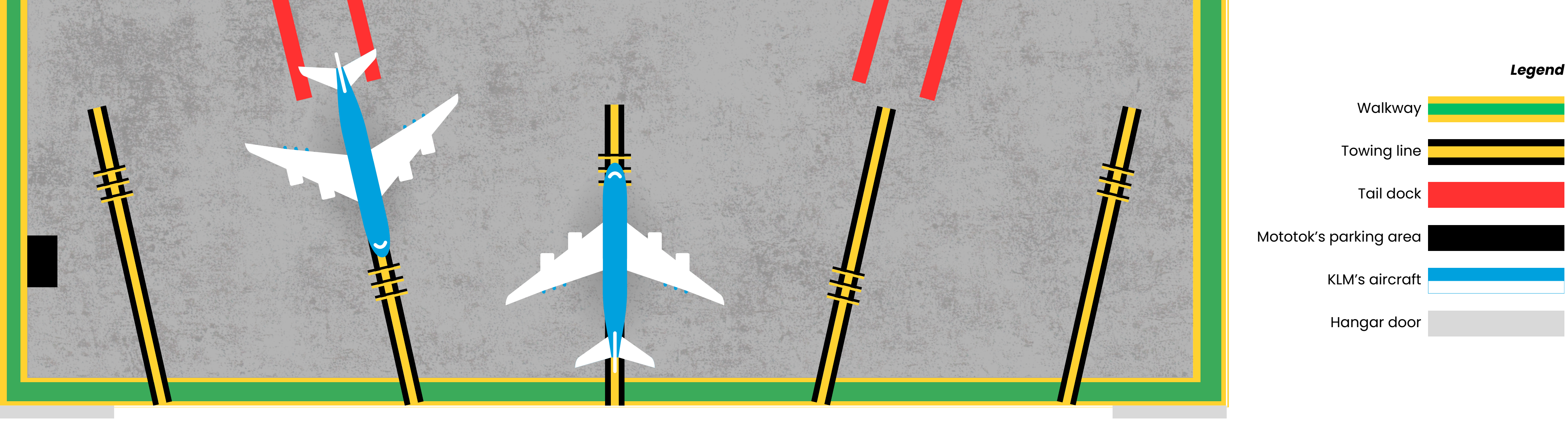
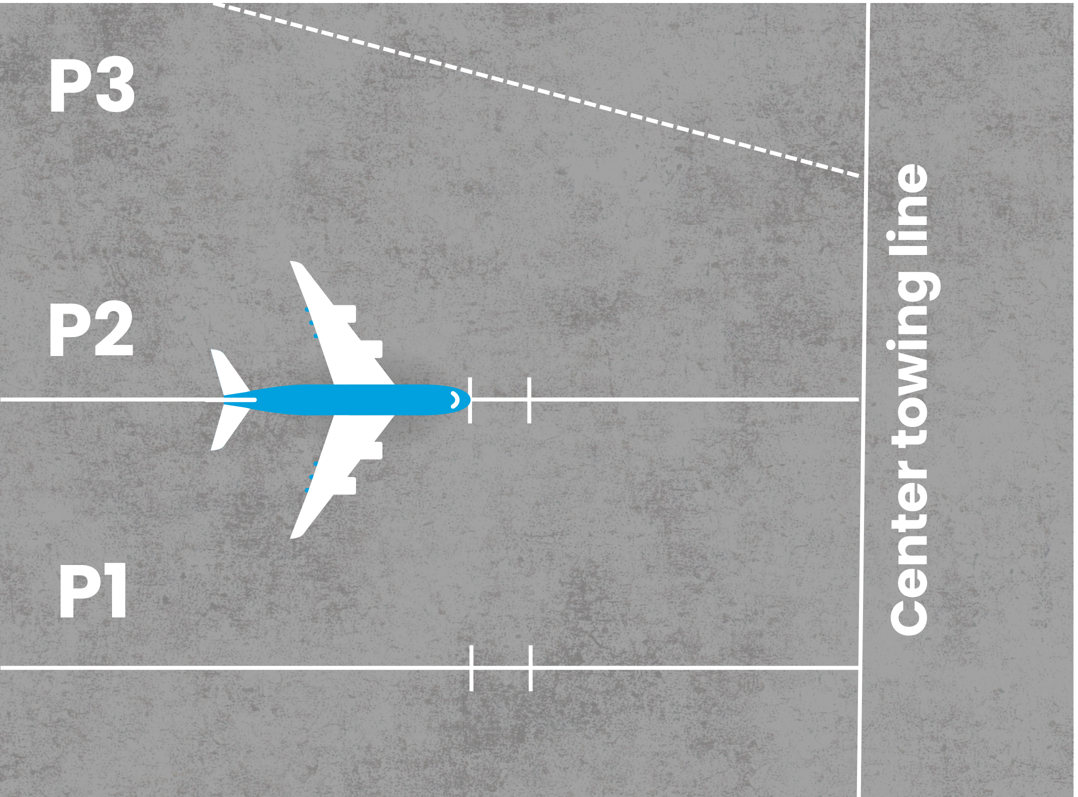


Figure 11. H12 interior

Figure 12. H12 exterior



4.3 Outside the Hangar

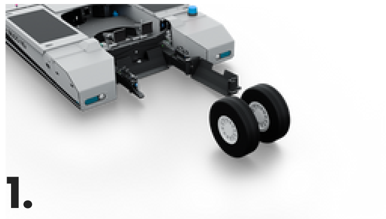
The center towing line inside H12 continues to the main towing line on the outside, where the parking area for aircrafts is located. Each parking stand in the parking area has a towing line. While the first and second parking spaces accommodate straight-line parking, the third position is inclined at an angle. Each towing line in the parking stands has an endpoint. The rear areas of each parking stand have metal plates on the floor, due to which no personnel/vehicles are allowed to stand/be parked on them. As a result, even though the process of moving the aircraft towards the parking stand is preferably towing, the actual movement of the aircraft into the parking stand is generally a pushback so that all operators involved in the process don't stand on the metal plates at the rear end. Figure 12 depicts the schematic layout of H12's exterior from a top view.

4.4 Towing using the Mototok

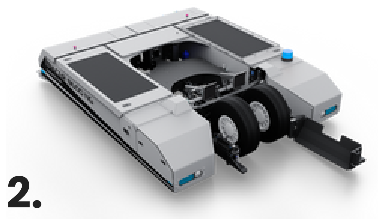
Towing is a well-established procedure within the aviation environment. While ample resources (through pictures and videos available online) exist to understand the process of towing using a conventional towing truck, Mototok's differences in driving and functionality make it essential to understand the process from end to end. While regulations demand that the overall objectives of the process do not change via this new manner of towing, the manner of achieving the end objectives is different in comparison with conventional towing.

The company highlights its selling point against conventional towing trucks through some product and process benefits (Mototok, 2025). The most relevant ones to this context are:

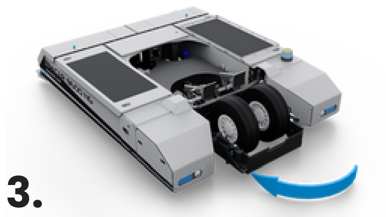
a) Process and Efficiency: automatic nose wheel clamping and lifting system in comparison with conventional towbar-based manual coupling (see Figure 13).
b) Manpower: just one operator, i.e., the towing driver required for the towing process in comparison with the conventional process, which requires at least three for adequate vision during towing.
c) Communication: through direct radio communications in comparison with intercom and hand signals during conventional towing.
d) Operation: both towing and pushback are possible in tight spaces, in comparison with conventional towing, which requires greater turning areas.
e) Onboarding: faster learning procedures, in comparison with the longer training and certification periods of conventional towing.
Mototok provides a radio remote control with batteries that controls its movement and docking capabilities, a driver headset with a microphone, and a steering bypass pin to lock the hydraulic system of the aircraft before docking.



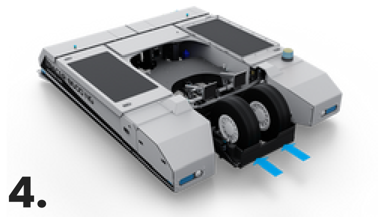
Mototok's nose wheel platform is lowered and the hydraulic door opens



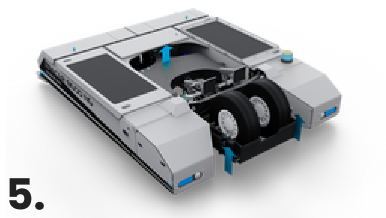
Aircraft's nose wheel enters the door and touches the nose wheel platform



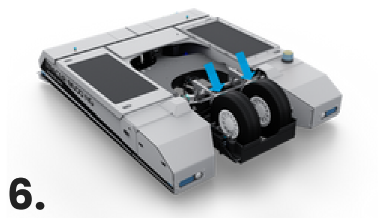
The hydraulic door closes after the wheel is completely inside



The door presses the wheels against the platform at a specific pressure



The platform lifts up and raises the nose wheel



The driver manually brings down the safety paddles onto the wheel, and the aircraft is ready for towing

Figure 13. Aircraft loading using the Mototok (Mototok, 2025)

4.5 Preliminary Research

4.5.1 Interview with a Mototok Driver at KLM

To get introduced to the H12 working environment and the Mototok, a discussion session was arranged with a licensed Mototok instructor. This operator was in direct contact with the Program Manager at MRO and thus was chosen as the first qualitative source of information. Having worked at the company for nearly 30 years, his experience was a valuable start to understanding the process. However, due to limitations around towing using the Mototok during morning shifts, the actual towing process could not be demonstrated, and rather an experienced outlook was provided using Mototok's features.

Contrary to Mototok's claims of requiring a single operator, i.e., driver, for the towing process, regulations at KLM require a minimum of five other operators. The driver is accompanied by an operator standing close to relay instructions in the event the driver's communication fails. Two operators stand by each wing tip, along with an operator by the tail to look out for potential collisions. Finally, the aircraft cockpit is occupied by a brakeman, who is licensed to operate the aircraft's braking controls and applies/releases the brakes at specific points in the towing process. The other equipment required for the towing includes the wheel chocks for the aircraft's main landing gear and the cockpit ladder for the brakeman. Based on the operator's insights, the entire process was divided into phases, with each phase describing a specific operation during the towing. Additionally, three different levels of communication were realized from the session: Driver-Product (i.e., Mototok) (D-P), Driver-Operator (D-O), and Operator-Operator (O-O).

Despite receiving ample information from the session, not all details could be elaborated upon due to the limited time availability of 35 minutes. Apart from the other process insights regarding towing, which will be elaborated on in a further section, several other notable conclusions were drawn. Despite having purchased the Mototok nearly five years ago, its incorporation as an alternative towing method began only a couple of years ago, due to restrictions by the towing department at KLM on its use. Similarly, the airport had previously tried using it for pushback processes, but eventually decided against it. A potential reason behind both was the lack of trust in the product. This was because the operators at H12 were not involved in the process of acquiring the technology and were unaware of its usability. However, after having seen its capabilities, the operators were open to further improvements that might be made to make the towing process more autonomous, which would reduce their workload.

> “They have plenty of updates for the Mototok, like some kind of a machine with a 360-degree view, so that you don't need any colleagues anymore.”

Source: Mototok driver, about Mototok's add-ons, which might reduce the number of operators required while towing

4.5.2 Interview with a Safety and Compliance Leads

To understand the safety regulations at H12, a meeting was arranged with the Safety and Compliance Leads. The following were the key insights from the conversation:

a) The towing platform at H12 will undergo reconstruction within the next few years, which gives KLM the ideal opportunity to make investments that may require infrastructural changes to implement autonomy.

b) The towing manual developed when the Mototok was first introduced required a human to always be in control of the process. Here, control refers to two features. First, it refers specifically to the fact that the driver must lead the operation and command the movement of the Mototok, which directly implies that the driver must perform the capabilities of the Mototok, including movement and docking. Secondly, the decision-making process must still be controlled by the driver, because a certified driver's opinions and decisions during the process are highly trusted.

From these insights, it becomes clear that the action-performing and decision-making phases of the driver cannot be automated, as the safety standards at KLM do not yet allow it.

4.5.3 Challenges

Understanding the KLM-specific towing set forth a complex problem, as previously mentioned; the towing process using the Mototok was performed only at night. Due to this, the difficulty in accessing the right context became apparent. In addition, there was no schedule for towing during the night shift, since the airport made no contact for towing during that period. As a result, decisions for all internal towing processes to accommodate maintenance tasks were performed as and when required. Thus, keeping aside viewing the regular Mototok movement and capabilities, it was quite difficult to achieve a live viewing of the Mototok towing an aircraft, which would have provided more detailed insights into the process.

Another challenge was to find the right contact sources. KLM has sixteen licensed Mototok drivers, with each working different shifts. Thus, getting an available source of information at every point was challenging, demanding the assumption that all operators had a nearly similar approach to towing. This was guaranteed by the common towing program they followed.

4.6 Research Design

Even after receiving qualitative insights from preliminary research, the inability to view the towing process live with the aircraft made it hard to understand all actions relevant to the different stakeholders in the towing process, and how communication occurred amongst them. It was understood that different operators performed a wide range of tasks, some even being repeated across different phases of the towing operation. However, these tasks were not categorized across the phases, which made it difficult to understand roles and responsibilities. Since the final objective was to identify an applicable part or process within towing that could be automated, having a clear idea of the different phases in the towing process, the roles of each operator, and the communication between them was important.

4.6.1 Method

Simulated Ethnography was used as a research tool to understand and better visualize the towing process. Ethnography is a qualitative research method that helps researchers understand how people interpret, experience, and give meaning to daily life (Wolf, 2012). The technique has often found applications in more complex settings, where immersion in the actual environment is difficult, risky, or impossible. Simulated ethnography enables researchers to collect ethnographic insights through re-created/simulated environments.

Several contexts have applied this method in practical applications. For instance, research on autonomous vehicle development involved digitally simulating the movement of a large number of people in an urban environment amongst autonomous vehicles (Charlton et al., 2020). This also helped simulate the potential interaction modes between humans and vehicles. Other examples include training doctors in surgical procedures (Pérez-Escamirosa et al., 2020) and modelling complex urban logistical systems (Gebetsroither-Geringer & Loibl, 2016) through virtual environments. In this project, simulated ethnography has the potential to work better than shadowing, since the entire infrastructure is provided to the operator at once. This gives the freedom to create both ideal and boundary conditions, which may not have been possible through shadowing. Additionally, all moving components of the environment are visible together, which helps reflect upon the relative positions and movement patterns.

Based on the insights from Mototok's working manuals and the specific insights from the Towing expert, a scaled-down version of H12 was 3D printed at the MRO Lab (see Figure 14). The layout included the green walkways around the hangar, the black parking area for the Mototok, and the towing lines for the aircraft. Every component of the towing process was printed in a different colour to ensure distinction. The operators involved in the towing process were also printed as miniaturized pieces. There was an attempt to ensure the dimensions of each component were roughly proportionate to their size in real-time.

A semi-structured interview process was chosen for the study. This was to ensure that the operator had the opportunity to elaborate on their perspectives and allowed for the exploration of unanticipated topics that may arise during the interview. Additionally, the type of questions to be asked would depend on the information provided by the operator. The idea was to video-record the entire interview, to record and store insights from the simulated setup, and specific insights that came up during the process.

Mototok's communication equipment, such as the headphones, would be brought to the interview. To dissect the modes of interaction better, a map displaying interaction across the three levels, i.e., Driver-Mototok, Driver-Operator, and Operator-Operator, was developed to understand the When, Who, What, and How of interaction across each level.

The combination of simulated ethnography and unstructured interviews was used to get an in-depth understanding of the process and multi-level communication patterns.

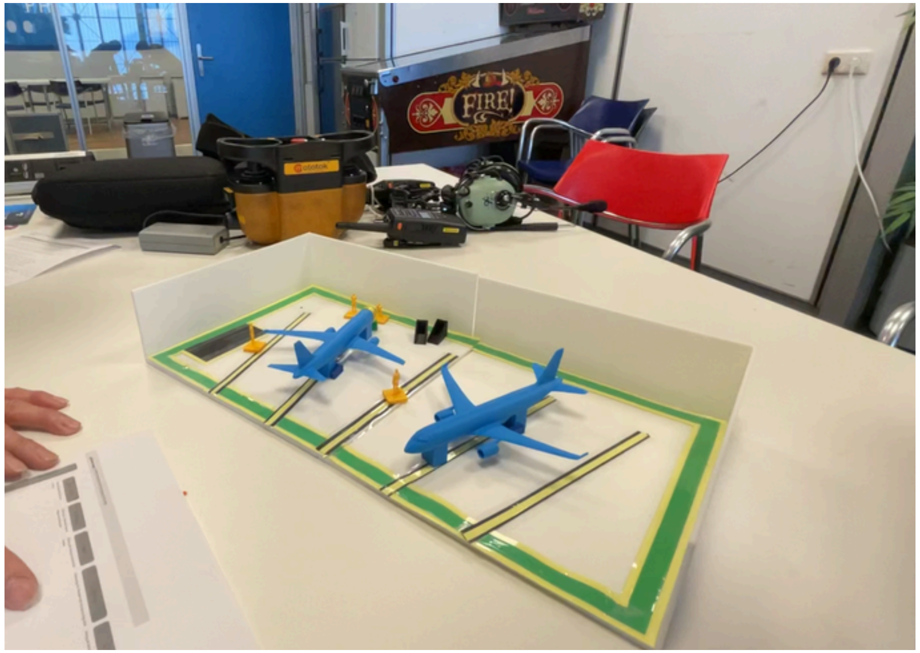


Figure 14. Scaled down setup of H12

4.6.2 Pilot Test

Pilot tests were performed with the Program Manager and other thesis students at the MRO Lab to test their understanding of the layout and feasibility of moving the different components. The test was performed in person at the MRO Lab. The results were positive, as the participants understood the process and different moving components with relative ease. No changes in the setup were required.

4.6.3 Participants

The participant recruitment process was based on three criteria: ability to converse in English, experience in towing using the Mototok, and a good understanding of operations at H12. The process of recruiting participants was difficult due to conflicting timings and shifts. To nullify this problem, direct attempts to reach out in person to experienced personnel were made. This included multiple trips to H12 during different shifts to locate a participant satisfying the recruitment criteria. Finally, two operators were recruited as participants, and a meeting time at H12 was fixed in advance. Both participants were licensed Mototok drivers, with two years of experience towing with the Mototok. While two participants are not a representative sample size, their insights would still help provide relevant qualitative information on the towing process.

4.6.4 Tools

a) Informed Consent Forms (refer to Appendix A)
b) 3D printed setup of H12
c) A recording device with a stand
d) Mototok's communication equipment
e) Sheet with pre-determined phases
f) Interaction map
g) Notebook and pen
h) Operator meeting room at H12

4.6.5 Procedure

The main researcher conducted the interview in person at a meeting room in H12. Together with both operators, the interview was arranged for a 60 to 90-minute period. The researcher arranged the 3D-printed setup, the sheets with phase information, the interaction level guide, and the recording equipment. During this period, the operators were also asked to carry the Mototok-related equipment to the interview room.

The operators arrived together at the interview and signed the informed consent forms. After starting the recording, the session began with the main researcher's introduction, followed by the introduction of the operators. Following the introductions, the researcher provided an overview of the research topic, its purpose, and emphasized the participants' right to withdraw any statements/ their participation from the interview at any time.

The interview was structured in two main parts: a process part and an interaction part. The process part involved utilizing the 3D printed setup to understand Mototok's towing capabilities and process. The researcher introduced every component of the setup to the operators and emphasized the freedom to utilize the components freely to describe the towing process from start to finish (see Figure 15). The operators were also provided with a sheet with the process phases for reference.

In the second part, the researcher introduced the interaction mode guide and asked the operators to recall their communication patterns for every phase of towing. The operators took this opportunity to go into details about communications modes, while utilizing Mototok's communication equipment they carried to the interview to display the purpose of different buttons on the remote.

Finally, the main researcher asked operators about their opinions and outlook on the autonomous towing program, and what they believe would be the right method to go about developing it. The interview concluded with the main researcher thanking the participants.

4.6.6 Data collection

The interview was video recorded to observe the simulated environment. For the most part, the main researcher guided the conversation and made notes using the notebook and pen as necessary, but had to intervene sometimes to help with Dutch to English word conversions and pronunciations. The operators were focused throughout the interview, despite some interruptions by other hangar operators in the room. At certain moments in the interview, the operators strayed from the chronological order of the process, due to which the researcher had to bring their attention to the phase chart. Being experts in their field, they were also familiar with the capabilities of autonomous towing and gave some specific insights into what can/cannot be changed with the new towing vision.

4.6.7 Data Analysis

This section involved arranging all the gathered data, re-collection of recorded information, and developing insights through the transcribed recordings. The process and interaction maps were officially filled out based on the received information. The notes taken down during the interview were also digitally stored along with the process and interaction maps. Since the process and interaction maps had a large number of steps, Data Clustering was used as a method to generate broad themes within which each action of the process and interaction map would lie. Cluster Analysis has been used as a valuable tool to arrange and store information in broader themes, which makes it easier to interpret (Guest & McLellan, 2003).

During transcription, it was observed that the pre- and post-tow phases led to some confusion regarding when they occurred. Pre-Tow could also refer to all the operations performed just before the Towing phase, i.e., Pickup and Positions, Travel and Docking. Thus, the names of the Pre-Tow and Post-Tow phases were changed to Setup and Wind-up to help order the process better and avoid any confusion.

Figure 15. Operators using the setup to explain the towing process

4.7 Results

The following sections utilize the data gathered to create functional clusters and quantify the responsibilities of the different operators involved to finally derive a potential area of automation in the towing process.

4.7.1 Framework

Since the literature review did not reveal a standard process for determining an area where automation could be introduced in the towing process, a more custom, context-based approach was utilized (see Figure 16). The outputs of the process and interaction maps were processed in two blocks; Block A determined a particular functional task within the process that could be automated, and Block B determined a particular operator's role that could be automated for that function. The insights of the safety requirements were aspects in both blocks.

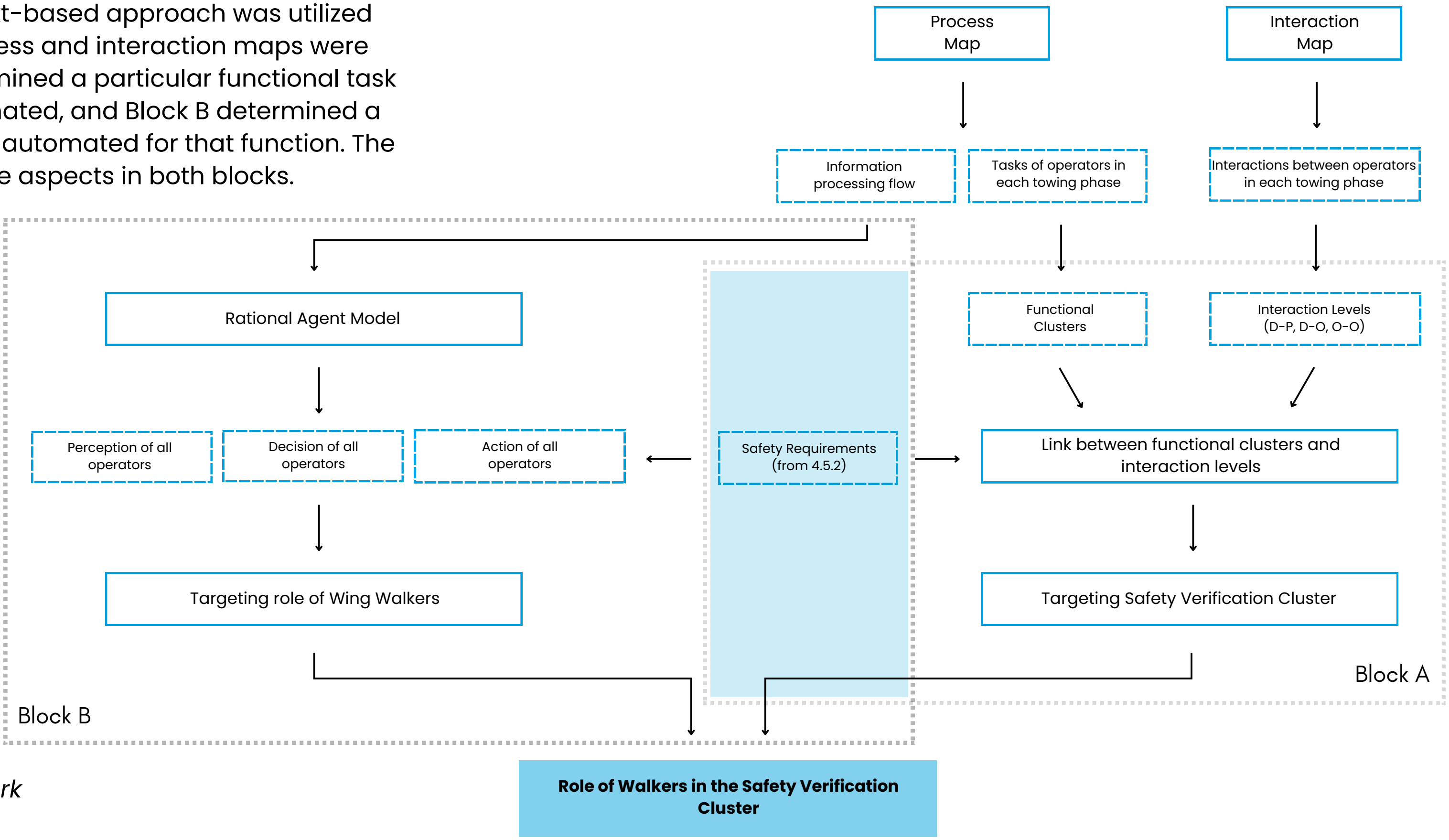


Figure 16. Area of Automation Framework

4.7.2 General perspective on autonomous towing

According to the operators, regardless of the degree of autonomy, the presence of a human operator was non-negotiable across three functions: application of aircraft brakes, application of wheel chocks, and the application of the steering bypass pin. Since the driver is the only licensed person to drive the Mototok and has the most experience, any administrative roles that may arise due to the automation should preferably be given to the driver. At the same time, every person involved in the process must then be trained on the characteristics and potential shortcomings of the autonomous system.

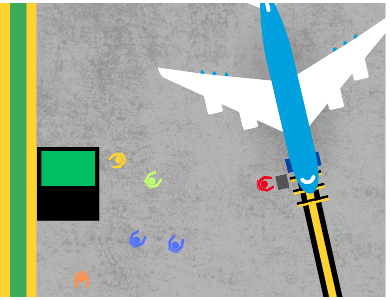
An important, recurring highlight of the conversation was the implicit trust in the training procedure for the Mototok. The rules and regulations relating to the towing process are emphasized during training, following which practice with mock-ups allows trainees to apply the safety procedures. There is a strong trust in the quality of the training process, with the actual towing procedure just becoming a task of following the safety protocols learnt during the training.

The most important insight gained from this question was that the towing process can never be made truly autonomous unless the infrastructure in the hangar is capable of executing the non-negotiable functions from a functional and safety perspective. At the same time, a few operators can be eliminated from the process through autonomy, which allows them to focus on other tasks at H12.

4.7.3 Process Map

The process map (see Figure 17) was filled out, which consisted of every step in each towing phase, and the intermediate steps between phases. Each phase consists of a schematic that demonstrates the relative movement of operators and infrastructure during that phase.

Figure 17. Visual Process Map (1/3)



A. Setup

Steps followed while organizing the towing

1) The hangar and the parking area must have the space required to hold the aircraft before the process begins.

2) The order for a towing process is given by the Towing Lead at the particular shift.

3) The Mototok's licensed driver is made in-charge of the towing process.

4) The driver collects the keys for the Mototok's secure equipment cupboard and walks towards it.

5) The driver collects the Mototok's radio remote control, headset, bypass pin and walkie-talkies from the cupboard.

6) The driver invites available technicians in the Hangar to join the towing operation (they may/may not be licensed drivers).

7) The driver assigns tasks to each technician: one proximity operator next to the driver, one brake operator (brakeman) in the cockpit (who requires to have completed a course to have a license to change cockpit controls), two wing walker operator and one tail walker operator.

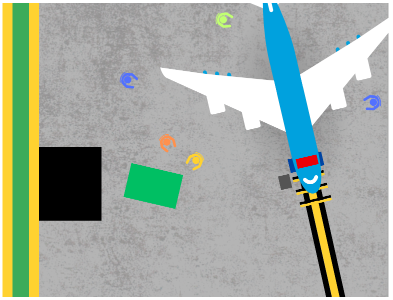
8) The operators take walkie-talkies. One operator takes the bypass pin. The driver takes the headphones and remote.

9) One of the operators installs the cockpit ladder.

10) One of the operators opens the hangar door.

Hangar door opened

Cockpit ladder installed



B. Pickup and positions

Collecting the Mototok from the parking spot, and operators taking positions

1) The driver disconnects the charging cable from the Mototok.

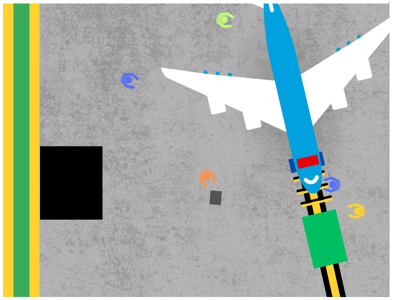
2) The driver switches the Mototok on using the start button.

3) The Mototok is reversed out of its parking spot.

4) The proximity operator stands next to the driver, as the main communication source if driver's communication fails.

5) The brakeman enters the cockpit using the ladder to take charge of the braking controls.

6) The two wing-walker operators take their place next to the wingtips, and a tail walker just behind the tail.



C. Travel

Moving the Mototok towards the aircraft

1) The Mototok is driven towards the aircraft nose.

2) The Mototok is aligned with the nose landing gear, and stopped 2-3 meters from it.

3) An operator attaches the bypass pin to the nose landing gear. This is confirmed by the driver.

4) One of the operators removes the cockpit ladder.

Bypass pin inserted

Cockpit ladder removed

Legend

Operators

Driver

Wing walkers

Tail walker

Brakeman

Proximity operator

Equipment

Mototok

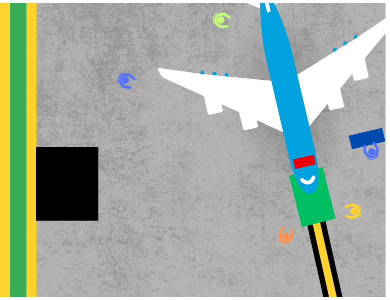
Cockpit ladder

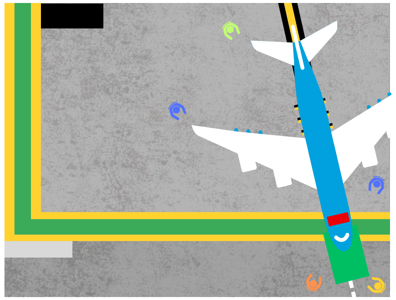
Wheel chock

Key Findings

The tasks in the setup phase do not directly impact the Mototok or the aircraft, and are only related to the supporting infrastructure in the towing process (hangar doors, cockpit ladder, etc). There seems to be little scope to introduce autonomy here.

There is an underlying understanding between operators for some tasks. The task of installing and removing the cockpit ladder, for example, is not assigned to any one person. It seems that the person closest to the ladder installs it.





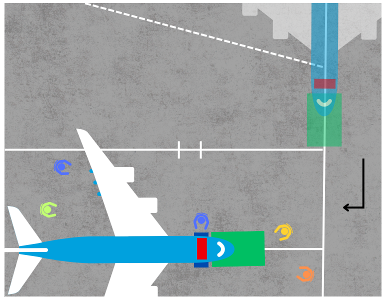


Figure 17. Visual Process Map (2/3)

D. Docking

Connecting the Mototok with the nose landing wheel

1) The hydraulic automatic door gets pushed out and opens.

2) The Mototok is moved closer towards the nose landing wheel.

3) When the wheel touches the nose wheel platform, the Mototok is stopped.

4) The door then closes and retracts back.

5) The paddles are brought down onto the wheels, thus securing them.

6) Driver completes a communications check with operators via an open channel.

7) One of the wing walkers is instructed to remove the wheel chocks.

8) The aircraft tail is checked for any obstructions under or around it.

9) The nose wheel platform lifts the wheels above the ground.

10) The brakeman is instructed to release the aircraft brakes.

Wheel chocks removed

Aircraft brakes released

E. Towing

Moving the aircraft from the hangar to the parking area.

1) The driver announces the start of the towing.

2) The Mototok either pushes or pulls the aircraft out of the hangar along the towing line. Pulling is preferred to pushing.

3) The aircraft is towed on the towing line till the hangar door followed by turning it onto the line outside the hangar.

4) Every operator maintains their position dynamically during the towing process.

F. Parking

Positioning the aircraft at the parking stand.

1) As the aircraft approaches a parking stand , it is turned to align with the towing line of that stand.

2) For a pushback towing, the aircraft is parked tail first. For a pull towing, pushback occurs while parking.

3) The aircraft is stopped at a marker on the towing line in the parking stand.

4) The tail walker shifts his position to the join the wing walkers close to the end of parking.

5) The brakeman is instructed to apply the aircraft brakes.

6) One of the wing-walkers intuitively applies the wheel chocks.

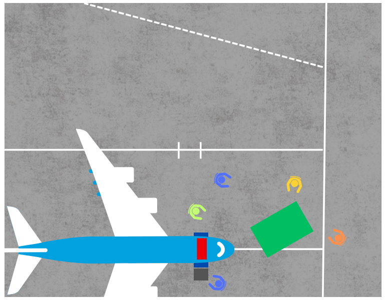
Aircraft brakes applied

Wheel chocks applied

Key Findings

The docking phase is heavily dependent on the Mototok's capabilities, and cannot be influenced by the towing context. Thus, this phase is heavily dependent on the driver.

Intuition and experience play a role in the walkers' tasks. They take up positions dynamically and are present where they need to be. This might be done without communication from the driver, thus indicating the driver's trust in the walkers.



G. Undocking

Separating the Mototok from the nose landing wheel.

Bypass pin removed

Cockpit ladder installed

1) The nose landing gear is lowered.

2) The paddles get separated from the wheel.

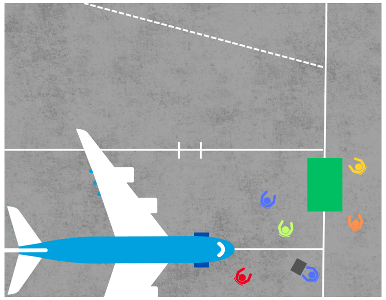
3) The door opens and is retracted out.

4) The Mototok is reversed outwards.

5) The door closes and retracts back into the Mototok.

6) The steering bypass pin is removed and is kept with the operator who removes the pin.

7) One of the operators installs the cockpit ladder.



H. Wind-up

Process followed after the towing.

Cockpit ladder removed

Hangar door closed

1) The brakeman exits the aircraft through the ladder.

2) One of the operators removes the cockpit ladder.

3) The driver drives the Mototok back to its parking area, and is accompanied by all other operators.

4) One of the operators closes the hangar doors.

5) The driver keeps all the equipment back in the Mototok closet, locks it and returns the keys to its initial location.

Figure 17. Visual Process Map (3/3)

Key Findings

The brakeman only operates from within the aircraft. Unlike other operators, the brakeman performs a singular type of task, which is to apply and release aircraft brakes when instructed. This reduces the scope of automation for their tasks in this study.

In summary, the final decisions that directly impact the aircraft's movement are made by the driver. This might be done in consultation with the other operators.

4.7.4 Insights

The training process for the Mototok holds particular significance in the operators' confidence in performing the task. Once trained, the process is simple to follow with little chance of error occurrence. The fact that the Mototok towing has experienced no accidents confirms this. According to the operators, the only errors that have occurred are the Mototok stopping its movement if the connection between the radio remote control and the Mototok is lost, due to which the Mototok stops automatically within a braking distance of roughly 5 meters. It is also important to note that the reverse section of the process, i.e., from the parking stand to the hangar, follows the same steps, in reverse.

The drivers mentioned an analogy to learning the towing process by comparing it with driving a remote-controlled car. He mentions that many operators played with such toy cars during their childhood, which has allowed them to learn the process quicker and with confidence. This underscores the fact that the learning process of towing using the Mototok is less steep than a conventional tow truck.

Execution of steps is the most important part of the process. After tasks are assigned and everyone understands their responsibility, the success of the towing process is dependent on the execution of individual tasks.

4.7.5 Functional Clusters

The current process map is chronologically clustered, i.e., with every phase arranged in the order in which they are performed, with each step arranged in the phase in which they occur. To simplify the process based on tasks, a function-based clustering method was used to allocate steps from each phase into different clusters.

a. Pre-Towing Preparation cluster

Function: This cluster encompasses all preparatory steps required before the physical towing process can begin. It establishes the necessary conditions, resources, team structure, and equipment readiness.
From A. Setup phase: Steps 1-10
From B. Pickup and Positions phase: Steps 1-2, Steps 4-6

b. Individual Mototok Movement and Connection Cluster
Function: This cluster focuses on the movement of only the Mototok and all tasks associated with the connection with the aircraft's nose landing gear.
From B. Pickup and Positions phase: Step 3
From C. Travel phase: Steps 1-4
From D. Docking phase: Steps 1-5, Step 9

c. Safety Verification cluster
Function: This cluster incorporates all steps related to communication to ensure environmental and mechanical safety while making the connection, and also after the connection is made.
From D. Docking phase: Steps 6-8, Step 10
From F. Parking phase: Steps 4-6
From E. Towing phase: Step 1, Step 4

d. Aircraft movement cluster
Function: This cluster encompasses the actual movement of the aircraft-tug combination from origin to destination, including path navigation and positioning.
From E. Towing phase: Steps 2-3
From F. Parking phase: Steps 1-3

e. Disconnection and wind-up cluster
Function: This cluster focuses on safely terminating the operation by disconnecting the Mototok from the aircraft and returning all systems and equipment to their proper post-operation state.
From G. Undocking phase: Steps 1-7
From H. Wind-up: Steps 1-5

4.7.6 Interaction Map

The interaction map is linked with the process map to help understand communication at each stage of the process, and across each level of communication. The When column is where the process map is linked. For instance, in the Setup phase, the Operator-Operator communication occurs at 3, which is the third step in that phase. The Who column connects the points of communication in the interaction. The What column refers to the content of the communication, and the How column refers to the mode of communication.

4.7.7 Insights

Based on the current communication system, there have never been any serious communication faults during the process. Communication can be initiated by anyone during the process only if needed. Silence across the open channel is preferred, and since the operators are familiar with the process, they are aware of their responsibilities.

At times, however, the driver's headset fails, which is realized when he can hear the environment's sound through the headset. Under normal circumstances, the headset is noise-cancelling, and its microphone gets activated only under stimulation from the driver through speech. Under a worst-case scenario, if the driver's operator fails, he can continue communication with the walkie-talkie available with the proximity operator. If the walkie-talkies fail, they are immediately replaced with alternate ones available in H12. A reference was also made to conference calling via mobile phones if all else fails. Besides these modes, there are no verbal/physical means of communication followed. Since the towing is performed at night, natural environmental silence aids the process and provides chances of talking normally if required.

A. Setup

Interaction Level	When	Who	What	How
Driver - Product				
Driver - Operator	6	Driver - All operators	The driver invites technicians to help with the towing. They now become towing operators.	Verbal
	7	Driver - All operators	The driver assigns roles to all the operators.	Verbal
Operator - Operator	3	Towing Lead - Driver	The Towing Lead asks the driver to perform the towing process. The driver now becomes the towing lead.	Verbal

B. Pickup and positions

Interaction Level	When	Who	What	How
Driver - Product	1	Driver - Mototok	The driver disconnects the charging cable from the Mototok.	Physical
	2	Driver - Mototok	The driver switches the Mototok on using the start button.	Button: Mototok's remote
	3	Driver - Mototok	The driver reverses the Mototok out of the parking spot.	Joysticks: Mototok's remote
Driver - Operator				
Operator - Operator				

C. Travel

Interaction Level	When	Who	What	How
Driver - Product	1,2	Driver - Mototok	The driver drives the Mototok towards the aircraft and stops it near the nose landing gear.	Physical
Driver - Operator	3	Driver - Operator with the Steering Bypass Pin	The driver instructs the operator to attach the bypass pin to the nose landing gear.	Verbal
Operator - Operator				

Figure 18. Interaction Map (1/3)

D. Docking

Interaction Level	When	Who	What	How
Driver - Product	1	Driver - Mototok	The driver presses a button for the hydraulic automatic door to slide out and open.	Button: Mototok's remote
	2,3	Driver - Mototok	The driver drives the Mototok towards the nose landing wheel and stops when the wheel touches the nose wheel platform.	Joysticks: Mototok's remote
	4	Driver - Mototok	The driver presses a button for the hydraulic automatic door to retract and close.	Button: Mototok's remote
	5	Driver - Mototok	The driver presses a button to bring the wheel securing paddles in contact with the nose wheel.	Button: Mototok's remote
	9	Driver - Mototok	The driver presses a button to lift the nose wheel platform above the ground.	Button: Mototok's remote
	9	Driver - Mototok	The driver presses a button to lift the nose wheel platform above the ground.	Button: Mototok's remote
Driver - Operator	6	Driver - All the Operators	The driver initiates an open communications check. The operators confirm this.	Driver: Headset Operators: Walkie-Talkie
	7	Driver - A wing walker	The driver instructs a wing-walker to remove the wheel choke. The operator confirms when done.	Driver: Headset Operators: Walkie-Talkie
	8	Driver - Tail walker	The driver instructs the tail walker to check the tail for any obstructions. The tail walker confirms and provides clearance.	Driver: Headset Operators: Walkie-Talkie
	7	Driver - Brakeman	The driver instructs the brakeman to release the aircraft brakes. The brakeman confirms when done.	Driver: Headset Operator: Aircraft's comms system
Operator - Operator				

E. Towing

Interaction Level	When	Who	What	How
Driver - Product	2,3	Driver - Mototok	The driver navigates the aircraft towards the parking area using tow lines as guidance.	Driver: Headset Operator: Walkie-Talkie
Driver - Operator	1	Driver - All the Operators	The driver announces that they will begin the towing process.	Driver: Headset Operator: Walkie-Talkie
Operator - Operator	1	Driver - All the Operators	The driver announces that they will begin the towing process.	Driver: Headset Operator: Walkie-Talkie

F. Parking

Interaction Level	When	Who	What	How
Driver - Product	1,2,3	Driver - Mototok	The driver parks the aircraft at a parking stand.	Joysticks: Mototok's remote
Driver - Operator	5	Driver - Brakeman	The driver instructs the brakeman to apply the aircraft brakes. The brakeman confirms when done.	Driver: Headset Operator: Aircraft's comms system
Operator - Operator	1	Driver - All the Operators	The driver announces that they will begin the towing process.	Driver: Headset Operator: Walkie-Talkie

Figure 18. Interaction Map (2/3)

Phase	Interaction Level	When	Who	What	How
G. Undocking	Driver - Product	1	Driver - Mototok	The driver presses a button to lower the nose wheel platform onto the ground.	Button: Mototok's remote
		2	Driver - Mototok	The driver presses a button to separate the wheel securing paddles from the wheel.	Joysticks: Mototok's remote
		3	Driver - Mototok	The driver presses a button for the hydraulic automatic door to slide out and open.	Button: Mototok's remote
		4	Driver - Mototok	The driver reverses the Mototok out from the landing gear area.	Joysticks: Mototok's remote
		5	Driver - Mototok	The driver presses a button for the hydraulic automatic door to retract and close.	Button: Mototok's remote
	Driver - Operator				
	Operator - Operator				

Phase	Interaction Level	When	Who	What	How
H. Wind-up	Driver - Product	3	Driver - Mototok	The driver drives the Mototok back to its parking area.	Joysticks: Mototok's remote
	Driver - Operator				
	Operator - Operator				

Figure 18. Interaction Map (3/3)

The degree of importance of each task was understood through the experiment. It was observed that in tasks with minimal Mototok movement, communication had low importance, such as the pre- and post-tow, and travel. However, as the docking process begins, so does the importance of communication, which is confirmed by the process map, where the driver interacts with the brakeman and an operator for bypass pin insertion. The most important section of the process from a communication perspective was towing, where potential inputs from operators can be of significant importance. Thus, the importance of communication rises as the process moves towards towing, where it peaks, and finally drops.

4.7.8 Link with the functional clusters

By linking the interaction map with the functional cluster, the total interactions per cluster and the frequency of interactions at each level throughout the process can be understood.

Nomenclature for measuring frequency: (number of occurrences) (name of the phase)

a. Pre-Towing Preparation cluster
D-P frequency: 0A + 2B = 2
D-O frequency: 2A = 2
O-O frequency: 1A = 1
Total = 5

b. Individual Mototok Movement and Connection Cluster
D-P frequency: 1B + 2C + 6D = 9
D-O frequency: 1C = 1
O-O frequency: 0
Total = 10

c. Safety Verification cluster
D-P frequency: 0
D-O frequency: 4D + 1F + 1E = 6
O-O frequency: 0
Total = 6

d. Aircraft movement cluster
D-P frequency: 2E + 3F = 5
D-O frequency: 0
O-O frequency: 0
Total = 5

e. Disconnection and wind-up cluster
D-P frequency: 5G + 1H = 6
D-O frequency: 0
O-O frequency: 0
Total = 6

Total D-P interactions: 22 (68.75% of all interactions)
Total D-O interactions: 9 (28.12% of all interactions)
Total O-O interactions: 1 (3.12% of all interactions)

4.7.9 Structuring the process logic

The Rational Agent Model (RAM) is a concept that helps define the behaviour of systems that make the best possible decisions. A rational agent is an entity that is capable of perceiving its environment, planning its actions, and executing them, all to achieve the objective set out for the process. It is important to observe that while RAM is usually applied to systems with some degree of autonomy, it is not confined to them; rather, it can be applied to any decision-making entity as long as the perception, decision-making, actions, and the objective are well defined. Here, the RAM is applied only to break the information flow across the operators involved in the process.

The RAM is applied across all functional clusters to structure the processing of information for each task (refer to Appendix B). The functional clusters of each phase have an objective that needs to be achieved (as determined by the title of a cluster). Within each cluster, the components of the cluster, i.e., operators, are responsible for the information processing, i.e., perception, actions, and decision-making, which helps provide clarity into how data flows throughout the towing process.

4.7.10 Role Specialization Analysis by Operator

This reveals the degree of specialization for each role, highlighting which operators perform narrowly focused tasks versus those with broader responsibilities. This is just to further understand and summarize the distribution of roles across functional clusters (see Figure 19).

Operator	Primary function area	Cluster concentration
Driver	All functional clusters	100% concentration in Aircraft Movement, 87.5% in Disconnection, 76.9% in Pre-Towing, 62.5% in Safety Verification
Proximity operator	Pre-Towing Preparation only	100% concentration in Pre-Towing
Wing walker	Pre-Towing Preparation only	37.5% concentration in Safety Verification
Tail walker	Pre-Towing and Safety Verification	37.5% concentration in Safety Verification
Brakeman	Pre-Towing, Safety Verification, and Disconnection	Distributed across clusters: 33% each in Pre-Towing, Safety Verification, and Disconnection

Figure 19. Role Specialization Analysis

4.7.11 Conclusions

a. From preliminary research, conversations with the Safety and Compliance Lead (see 4.5.2) informed that automation should not take over the driver's action-taking, i.e., manoeuvring the Mototok and decision making during the towing. From the functional clusters, it is clear that the Safety Verification cluster is the only one without any interaction between the Driver and the Mototok, which makes it a suitable candidate to introduce autonomy into.

b. The Safety Verification cluster is performed by the Driver, the Walkers, and the Brakeman. Since every task of the Driver includes some decision-making, the Driver's role in the safety verification cluster cannot be automated. Additionally, the Brakeman's role in this cluster includes releasing and applying aircraft brakes where necessary, automating which would require changing control infrastructure. This would be impractical to set as an objective, since KLM has no authority over changing any Original Equipment Manufacturer (OEM) setups in the aircraft. Thus, the only possible target for autonomy in the cluster is the role of the tail and wing walkers.

c. The Role Specialization Analysis reveals that the majority of the tasks of the walkers are concentrated in the safety verification cluster. These tasks are limited to interactions with the driver, without any direct input onto the aircraft or the Mototok. This makes the first step towards introducing autonomy simpler, as it requires no change in infrastructure at H12.

Chapter 5.

The Next Level of Autonomy

Based on the conclusions of Chapter 4, the role of the walkers in the safety verification cluster is chosen for automation. This chapter first determines the current level of autonomy in the safety verification cluster. Through a systematic assessment of safety and regulations and KLM's autonomy objectives, the chapter concludes at a final level at which autonomy should be introduced in the towing process.

5.1 Framework for LoA determination

The Parasuraman, Sheridan, and Wickens (PSW) Framework provides a comprehensive approach to evaluating autonomy in complex systems (Parasuraman et al., 2000). The development of this framework was based on the notion that automation is not a concept that can be applied to all aspects of a system equally.

The central aspect of the framework was dividing autonomy into four stages of information processing: information acquisition, information analysis, decision selection, and action implementation. For each functional stage, the framework applies a 10-level scale of automation, allowing for a more nuanced evaluation of where automation can be applied in a system.

The stages of information processing represent some key cognitive functions in human-machine systems:
a) Information acquisition refers to the sensing and registration of data, which includes data gathering, organization, filtering, and highlighting relevant information (Perception as per RAM).
b) Information analysis refers to cognitive functions like integration, diagnosis, and inference, which include predictive calculations and contextualizing information (Decision-Making as per RAM).
c) Decision selection refers to making selections based on the analysed information, including making suggestions (Decision-Making as per RAM)..
d) Action implementation refers to executing the selected decision across different autonomy levels (Action-Taking as per RAM).

In the context of HMC, the PSW has been used to assess how automation levels impact operator awareness and task performance on manufacturing assembly lines (Gopinath & Johansen, 2019). The framework has also been applied to understand function allocation between humans and automation in flight management systems (Pritchett et al., 2014). Based on the process map, the RAM completely distributed the information flow across three functions: perception, decision-making, and acting. The PSW framework also distributes tasks according to a similar logic, making it easier to overlap the two models.

5.2 Current LoA determination

Before determining the next LoA for the system, it is necessary to understand where the current autonomy lies.

Sheridan’s 10-level scale:
Level 1: Computer offers no assistance.
Level 2: Computer offers complete set of action alternatives.
Level 3: Computer narrows selection down to a few choices.
Level 4: Computer suggests a single action.
Level 5: Computer executes suggestion if human approves.
Level 6: Computer allows human limited time to veto before automatic execution.
Level 7: Computer executes automatically then informs human.
Level 8: Computer informs human after execution only if asked.
Level 9: Computer informs human after execution only if it decides to.
Level 10: Computer decides everything and acts autonomously.

The PSW framework allows for a LoA to be implemented across all tasks within a functional cluster. Through this, a separate level of autonomy for each stage of information processing can be developed, making the LoA determination process more flexible. Figure 20 indicates the current LoAs.

5.3 Conclusion: The Next LoA

Based on Sheridan's scale, every information processing step in Safety Verification is at Level 1. Every level beyond Level 2 involves some form of decision-making being executed by the autonomous system. Since the decision-making needs to remain a responsibility of the driver, Level 2 is the possible opportunity to introduce autonomy to the safety verification cluster. This would mean that the roles of the walkers, which are to instruct and inform the driver towards safe aircraft movement, will now be replaced by a system offering Level 2 autonomy, i.e., offering a set of action alternatives.

Level 2 autonomy is strikingly close to the tasks performed by the walkers in the safety verification cluster. Thus, autonomy in this cluster would not be to perform tasks in a quantitatively and qualitatively better manner than the walkers, but rather to serve as a replacement for the roles of tail and wing walkers, thereby reducing the number of operators required for the towing process. This aligns with KLM's Back-on-Track program, aiming to introduce autonomy to offset the shortage of manual labour.

To create a comprehensive overview, a final framework linking the conclusions of this chapter with the Area of Automation framework was created (see Figure 21). Block C represents the structure of this chapter.

Functional Cluster	Perception	Decision-Making	Action
Pre-towing preparation	Level 1	Level 1	Level 1-2
Individual Mototok movement and connection	Level 1	Level 1	Level 2-3
Safety verification	Level 1	Level 1	Level 1
Aircraft movement	Level 1	Level 1	Level 2
Disconnection and wind-up	Level 1	Level 1	Level 2

Figure 20. Current LoA's of each cluster

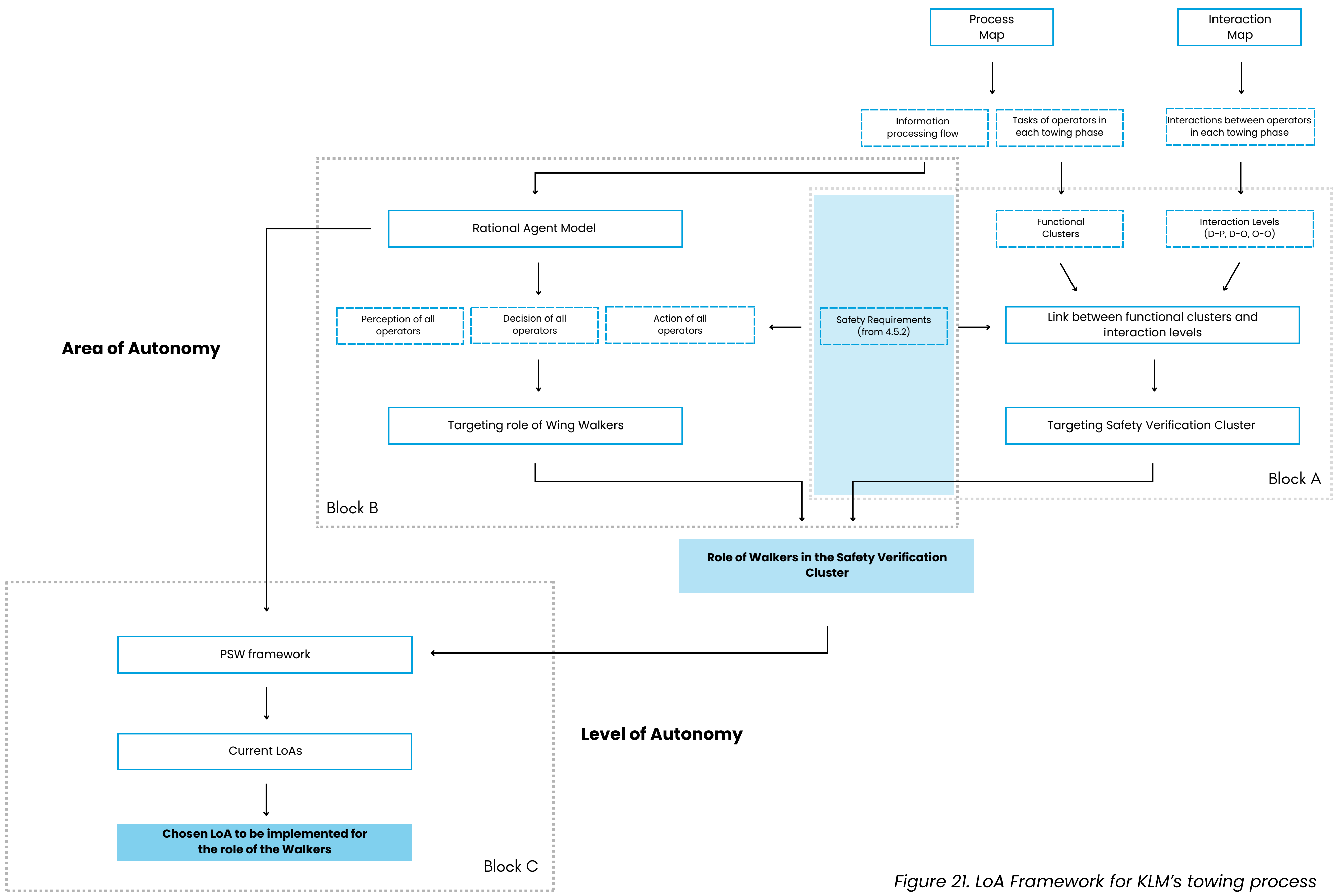


Figure 21. LoA Framework for KLM's towing process

Chapter 6.

The Impact of Autonomy

From the previous chapters, the roles of the wing and the tail walkers are chosen as the ones to be automated at Level 2. This section explores the impact that the increased autonomy would have on the information flow in the RAM, and why the decision-making of the drivers would be essential to be tested in the new system.

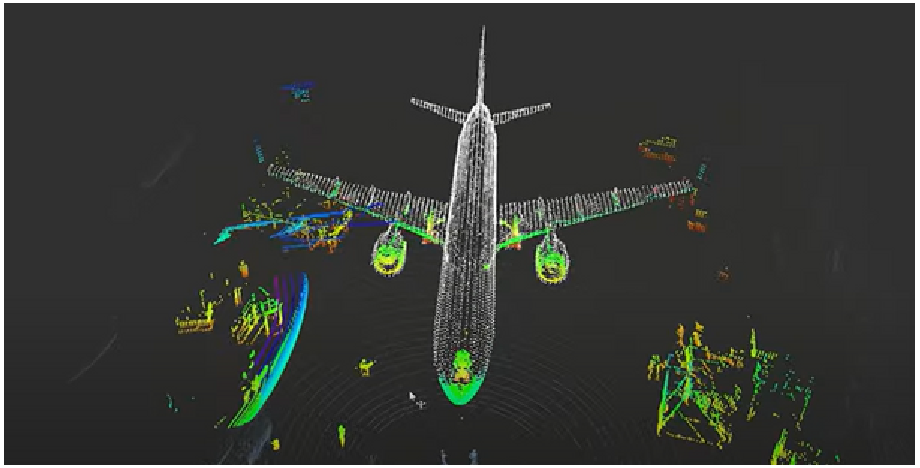
6.1 Technology

Evitado Technologies is a product and service company aiming to revolutionise autonomous airside operations through its perception systems. With 12 partners in the aviation industry, Evitado has been at the forefront of developing perception systems that reduce the chances of collision occurrence by providing real-time data about collision warnings. This system includes a LiDAR (Light Detection and Ranging) sensor that can be attached to aircrafts or ground service equipment that are potentially susceptible to collisions. The sensor scans the environment through 360 degrees and develops a real-time 3D environment through data points, which is communicated to maintenance operators during operations.

Evitado has previously collaborated with companies that develop remote-controlled aircraft tows. To enhance the autonomy (by reducing the number of operators required to be present for a towing process) and reduce collision possibility, Evitado magnetically attaches a LiDAR sensor to the towing vehicle (see Figure 22a), thus eliminating the need for physical assembly. The sensor data is fed directly to the driver of the tow through a user interface device, which shows the 3D visualization of the towing process in real-time from a bird's eye view (see Figure 22b). Alerts about collisions are sent through the interface via visuals and audio, to keep the driver alert of their surroundings.

Evitado has successfully integrated its product with several towing vehicles globally. Their perception system is trusted by both airlines and airports for towing and pushback operations, which makes it an ideal solution for the perception requirement in this project.

(a)



(b)

Figure 22. Evitado's LiDAR sensor (a) On an aircraft tug, and (b) the sensor feed to the driver

6.2 Product and System Level

The tail and the wing walkers perform two broad actions during the aircraft towing process (see Figure 23):
a) Visually monitoring aircraft clearances during movement. This is the main part of the safety verification cluster.
b) Communicate potential threats/hazards to the driver.

The roles of the walkers are split across two levels: a product level and a system level. The product level refers to the individual ability of the walkers to accurately evaluate their environment, such as monitoring aircraft clearances. This product level depends on the individual ability of the walkers, and is not associated with any other operator associated with the process. The system level refers to the flow of information between operators during the aircraft towing process, more specifically, the communication of the perceived information from the walkers to the drivers in this case, and the subsequent decisions and actions taken because of it. A systems thinking perspective hypothesizes that in complex systems, factors such as safety are dependent on interactions across the entire system, rather than just a component (Read et al., 2021). The system level is not only dependent on the ability of the individual operators in the process, but also on external factors that could compromise the communication between them. Thus, the system level is a function of two factors: how the driver perceives the information and how it impacts the consequent decision-making and action-taking.

Evitado's perception system performs exactly the tasks that the walkers currently perform, with the only difference being how the perception information is communicated to the driver.

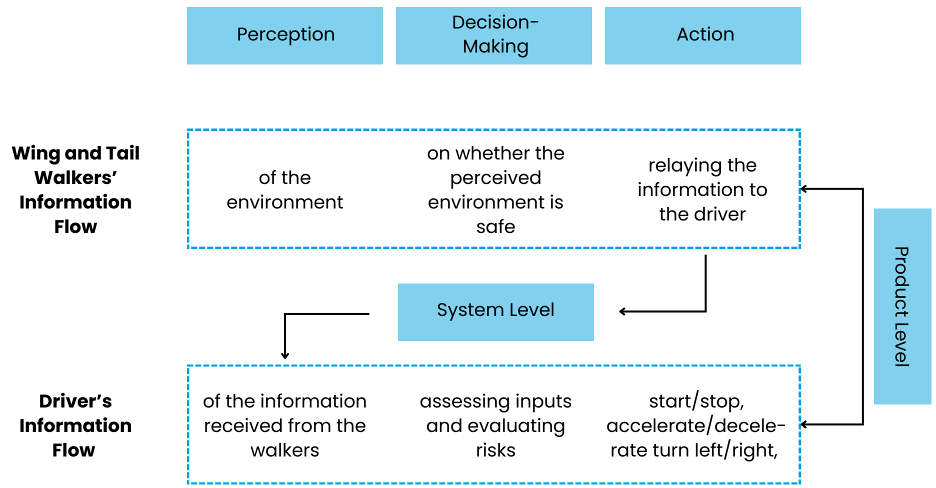


Figure 23. Information flow between the walkers and the driver

6.3 Testing the system

To understand if the perception system can be successfully integrated into the towing workflow, it needs to be tested in the operational context. Testing is an important phase of autonomous technology introduction in aviation, as it helps understand the impact of the technology on its working context (Schiphol, 2021). While Evitado's perception system has been tested in different aviation environments, it is important to note that the operational contexts often differ from each other; for instance, the layout of a towing environment in an airline where Evitado is successfully being operated would differ from that of KLM's Hangar 12. Moreover, the differences in safety guidelines also create potential constraints or liberties in the manner in which the system can be used. Therefore, even though the product-level capabilities might not change across contexts, the impact of said capabilities on the system-level needs to be studied.

From a system-level perspective, the perception system directly impacts the driver (as shown in Figure 23). The perception system would perform no tasks that would impact the towing process directly. Rather, the inputs provided by the system would help the drivers in determining the right course of action while towing.

6.4 The need to test Decision-Making

The visual monitoring of the environment is a product-level characteristic, both for the walkers and eventually the perception system. In both cases, the ability to perceive the environment is dependent on the capability of the walkers, which is secured by their training process. Similarly, the monitoring capabilities of Evitado's LiDAR can be assumed to be accurate, since they have multiple aviation clients using their system and have never encountered any problems. Thus, this product level is assumed to be constant, i.e., it is assured that the monitoring capabilities of both the walkers and the LiDAR are at a level sufficient to send the right feedback to the driver.

After perceiving information from the walkers, the decision-making of driver is subject to the manner in which information is perceived and the individual capability of the driver. The decisions made eventually impact the quality of actions taken. The decision-making is especially important if the information perceived contains warnings about potentially hazardous situations encountered by the walkers. The quality of the decisions made by the driver eventually impacts the safety of people and assets at H12, thus holding significant importance.

When a perception machine takes over the role of the walkers, how the information is visualized remains the responsibility of the system, which, in Evitado's case, is trustworthy. However, how information is communicated to the driver impacts the decision-making of the driver, as proven by several studies (Vicente et al., 2023; Aguodo et al., 2024). Thus, if the role of the tail and wing walkers is replaced by a machine, it is important to assess the decision-making of the driver.

6.5 Testing with the walkers

To test the decision-making of the drivers with the perception system, it would be important to understand specifically the factors that drive he decision-making of the drivers.

The driver's decision-making process can be attributed to interactions with the walkers over time, owing to which they have developed a natural manner of making decisions from the walker's inputs, which seems to be quite smooth due to an inherent understanding of the walker's capabilities. The acceptance of the system into the workflow is subject to preserving these natural decision-making instincts, i.e., the perception system should not cause the driver to alter his current decision-making pattern, which could lead to cognitive overload and impact the quality of decisions as well as the duration of towing.

Currently, there is no information on the decision-making process of the drivers. Thus, it is first important to test the decision-making of the drivers with the walkers to understand what the regular decision-making process looks like. Additionally, testing this decision-making process could help derive more specific factors that could be tested during the test with the perception system.

Section 3.
Develop

This section starts by formulating the design goal and requirements to achieve the goal. Based on references from literature and autonomous technology introduction in safety-critical contexts, the impact of testing for worst-case scenarios was found to be valuable to assess the decision-making of the driver. By understanding the training procedure for the Mototok, worst-case scenarios were explored, which the drivers were not trained for in training. Moreover, to make the testing more specific, a critical situation was identified that could impact the decision-making ability of the driver in said scenarios. Finally, the Critical Decision Method was used as a technique to test decision-making in the worst-case scenarios, with the results presented at the end of the section.

Chapter 7. Defining the Design Goal
Chapter 8. Scenario Development
Chapter 9. Critical Decision Experiment

Chapter 7.

Defining the Design Goal

In this chapter, the insights gathered are summarized and used to answer the research questions. The problems identified are formulated into a challenge, which forms the base for the design goal.

7.1 Answering the research sub-questions

This chapter concludes the research part of the project and utilizes the insights to answer some research sub-questions and formulate a design goal.

1. When is a towing operation considered successful? What factors influence the success of the towing?

Based on the simulated experiment to understand the towing process, any towing performed safely, i.e., without any damage to the aircraft, Mototok, or hangar infrastructure, is considered a successful operation. While the duration of the process is an important factor in determining the turnaround time, the safety of the operation has a much greater weight as a success metric.
More specifically, patterns emerged of situations that may affect a successful towing operation. The Safety and Compliance Leads emphasized the driver's control over the process at all times, regardless of any automated system that is introduced. Any hindrance to driver control would directly conflict with the regulations. Since the towing process has a lot of steps from end to end, communication throughout the process is vital, especially from a safety verification perspective between the driver and the walkers. While communication to the driver might be replaced by a system with comparable capabilities, the decision-making of the driver must remain unchanged, and the final call will still be made by the driver in the first step of introducing autonomy at KLM.

2. How can the towing process be visualized if a real-time towing operation cannot be performed?

The fact that a live towing operation may not be feasible was factored into the steps of the research process. The primary criterion to visualize the towing procedure was to set up a similar environment with the essential infrastructure, which would help drivers resonate with the setup. Another criterion was to ensure that the setup was easy to build and simple to explain to the drivers so that it could be used effectively. Owing to the availability of 3D printers at the MRO Lab and access to the Hangars, a scaled-down, physical model of H12 was the easiest to build. The drivers found it easy to use the miniature models in the setup, and thoroughly explained all steps in the towing. A significant advantage of this setup over real-time towing was that during an actual towing process, the drivers may not have been able to explain the entire process, but would have had to be deduced through recordings of the towing process. This setup allowed drivers to explain all important steps in the process, which was a more direct and quicker approach.

3. What methodology can be utilized to derive a level of autonomy for the towing process?

The literature research gap revealed that no published research accounted for a methodology that might be used to evaluate the current and the next possible LoA of a process. Thus, the process of determining the area of introducing autonomy and its level had no reference point and required a more practical, context-dependent approach. In general, the process of elimination was used to determine which towing segment could be automated. The practical information from the process and interaction maps and the regulatory data at H12 were coupled with design frameworks to derive the final level of autonomy for the process.

4. How can the impact of autonomy on the towing be assessed?

The difference between the product and system levels helped understand what particular areas of the information processing would be automated. While the product-level roles are automated, the impact on the system-level is important to be assessed, since this is where the final actions are taken directly on the towing environment. These actions are heavily reliant on the decision-making of the driver, which is in turn dependent on the inputs received from the perception system. Since the decision-making of the driver is the bridge between what is perceived and what actions are taken, they are considered the most important area where the impact of autonomy must be assessed.

7.2 Defining the Design Goal

From the initial Project Brief, after determining the starting point of automation, the challenge was to perform an equivalency test to understand how the new system would fare in the existing towing environment. Through research, the decision-making of the drivers was determined to be the most important part of the RAM to be tested.

While Evitado's perception system was chosen as the ideal replacement for the role of the walkers, it was still important to understand how the driver's decision-making is driven by the walkers. As derived from 6.5, testing with the walkers could reveal valuable information that can be used to specifically set up the test with the perception system.

Thus, it became clear that an experiment was required to first derive the factors affecting decision-making with the walkers, followed by testing those factors with the new perception system. Due to the bottlenecks of real-time experimentation with Mototok and Evitado's perception system, the equivalency experiment would require simulation. These factors helped set up the design goal for the project, which is formulated as follows:

"Design an experiment to understand the factors affecting the decision-making of the drivers with the walkers as the perception source, and then potentially evaluate how those factors can contribute to testing decision-making using the perception system."

Design an experiment to understand the factors affecting the decision-making of the drivers with the walkers as the perception source

7.3 Design Requirements

To design an experiment capable of recreating the towing process, a set of design requirements was established. Design requirements can be described as characteristics that must be fulfilled for the design goal to be successful (Chakrabarti, Morgenstern, & Knaab, 2004). The following are the design requirements for the experimental setup:

1. To create a setup of a relatively similar layout to H12

For participants to visualize their roles in towing and break down the process, the towing environment must be set up in a way that replicates the real-time hangar environment. This reduces the sensitization period and makes the familiarization process easier. Besides, from a more technical perspective, the movement and interactions between the tools in towing are dependent on each other's relative size, which further justifies the requirement of relative proportions. The layout includes the use of all relevant markings and assets during the towing operation.

2. To establish the roles of participants clearly

Due to previous concerns about driver availability, non-driver participants may be recruited for the study. In that case, it would be required to explain the setup, roles, and the objective of the experiment in greater detail. The accurate depiction of towing requires the correct understanding of individual roles and responsibilities.

3. To enable participants to communicate information effectively with each other

The decisions made during the towing are dependent on how well the driver receives communication from the walkers. Additionally, to conclude the decision-making factors, it is essential to understand how the driver approaches a situation and what prompts them to react in a particular way. This requires a method for all participants to communicate openly, not only to replicate the towing process but also for the researcher to draw conclusions.

4. To simulate the vision of the participants, as the vision of the operators in real time

The limited range of vision of the driver in real-time is the reason behind the requirement of multiple walkers to contribute indirectly to the driver's perception. To understand the decision-making accurately, each walker must be shown only what they see, i.e., only what is relevant to them while towing. By doing this, they contribute to the driver's perception in a manner similar to the current towing process.

5. To simulate only what is essential to understand the decision-making process of the driver

The tight schedules of employees often make it difficult to arrange for long experimental durations. Thus, it is essential that the experiment is conducted to focus primarily on the most critical scenario relative to decision-making, rather than performing the entire towing from end to end.

6. To collect information in a structured manner

Since the experiment involves multiple participants, the information must be collected in a structured manner, which makes it easier to evaluate and draw conclusions from. It would be useful to utilize a framework that has previously been applied in similar applications to understand decision-making, thus serving as a reference to this project.

Chapter 8.
Scenario Development

This chapter starts developing the testing scenarios for the experiment. Through conversations with a Mototok driver, worst-case scenarios are developed to understand the decision-making of drivers in conditions they are not trained for. A situation of multiple inputs from the walkers is also discussed based on other safety-critical scenarios like the towing process.

8.1 Training

8.1.1 Standard Procedure

In most cases, the ability of the driver to make decisions is dependent on the training process. As explained previously, the inherent trust in the driver's decision-making capability lies in a successful training program, where, over two days, he receives all theoretical and practical information regarding the towing process. The theoretical information constitutes the KLM-specific safety and regulations, and some instructional information about towing using the Mototok. The practical side refers to the licensed drivers performing a demo for the trainees using the Mototok and an aircraft, and then allowing the trainees to take turns towing the aircraft. It was also influential to learn that the safety regarding the completion of the process mattered much more than the time taken for it.

From a conversation with a trained driver, it was understood that most of his decision-making relies on the training process itself. This decision-making is mostly understood during the practical part of training, when trainees are allowed to drive the Mototok. For the most part, the training guides the trainees towards maneuvering their way around the most difficult aspects of the towing process. These aspects include recurring scenarios where the decision-making of the driver is of key importance, a poor result of which could harm the well-being of personnel and the assets in H12. The drivers are usually trained in three scenarios, which they must learn to overcome one at a time:

a) When the aircraft is just entering the hangar, it must follow the towing line. If followed imperfectly, it could lead to a collision with the hangar wall upon entry.
b) After entry, special emphasis is paid to watch out for collisions between aircraft wing tips, in case the adjacent towing line houses a parked aircraft.
c) If the aircraft is being parked into a towing line with a tail dock, tit is essential that the towing is performed in a manner that avoids collision between the docks and the tail itself.

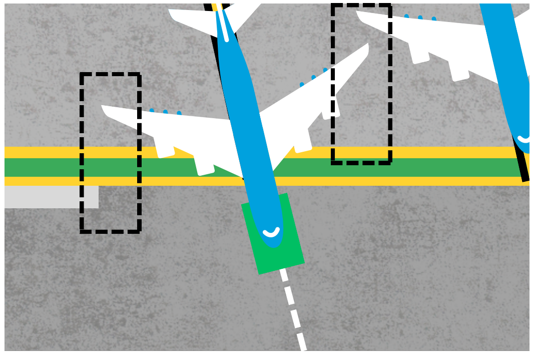
8.1.2 Shortcomings and worst-case scenarios

Through each of these scenarios, the trainee is assigned respective tail and wing walkers to provide visual monitoring and communication. The tail and wing walkers have no particular training of their own, but are rather operators with general instructional training on maintaining operations within H12. While the trainees are guided towards the use of communication instruments, i.e., the headsets, the emphasis remains on training the individual ability of the trainees to manoeuvre the aircraft safely.

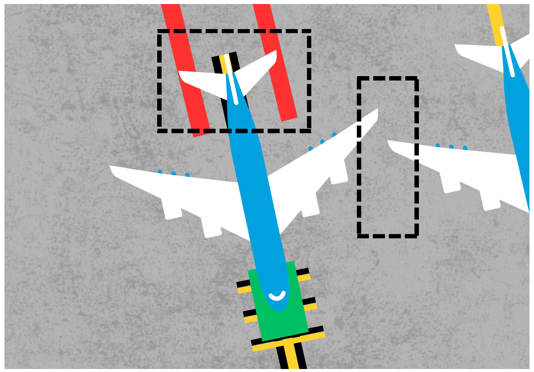
The training procedure is currently not designed to develop decision-making under worst-case scenarios. While the training equips the drivers for conventional circumstances, the chances of unconventional circumstances occurring while towing are not considered impossible. Thus, the scenarios performed during towing might overlap. This is just an instance of a worst-case scenario. On further conversation with the trained driver, it was discovered that multiple types of worst-case scenarios might occur during the real-time towing (the training process only instructed trainees to perform one scenario at a time). However, the trained drivers were trusted to make the correct decisions in the towing environment. Two critical scenarios were uncovered during the conversation where decision-making based on the perceived information from the walkers was critical:

a) Scenario 1: While entering the hangar, it was possible that a wing of the aircraft could collide with the wing of the aircraft parked on the adjacent towing line, while the other wing of the aircraft being towed could potentially collide with the hangar wall (see Figure 24a).
b) Scenario 2: While docking the aircraft's tail, it was possible that a wing of the aircraft could collide with the wing of the aircraft parked on the adjacent towing line, while the tail could collide with the dock itself (see Figure 24b).

This is where the training process lags; it does not take into account overlapping scenarios and the decision-making of the drivers during such periods. Thus, if the ability of a perception machine needs to be tested, it must be tested in an environment where these worst-case scenarios might occur. This often uncovers hidden failures that may not occur under regular circumstances, and can also define the limits of operational capability of a system (Glaessgen et al., 2012). If the decision-making of the driver can be tested to understand his response to such scenarios, the extent to which the new system takes over the role of the walkers can be understood, and potential improvements can be recommended.



(a)



(b)

Figure 24. Worst-case scenarios during towing

8.2 Situations in the worst-case scenarios

While the training covers some key scenarios for the drivers, it fails to recognise the worst-case scenarios, and therefore, an important situation that would affect decision-making during the towing. In both Scenario 1 and 2, the driver would communicate with at least one, or more likely, more than one walker. However, the timing of this communication matters, since it could lead to a situation where the driver receives multiple inputs at once. Theory often describes this as multi-tasking, requiring the decision-making human to work on multiple inputs at once (Salvucci et al., 2008). This multi-tasking requires greater attention and working memory (Endsley, 1995), which has a great impact on decision-making due to multiple reasons, for instance, cognitive overloading (Sweller, 1988).

The impact of this multi-input situation has been observed in practical scenarios as well. In a study observing the situational awareness of air-traffic controllers, multi-input situations resulted in task interruptions, which impacted the performance of the controllers (Zhou et al., 2024). A similar study found that multi-input situations for the pilots in an aircraft cockpit affected their ability to detect multiple tones for risk alerts due to increased mental load (Causse et al., 2022). This can be observed in studies beyond the aviation environment, where repeated alerts led to information desensitization of clinicians in clinical healthcare decision systems (Ancker et al., 2017).

Chapter 9.
Critical Decision Experiment

The chapter introduces the steps towards executing the Critical Decision Method, followed by the experiment in which the method was applied. The experiment was improved through ideations with the participants, which is also discussed, followed by the limitations of the experiment. Finally, a decision-making model is derived for the drivers in worst-case scenarios and multi-input situations.

9.1 The Critical Decision Method

9.1.1 About the Method

The Critical Decision Method (CDM) is an interview technique designed to extract expert knowledge about decision-making processes by focusing on specific instances where experienced practitioners faced challenging, non-routine situations that required critical thinking and expertise (Klein et al., 1989). Originally developed within the field of cognitive task analysis, CDM has proven particularly valuable for understanding how experts make decisions under time pressure, uncertainty, and high-stakes conditions (Crandall et al., 2006). The method has been successfully applied across diverse domains requiring complex human judgment, including medical emergency response, where researchers used CDM to understand how trauma surgeons make rapid treatment decisions (Militello & Hutton, 1998), air traffic control operations to analyze controller decision-making during critical traffic situations (Seamster et al., 1993), and military command and control environments to capture tactical decision-making processes (Kaempf et al., 1996). More recently, CDM has found applications in aviation maintenance contexts, where researchers have employed the technique to understand how maintenance technicians diagnose complex aircraft system failures (Rankin et al., 2014), and in maritime operations to examine pilot decision-making during challenging navigation scenarios (Mansikka et al., 2024).

9.1.2 The process

As mentioned earlier, the towing process can be subjected to certain worst-case scenarios that the towing drivers are not trained to deal with. Since the decision-making is heavily reliant on the towing process, the presence of new, previously unfamiliar scenarios can lead to difficulties in making the correct choices. As a result, CDM is chosen as a method to understand how drivers deal with these unfamiliar scenarios and what steps are necessary to make the correct and safe choice.

The CDM follows a semi-structured interview process consisting of three main steps (Butler et al., 2022).

Step 1: Identify Subject Matter Experts (SME)
To understand the decision-making process, it is necessary to find SME participants with substantial experience in the towing process. This step involves an in-person interview to recall the decision-making scenarios, specifically, non-routine, challenging, or critical incidents, which were particularly demanding to deal with.

Step 2: Timeline Reconstruction
This step involves creating a detailed timeline of the incident and identifying key decision points and actions taken throughout the incident. A decision point (DP) is a condition where the driver is required to solve more than one issue at a time, i.e., the driver's decision-making process is influenced by multiple issues. These DPs are identified chronologically to ensure the accuracy of recalling events.

Step 3: Deepening through probing
Since DPs are points where the driver's decision-making influences the outcome of the towing process, it becomes essential to understand what the driver does to navigate each DP. To do this, some questions are formulated. The focus of these probing questions, or probes, is to focus on the expert's thought process, situation assessment, and explore the cues that may be used to make decisions. Most studies usually derive their probes based on a comprehensive study on understanding the cognitive impact on task performance (Crandall et al., 2006). This study highlights a broad range of probing questions that can help researchers break down DPs, which are usually tailored to more specific contexts (Butler et al., 2022).

9.1.3 CDM customization

The CDM utilizes a semi-structured interview process for the participant to recall scenarios where they might have had to deal with DPs. This follows the assumption that a particular context offers such decision points, and that the participant might have experienced them. In the current context, however, the worst-case scenarios developed are not ones that the drivers have previously been trained for, nor have they occurred previously. As a result, the drivers have never had to deal with them. Thus, the requirement of asking participants to recall previous critical scenarios fails.

To offset this, a real-time towing environment offering these worst-case scenarios will be preferable to the traditional CDM process. This customization offers two key benefits to the CDM process.

1. Understanding decision-making in new scenarios
Through a real-time environment, the driver would be able to position himself in the actual towing process and provide insights into how he might deal with new situations that might arise.

2. Enhanced accuracy
Unlike the traditional CDM process, this customization captures decision-making as it occurs, eliminating potential distortions in memory recollection and biases.

Figure 25 summarises how the CDM would be performed in this project.

Figure 25. Summary of performing the CDM

	Creating a Team	Towing in real-time	Probing
GOAL	Before CDM can be performed, participants need to be scouted that could help break down the decision-making in the towing process	This helps recreate the towing process in real-time, but this time addressing the decision-making in the worst-case scenarios	To ask specific questions about how the driver makes decisions, to understand their thought process and method followed to make the correct decision while towing under multi-input situations
HOW?	The participants need to be SMEs, i.e,. people familiar with the towing environment, rules and regulations at H12, and experience driving the Mototok	This could be done within the actual towing environment at H12 or in a recreated setup simulating the towing process (simulation might be preferable to create worst-case scenarios)	A semi-structured interview process following the experiment contains probing questions targeting drivers to reveal their decision-making process in worst-case scenarios under the multi-input situation

9.2 The Critical Decision Experiment

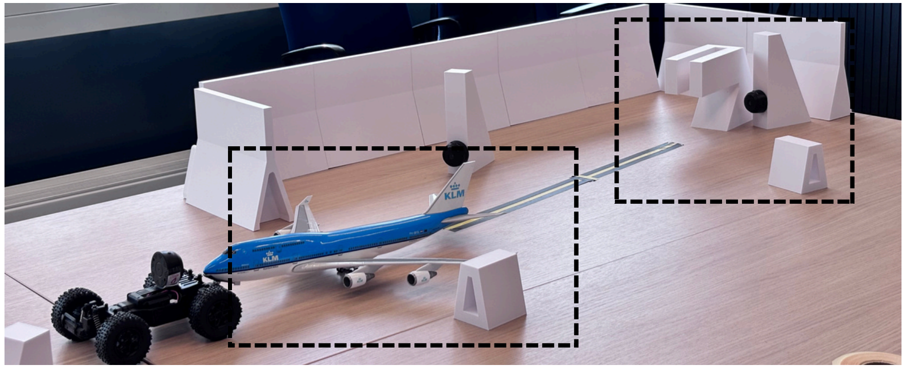
9.2.1 Method

Due to constraints on performing the towing operation in real-time, i.e., using the Mototok and aircraft, Simulated Ethnography was adopted again as the technique to visualize the towing process. From the previous study about visualizing the towing process, a few benefits of this method were concluded:

a) The process allows the driver to immerse in the towing procedure without the cognitive load of actually towing an aircraft. This way, they were able to point things out in greater detail.
b) The drivers were able to slow down the pace of the towing, which helped explain the process.

To simulate the towing process, the towing environment was again physically recreated. To facilitate easier observations and movement in the setup, it was decided that the scale of the experiment would be larger than that of the previous setup (refer to 4.6.1). The scale of this setup was determined by the largest available aircraft model that could be purchased, and the scale of the infrastructure was kept relative to the scale of the aircraft. Due to the larger size of the setup, only the relevant infrastructure would be printed, i.e., hangar walls and a tail dock. In addition, relevant markings on the hangar floor would also be made. The Mototok was replicated by a remote-controlled (RC) car with the capability to push and pull the aircraft model (see Figure 26a).

To simulate the vision of the operators involved in the process, camera setups were utilized. Small-scale security cameras were implemented for this. The camera would use the local Wi-Fi to send a live feed directly to a user interface device, each of which was provided to every operator in the experiment. A camera was attached to the RC car to simulate the live feed for the driver. This was done in a manner that the driver would have the vision to understand his proximate area only, and not the entire breadth of the environment, which is similar to the actual towing process. To simulate the vision of the walkers, cameras were connected to 3D-printed towers located in positions corresponding to the worst-case scenarios. While this vision was not dynamic, it was enough for the walkers to observe the aircraft's movement and send relevant communication to the driver. None of the participants were allowed to view the setup directly during the experiment, which further increased their viewing dependency on their camera feed (see Figure 26b). Finally, the entire experiment would be recorded on a recording device for reference later.



(a)

(b)

Figure 26. (a) Setup showing the two worst-case scenarios, and (b) Participants viewing the setup through individual interfaces

The mode of communication between operators was kept audio-based, similar to the actual towing process. However, instead of providing walkie-talkies to communicate, the drivers would talk to each other directly. This is because of two reasons:

a) All operators had to be present in the same room. This was because the camera feed on each interface was dependent on the proximity between the camera, i.e., the setup, and the interface.
b) If the operators were in the same room, the moment of communication would be ideally replicated just verbally, without audio devices. Audio devices might introduce a voice lag and might also interfere with the driver's ability to hear the walker directly.

9.2.2 Pilot Test

A pilot test was created to understand the technical feasibility of conducting the experiment. Interns at the MRO Lab were chosen as participants for this test. Since the setup consisted of several moving components and connected devices, the pilot aimed at uncovering potential bottlenecks that might occur during the actual experiment. The participants were assigned individual roles, and the test was conducted in the same area where the experiment would take place. The following key insights were drawn from the pilot:

a) The setup was a lengthy process, requiring a period of 30 - 45 minutes. This was primarily owing to ensuring the connectivity between the camera feed and the individual interface devices. The actual experimental setup period was further extended as a result.

b) The aircraft was not very easy to move around using the RC car. Additional anchoring was provided to ensure minimal relative motion between the car and the aircraft.

9.2.3 Participants

An attempt was made to recruit the same participants as in the previous experiment of trying to visualize the towing process. The constraints around conflicting schedules remained throughout, which was a challenging aspect for this study. An attempt was made to recruit participants with a profile close enough to the Mototok towing drivers. The following were the experiment recruits:

Mototok driver: Training Program Designer for the towing operations at H12

Wing Walkers: Instructor of Line Maintenance Operations, and a Continuous Improvement Intern

Tail Walker: Project Manager at the MRO Lab

Apart from the Continuous Improvement intern, all participants were familiar with the towing environment at H12 and Mototok's towing capabilities. The intern was sensitized to this information before the start of the experiment through the setup.

9.2.4 Tools

a) Informed Consent Forms (refer to Appendix A)
b) 3D printed setup of H12 (hangar walls, tail docking stand)
c) A recording device with a stand
d) User interface devices
e) Remote-controlled car
f) Aircraft model
g) Notebook and pen
h) Meeting room at the MRO Lab

9.2.5 Procedure

The main researcher would arrive at the meeting room in H12 before the scheduled experiment time. This would be to set up the environment, connect the cameras with the interface devices, and keep the informed consent forms ready. The towing environment is set up in a pushback style, i.e., with the experiment requiring pushing the aircraft model into the parking position at H12. This is because the pushback style allows for the experiment to end at the tail docking stand, which is required in one of the worst-case scenarios. The camera stands will be arranged in a manner consistent with the position of the walkers, ensuring that they can visibly notice their target monitoring areas.

After signing the consent forms and following the introductions by the researcher and operator, the researcher provides an overview of the research topic, its purpose, and emphasizes the participants' right to withdraw any statements/ their participation from the interview at any time. The operators would be assigned their respective roles; the driver would be given the remote control of the car and an interface device, and the walkers would be provided with their respective interface devices.

The procedure is divided into two main parts: the experiment and the interview. The experiment involves the driver towing the aircraft through Scenario 1, followed by Scenario 2. The Think-Aloud Protocol (TA) would be followed by the driver. This is to ensure that every decision and the reasons behind them are explicit throughout every stage of the towing. Additionally, the TA protocol works well with a simulation setup, as it allows for the approximation of a real-life environment and allows the user to be in control, which elicits more realistic statements (Fonteyn et al., 1993). Nudging would be used to remind the driver to continue expressing his thoughts throughout the experiment. The entire process would be recorded on the recording device.

Following the experiment, an interview would be conducted with the driver to further break down the decision-making process (see Figure 27). To implement this, the CDM would be utilised. The probing questions were targeted at understanding how the driver makes decisions at each DP, while potentially receiving multiple inputs from walkers. The questions for probing are thus framed as follows:

1. To understand the Input Sequencing

“When both wing walkers and the tail walker spoke within seconds of each other, walk me through exactly how you processed information.”

2. To understand the Input Prioritization

"In the moment when you received conflicting information (for example, left wing saying 'tight' and right wing saying 'clear'), how did you decide which one mattered more?"

3. To understand the Synthesis Point

"How did you combine multiple walker inputs into a single decision?"

4. To understand the Default Strategy

"When you couldn't process all inputs fully, what was your fallback approach?"

5. To understand the Overload Point

"Was there a moment when you felt you were getting too much information at once?"

9.2.6 Data Collection

The interview would be video recorded to observe the driver’s inputs on the simulated environment. Some notes were taken using a notebook and pen when necessary.

9.2.7 Data Analysis

This section would involve arranging all the gathered data, re-collection of recorded information, and developing insights. Cluster analysis would be used to derive themes around decision making, and the result of the experiment would be a decision-making model in the worst-case scenarios.

Figure 27. Interview with the driver after the experiment

9.3 Progressive Setup Improvements

During the experiment, the experience of the operators about the towing process and general experimentation motivated them to suggest changes to the setup, which would make it more practical and provide better results. Thus, the setup was ideated upon during the experimentation based on their feedback.

9.3.1 Ideation 1

The first ideation setup was designed to deal with some issues encountered with the current setup, which were as follows:

a) The Tail walker required the camera setup to be turned towards the hangar door, with the dock also in sight. This was because the tail walkers also viewed the general towing into the hangar, in addition to the docking.

b) The walkers required a more dynamic vision, requiring the researcher to move the cameras as and when required during the experiment (see Figure 28).

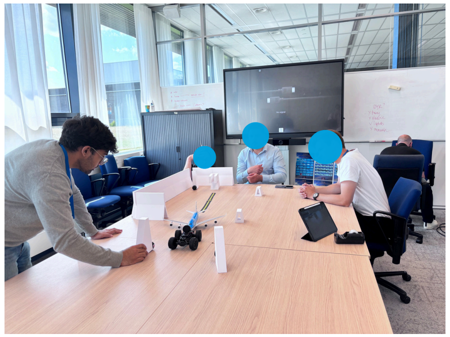
c) The driver's understanding of the towing movement was dependent on the vision of the car's turning axle, which was not visible.

To accommodate these changes, the following improvements were made to the setup and the procedure:

a) The walkers would view the setup directly for their respective focus areas and communicate them to the driver. This was to ensure a more dynamic view of the towing. Thus, the cameras for the walkers were removed from the setup (see Figure 29a).

b) Since the driver was dependent on the vision of Mototok's turning axle, his camera position was shifted to an area slightly behind but adjacent to the car. This camera would then be moved along with the car by the researcher (see Figure 29b).

Figure 28. Moving the camera as per the walkers' perception requirement during the experiment



(a)

(b)

Figure 29. (a) Walkers viewing the setup directly, and (b) The driver's camera being moved along with the aircraft, from behind the car

9.3.2 Ideation 2

While Ideation 1 improved the driver and walkers' ability to perform their tasks, the driver's control over the car was still a limiting factor in manoeuvring the aircraft. This was due to the relative movement between the aircraft and the car, making it difficult to steer the aircraft, due to which it did not move properly along the towing line.

To improve the driver's towing control, the following changes were made in the second ideation:

a) The car was eliminated from the process, and the driver would push the aircraft directly. This allowed him to move and turn the aircraft as required (see Figure 30).

b) Throughout the towing, the driver would not look directly at the setup, but only look at his interface device, which sends a live feed of the towing. This was done to ensure that he was still dependent on the walkers' inputs to navigate the worst-case scenarios.

c) The researcher would help move the interface device along with the driver, while the driver moves the car and the camera (see Figure 31). The roles of the walkers would be the same as Ideation 1.

Figure 30. The driver pushing the aircraft directly, with the walkers viewing the process and providing instructions

Figure 31. The researcher moving the driver's perception camera along with the aircraft

9.4 Limitations

Apart from the general limitations in experimental studies introduced by the Hawthorne Effect (change in the participants' regular behaviour due to observation) (McCarney et al., 2007), some specific limitations of the study were identified.

a) Limited sample size

The single case observation reduced the diversity of inputs, making it difficult to generalize the results of the experiment. The results of the experiment were dependent on the feedback of the driver, which could be different for other drivers. Additionally, the ideations performed on the setup were primarily recommended by only one driver, making it difficult to confirm if the ideations were sufficient to provide the highest possible quality of outputs. KLM is also actively introducing the role of female operators in hangar operations, which can reduce possible gender biases in results.

Additionally, the constraints around performing a single experiment discount the effects of trust in communicating over time. Studies indicate that trust in communication builds over time (Jarvenpaa & Leidner, 1999) and requires multiple interactions before the co-workers' communication methods can be fully understood and trusted (Meyerson et al., 1996).

b) Role substitution

While most of the participants were familiar with the towing process, they were not working within the towing environment at the time of the experiment. This meant that they were not familiar with the latest state of H12 or changes in layouts. Moreover, one of the participants was an intern and was unfamiliar with the towing process altogether. Despite the sensitization before the experiment, it is hard to determine if that was enough to guide him towards providing the correct inputs to the driver.

Despite the driver having multiple years of experience developing the towing training program, he had not been licensed to operate the Mototok. Thus, the inputs received from him throughout the experiment were based on his experience as a general towing driver and his limited knowledge of driving the Mototok.

c) Absence of real-time stakes

While the experiment attempts to evaluate decision-making in a real-time environment, the consequences of decisions are not replicated. Literature shows that the consequences of decision-making are related to the degree of taking risks; experimental participants are prone to making more expert decisions when the decisions have consequences (Greenberg & Liljeholm, 2021). This goes to indicate that without consequences, the participants might not have fully considered the impact of their decisions on the real-time environment. This eliminates, to some degree, the pressures of towing in real-time, for instance, the pressures of long towing durations, the financial risks associated with human and asset damages, and performance evaluation criteria, to name a few.

d) Scale incompatibility

Scale has an important effect on how humans perceive and treat information in space (Frank & Campari, 1993). The roles of each participant require an understanding of spatial relationships between themselves and the hangar environment. This understanding enables decision-making, for instance, by determining how far an aircraft wingtip is from a hangar door before the walker signals the driver to stop towing. The scale of the setup determines the distance between the walker and the wingtip, the viewpoints they can assume, and by extension, how accurately they can assess threats. Even after the ideations of the experiment, the field of view of the walkers could not be kept proportionate to their field of view in the actual towing process, which might have introduced inconsistencies in outputs. The limited view offered by both the static and dynamic camera setups contributes to scale-based issues.

e) Impact of artificial communication

The requirement for participants to be present close to the experimental setup (due to limited connection proximity between interface devices and cameras) introduces artificial interaction patterns, or ignores potential patterns such as body language and proximity cues that might exist in the real-time towing process (Cracco et al., 2018). Additionally, the experimental communication cannot replicate the impact of communicating through walkie-talkies and the potential delays, static, and interruptions it might bring to impact the decision-making of the driver.

f) Think-aloud protocol interference

The think-aloud protocol adds verbalization requirements to the participants' roles, which might create additional cognitive load (Hertzum et al., 2009), potentially hampering decision-making. The need to explain decisions might divert attention from the actual tasks. Moreover, the pace at which participants perform tasks might not match the pace at which they explain what they are doing, thus introducing information delay.

g) Researcher interference

The ideations required a more active involvement from the researcher, particularly in moving around some components of the setup, which introduces external control that does not exist in the real towing operations.

9.5 Answering the research sub-questions

While most of the research questions have been answered (see 7.1). The remaining research questions were based on the testing and results, and will be addressed here.

5. *Should the testing be done in training-like scenarios? Are there more scenarios that might be relevant to test the decision-making of the driver?*

Mototok's training program is structured to provide technical information on Mototok's capabilities, the rules and regulations to be followed, and practical exposure to using the Mototok. During training, the trainees are allowed to tow an aircraft under conventional towing scenarios. For instance, trying to follow the towing line, avoiding collisions, etc.

Even though the Mototok towing process has never been a victim of accidents, certain worst-case scenarios may test the driver's decision-making in ways that are not encountered during training. Testing the decision-making of the driver under nominal, training-like scenarios would help understand how decisions are made on most occasions. However, addressing the more critical scenarios, where the potential of accidents is the greatest, would through light on the decision-making of the driver under pressure. This would provide a more comprehensive understanding of decision-making.

6. How can the gap created by the limitations of the experiment be addressed if the experiment were performed under real towing conditions?

While several steps can be taken to ensure the experiment reveals accurate decision-making results, the most important ones are addressed here.

a) Decision-Making Authenticity Gap: Instead of artificial scenarios, observe naturally occurring critical situations during actual H12 operations (tight clearances, equipment malfunctions, weather challenges) to capture DPs in real-time environments.

b) Spatial Perception Gap: Use real aircraft wingspan clearances and actual hangar door distances so wing walkers make authentic distance judgments rather than scaled model approximations that distort their spatial assessment capabilities.

c) Communication Pattern Gap: Implement standard KLM walkie-talkie protocols with operational distances between driver and walkers, capturing real radio delays and static that influence actual coordination timing.

d) Cognitive Processing Gap: Replace concurrent think-aloud with immediate post-operation interviews using video replay of the actual towing sequence, allowing drivers to explain DPs without cognitive interference during critical moments.

e) Team Dynamics Gap: Study the communication between the crews who have developed trust and communication patterns over months of working together, rather than artificially assembled teams meeting for the first time.

f) Expertise Gap: Use only currently certified H12 Mototok drivers and active wing walkers rather than training personnel and interns, ensuring authentic expertise levels in decision-making analysis.

9.6 Results

9.5.1 Factors affecting Decision-Making

Broadly, two factors affected the driver's decision-making ability: static and dynamic knowledge (see Figure 32). Static knowledge refers to the information stored in memory through his training to become a towing driver and the experiences gained while towing. The training teaches the driver about the Mototok's controls and movements, as well as the rules and regulations at H12 (product and system level knowledge). This training occurs only during the initial training program. The towing experiences gained include the diverse scenarios encountered over multiple towing shifts (system-level knowledge). Dynamic knowledge refers to the information the driver receives during the towing process from his viewpoint while towing (driver's perception), and the inputs from the walkers' viewpoint (walker's perception).

When the driver performs the towing, he starts receiving information about the environment through what he sees and hears from the walkers. The first step he takes is to compare the scenario with his static knowledge to understand if he has encountered that situation before. If so, he deals with the situation as they would have during training or while towing previously, taking inspiration from it. If not, he is required to deal with it based on his decision-making abilities. Every new scenario encountered is stored in memory as a learning experience and may be referred to in the future. Static knowledge is recalled passively, whereas dynamic knowledge requires an active effort from both the driver and the walkers.

9.5.2 Decision Points

For each scenario in the experiment, the participant team had an objective to achieve. Each scenario was handled sequentially, focusing on the current scenario before thinking about the next. While initial research identified two worst-case scenarios, a new scenario was discovered in between. This is labelled Scenario 2 (see Figure 33).

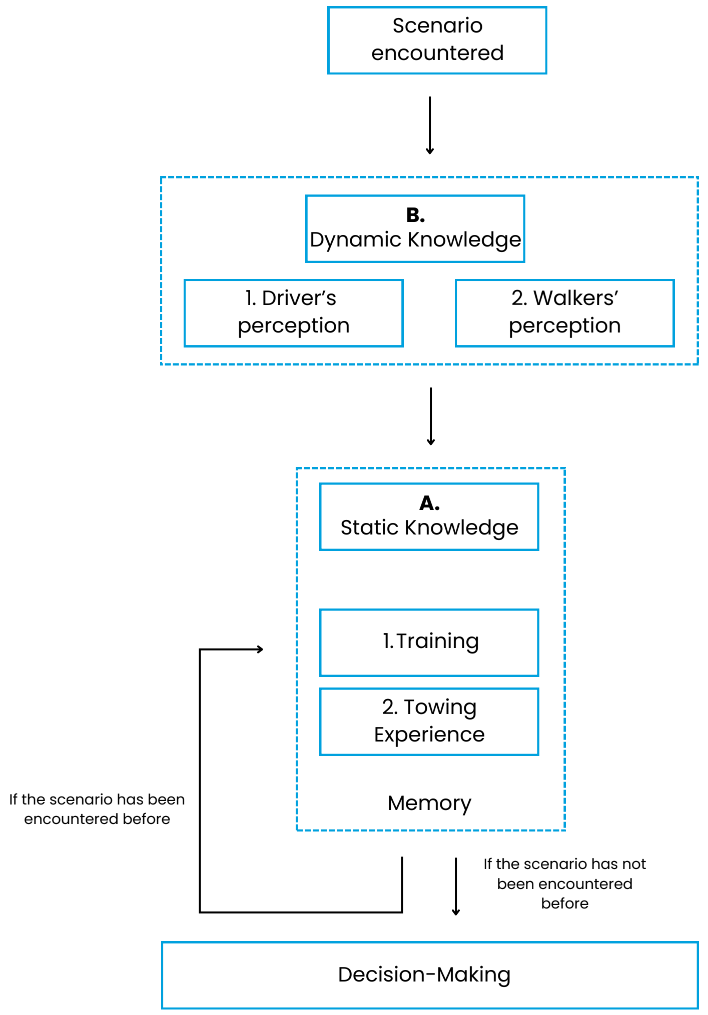


Figure 32. Factors affecting decision-making

For Scenario 1, the objective is to move the aircraft safely into the hangar. To achieve this, the driver's primary objective is to start aligning the aircraft's main landing gear with the towing line in the hangar. While the driver tries to do this, there is a moment when the walker communicates with the driver, informing him that the H12 door might not be open wide enough for the aircraft to pass through. Here, the first DP encountered (labelled DP1 in Figure 33), where the driver needs to decide if the hangar door opening holds priority over the landing gear alignment. Based on the information, the driver chooses to deal with the problem with the greater risk factor. The risk factor for drivers refers to the problem that has a greater potential to threaten the safety of operators and assets at H12. For instance, at DP1, since the hangar door opening determines if the aircraft will enter, that problem is dealt with first, after which the focus is back on aligning the main landing gear with the towing line. Towards the end of DP1, the main landing gear is almost aligned with the towing line, and the door is opened wide enough. Following this, DP2 occurs when the aircraft is midway through the H12 door, and the aircraft wing tip is close to the door. Here, the driver receives input about it from the walker/walkers, and a decision is made if the aircraft can be safely manoeuvred to avoid collision, or if a pullback and re-entry must be attempted.

For Scenario 2, the objective is to move the aircraft safely towards the tail dock. The main objective of the driver, as soon as the aircraft enters the hangar, is to align the nose landing gear with the towing line. Doing so completely aligns the aircraft with the tail dock. DP1 in this scenario occurs if obstacles are present around the towing line, while the driver is still trying the align the nose landing gear. Information about obstacles is provided by the walkers if they are not in the field of view of the driver. After the nose landing gear is aligned, the driver still needs to tow in a manner that keeps the aircraft aligned with the towing line while avoiding obstacles in the towing path. This is DP2, following which the aircraft is ready to be docked.

For Scenario 3, the objective is to dock the aircraft's tail into the docking stand. The only DP is to avoid obstacles while trying to dock the aircraft. Since the aircraft is already aligned, the driver needs to make decisions about stopping the aircraft at the right position based on the walker's inputs.

	Scenario 1	Scenario 2	Scenario 3
Objective	To move the aircraft into H12 safely	To move the aircraft towards the tail dock safely	To move the aircraft towards the tail dock safely
Decision Points	**DP1.** H12 door not opened wide enough/need to align main landing gear with the towing line	**DP1.** Obstacles need to be cleared around the towing line/need to align nose landing gear with the towing line	**DP.** Obstacles need to be cleared around the towing line/need to stop the aircraft at the correct position
	DP2. Wing tip too close to the H12 door, try to manoeuvre around it/ Wing tip too close to the H12 door, pull back and re-attempt entry	**DP2.** Obstacles need to be cleared around the towing line/need to maintain straight line towing on the towing line	

Figure 33. Summary of decision points across all scenarios

9.5.3 Decision-Making Model

At each DP of every scenario, the driver potentially faces a single-input or a multi-input situation at every DP. During a single-input situation, the driver trusts the walker's communication and makes the decision. During a multi-input situation, the information received could be about the same condition or different conditions possible at the DP. For example, considering DP2 from Scenario 1 (refer to Figure 33), both inputs could be about manoeuvring or both about pull back (both about the same condition), or they could be inputs about one of each condition (both about different conditions).

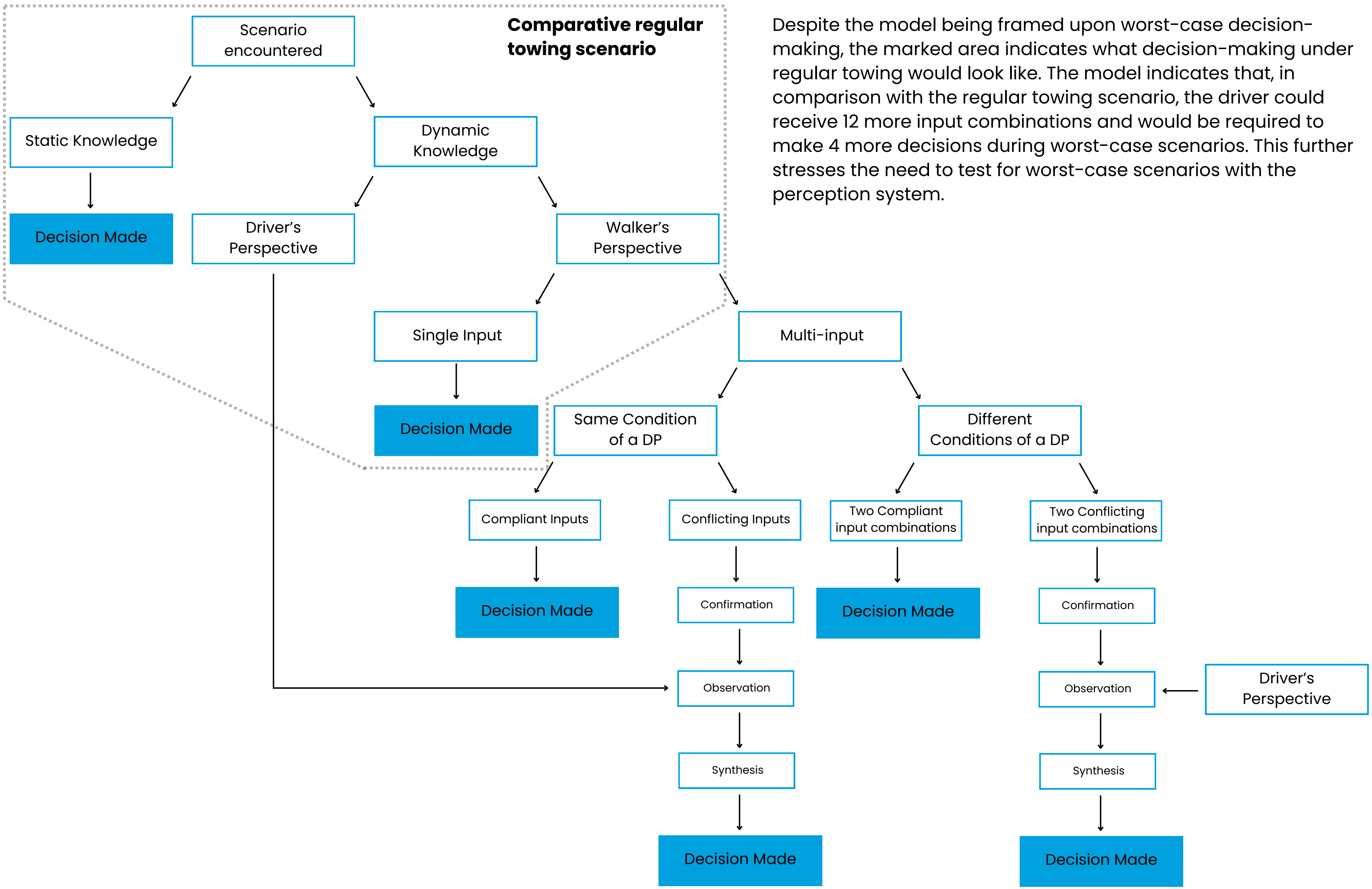
If both inputs are about the same condition, they could be compliant or conflicting in nature. Compliant information refers to the walkers agreeing with each other, and conflicting information refers to the walkers opposing each other. Using the example of DP2 at Scenario 2, if the input of both walkers is about pull-back, then the inputs would be compliant if both ask the driver to pull back, and the inputs will be conflicting if one walker asks for a pull-back but the other asks not to. For the compliant input, the driver trusts the walkers and makes the decision as required by the walkers. However, in the case of conflicting inputs, the driver performs a three-step process. First, the driver *confirms* if the inputs are conflicting via the communication channel. Second, the driver *observes* by employing his perception to understand the reason behind the conflict of information, preferably by moving towards the location. Finally, the driver chooses the walker's perception that matches his own, thereby *synthesising* the information. This leads to a decision being made.

Inputs of different conditions offer two compliant and conflicting types each (see Figure 34). If both walkers ask the driver to perform/not perform manoeuvring or pull back, the inputs are conflicting, whereas if one asks for manoeuvring while the other asks to avoid pull-back, both walkers essentially ask the driver to perform manoeuvring, thereby leading to a compliant input. For the compliant input, the driver performs the task as per their choice, while for the conflicting input, the driver performs the three-step process of confirmation, observation and synthesis. Figure 35 summarises the complete decision-making process.

During the multi-input situations in the experiment, it is possible that handling the inputs and understanding the synthesis point results in a cognitive overload. The sequential input consideration is done to avoid the overload point. Appendix C summarizes the entire experiment through a flowchart.

	Manoeuvring	**Pull-back**
Conflicting	Manoeuvre the aircraft	Perform pull-back
Compliant	Manoeuvre the aircraft	Avoid pull-back
Compliant	Don't manoeuvre the aircraft	Perform pull-back
Conflicting	Don't manoeuvre the aircraft	Avoid pull-back

Figure 34. Compliant and Conflicting inputs when both inputs are about different conditions (based on DP2 of Scenario 1)



Despite the model being framed upon worst-case decision-making, the marked area indicates what decision-making under regular towing would look like. The model indicates that, in comparison with the regular towing scenario, the driver could receive 12 more input combinations and would be required to make 4 more decisions during worst-case scenarios. This further stresses the need to test for worst-case scenarios with the perception system.

Figure 35. Decision-Making Model

Section 4.

Deliver

This section focuses on the final deliverables for KLM.

Chapter 10. Outcomes

Chapter 10.
Outcomes

The results reveal that trust in the walker's inputs impacts the decision-making of the drivers, and must be tested. The section also provides guidelines to test the driver's trust in the perception system.

10.1 Trust in the Walker's Perception

It is now understood that the static and dynamic knowledge of the driver serves as input into the decision-making process of the driver. The static knowledge and the driver's perception are product-level characteristics, while the walker's perception is a system-level characteristic since it depends on the communication with the driver. With the product-level being assumed constant, i.e., not dependent on other factors (refer to 6.3), the system-level factor of the walker's perception becomes the only metric that can be used to test the driver's decision-making.

Through the interview with the driver after the experiment, trust was found to be a significant metric in accurate decision-making (see Figure 36). Trust holds significant weightage in the collaboration between the operators in a workplace (refer to 1.3.1), and was found to have a similar type of impact in the relationship between the driver and the walker. Trust in the walker's inputs gives the driver the confidence to make decisions, since the driver is aware that the walker's inputs are accurate. The interview also revealed that the driver trusts the walkers because they know that the information they receive will be accurate. Research also indicates that the accuracy of information received plays a significant role in trust establishment (Lee & Moray, 1992). In situations other than the worst-case scenarios (i.e., when the walker's inputs are agreeable and non-conflicting), the drivers have an inherent trust in the walker's inputs. This can be attributed to the driver's workplace relationship with the walkers, which builds trust and understanding over a period of time. Also, every walker is an operator at H12 and would have completed a Hangar Training Program. Thus, even if the walkers are not familiar with the Mototok towing process, they have a basic understanding of safety and regulations at H12, which are an important part of the Mototok training program.

Trust in an automated system is often described as a belief that the system will help the user achieve the process target in a state of uncertainty (Lee & See, 2004). When Evitado's perception system is introduced, the driver must be able to trust the inputs provided by the system, i.e., believe that the information provided is accurate. Considering the assumption that the Evitado's perception system performs its product-level roles correctly, the driver must show trust in the information that is being provided to them and act accordingly. This driver's trust in the perception system must be tested to build a strong case for the system's acceptance into the towing process at H12.

*"Basically, you work on **trust** and rely on the accurate inputs of the walkers."*

*"If you have a mutual **trust** on your walkers, then if anyone has a callout, you will not question it and will react to it right away."*

Source: Mototok driver during the CDE, about the trust in the walkers' inputs while making decisions

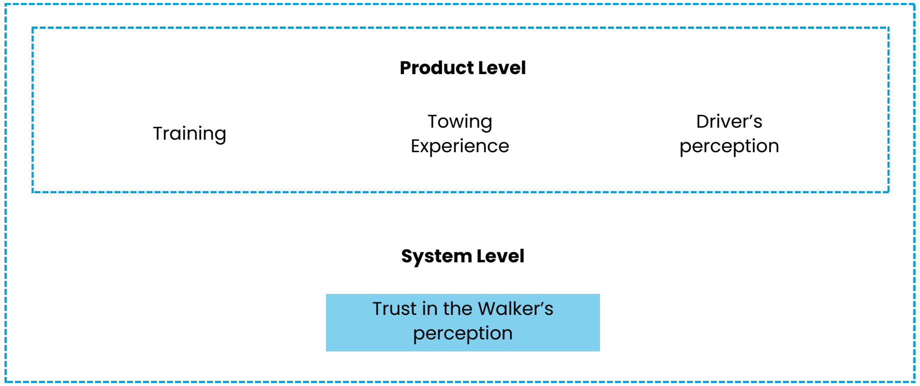


Figure 36. Factors affecting decision making distributed across product and system levels

10.2 Testing the perception system

To test the decision-making of the Mototok driver while using Evitado's perception system, it is necessary to test whether the driver trusts the inputs provided by the system. To do so, KLM aims to experiment with real-time towing conditions. This experiment must address the limitations of the CDE, which might be translated to the real-time towing environment.

Introducing a machine to replace the role of walkers, who, besides being humans, are also recognised by the driver, requires re-establishing trust. The drivers are not merely learning new technology; they are being asked to change a fundamental behavior that has been developed over years of interactions with humans. Simply telling drivers that Evitado's perception system can be trusted does not create a feeling of trust; rather, it requires gradual experimentation to measure and establish trust (Müller, 2024). The following segment establishes guidelines that can be implemented to test the driver's trust in the perception system.

1. Benchmark trust

Before understanding if the driver trusts the perception system's inputs, the degree to which the driver trusts the walker's inputs must be measured. This allows for a more comparative analysis. Under regular towing conditions, the driver has performed towing with the walker's inputs multiple times. However, since the decision-making critical cases, i.e., worst-case scenarios, are also important, it is important to first test the driver's trust in the walker's inputs under these scenarios. This means recreating the scenarios in the CDE in real-time, and taking the value of trust as a benchmark. This benchmark will be used as a comparison against the driver's trust under both regular and worst-case towing scenarios, thus helping establish the driver's trust in the perception system. In addition, testing in real-time, with the actual operators, eliminates Limitations (b), (c), (d), (e), and (g) (refer to 9.4).

2. Sensitization Period

Trust in the perception system cannot be directly tested and compared with the benchmarked trust values from the walkers' inputs. This is because the drivers have been naturally trained to work with the walkers; they understand human behaviour and know that the walkers are trained in the safety regulations at H12. To test the driver's trust in a machine against a human, without allowing for at least a sensitization period, would not make a scientifically accurate comparison.

It is recommended that the drivers be allowed to learn about and interact with the perception system over some time. Since the drivers are already used to training programs, a training program can be designed for the perception system. While common training scenarios can be practiced using the system (refer to 8.1.1), the worst-case scenarios must not be experienced by the drivers during the sensitization period to ensure they are exposed to them only during experimentation, delivering more accurate results.

3. Specific situations to test

Trust testing should be performed while towing with the walker's inputs (benchmarking) and while towing with the perception system. From the decision-making model (refer to Figure 35), the driver trusts the walkers' inputs when they are compliant and ensures that he introduces his perception during the observation phase when dealing with conflicting inputs, thereby cross-checking them. Therefore, it becomes necessary to test the trust of the walker in the perception system's inputs when the driver does not perform observation. Thus, two types of inputs must be tested: the single-input situation and the compliant inputs under both multi-input situations.

4. Measurement

Trust can be measured using quantitative means (Likert Scale, for example), as it needs to be compared. Ideally, the experiment should be performed on a larger sample size to ensure generalizability and prevent the skewness of data, which also eliminates limitation (a). Since trust is a dynamic entity, it is better to measure post-experiment. Research shows that trust can adjust dynamically during an experiment; failures can cause drops in trust, while success can cause trust to peak (Yang et al., 2023). This also eliminates limitation (g).

Section 5.

Discussion

This section evaluates the project methodology and outcomes.

Chapter 11.
Discussion

With the deliverables defined, this chapter summarises the project by revisiting the main research question. The contribution to academia and the client is evaluated, followed by discovering the applicability of the project methodology and results across contexts. The general limitations of the study are addressed, followed by an elaboration on how the project can be carried forward. Finally, a personal reflection is provided to encapsulate the experience and learnings from the project.

11.1 Summary

The initial brief received from the client was simple: make the towing process using the Mototok more autonomous, which became the aim of this project. To approach this project, three main steps were taken:

1. Understanding the current towing process using the Mototok and uncovering the rules around safe operations at Hangar 12.

2. Interpreting an entry point for autonomy, specifically, a particular area and level at which the autonomy can be introduced.

3. Determining the factors that need to be tested when the autonomous technology is introduced in the towing process.

The deliverables of this study were specific factors that would need to be tested when a perception system is introduced to replace the role of the wing and tail walkers, and guidelines that should be followed to perform a test.

This section attempts to journey back into the different aspects of the project, specifically the results of both experiments (about the towing process and the Critical Decision Experiment) and the information received through interviews with experienced towing drivers and safety leads to answer the main research question of the study, which was:

What process can be followed to introduce an autonomous technology into the Mototok towing workflow?

11.1.1. The role of a user-centered approach

This project took a technological pull approach, i.e., inputs were considered from the final users of the technology (Mototok drivers) to determine the area of autonomy. Rather than introducing the technology and testing it with the users, the focus was maintained on ensuring that they were involved in the project development process. This improved their understanding of what technologies might come in the future, improving their acceptance of them.

The inputs of end-users were considered across multiple phases of the project. To start, the roles of the operators were identified during the scaled-down experiment (refer to 4.6), and the setup allowed them to reveal their perspectives about what the ideal towing operation should look like. The setup was found particularly helpful in revealing more specific details about the process, which might have potentially been missed out on if a real-time towing operation was used to explain the towing process (due to the operators' focus on their roles). The experiment revealed communication patterns that the drivers had not considered before, aiding their approach towards towing.

The safety and regulatory perspective was particularly impactful for the project, as it helped uncover the extent to which autonomy can be introduced. Interviews with the safety experts helped define the boundary for autonomy in the towing process. These inputs were especially valuable while identifying the area and the level at which the autonomy can be introduced (see Figure 21). Receiving these inputs meant having the latest understanding of Hangar 12 operations, rules, and standards while developing the LoA framework, which may have been missed out on if the project took a technological push-based approach. Other interviews involved deriving the specifics on the Mototok training program, which specifically highlighted some edge cases that the technology might encounter, and served as the basis for the CDE.

The CDE was the first instance of performing a real-time towing process in a scaled-down towing environment. The experiment brought together experts with different ideas on the towing process, and while they were not licensed Mototok drivers, their experience having viewing the Mototok towing and the general towing operations provided a diversity in inputs. The post-experiment interview with the driver revealed specific decision-making patterns while towing, which were critical in determining how a more autonomous perception system would need to be tested in the towing environment.

Overall, a user-centered approach provided real-time and the latest contextual information about the towing process, and helped determine how technologies can be tested.

11.1.2 Level of Autonomy Framework

The idea of making towing autonomous started with attempting to understand where towing can be introduced. The literature review did not reveal a specific manner in which this area of autonomy can be discovered, due to the impact of context-related information that could not be found in literature sources. Thus, a more custom approach was implemented.

The framework combines the practical viewpoints of the towing process with an existing theoretical model (PSW Framework). The practical information refers to the data received from the process and interaction maps, structuring it across functionality and the flow of information, and using the safety regulations as the boundary conditions to derive the area in which autonomy can be introduced. As for the level of autonomy, a theoretical model was utilized, which provided the scales on which autonomous levels can be classified. A combination of both was crucial in developing the LoA framework.

The framework contributes to the research question by demonstrating that autonomous technology introduction requires systematic progression, from developing an operational understanding, to focusing on the roles of humans, to finally using boundary conditions to derive a specific area of interest for autonomy. This creates a replicable methodology for introducing autonomous technology while maintaining safety compliance and operational effectiveness in aviation environments.

11.1.3 Testing the autonomous technology

Before introducing the autonomous technology into the Mototok process, it must be tested. The project concluded that a system-level testing approach is preferable, especially if it can be assured that the technology can perform its product-level tasks accurately. System-level testing allows for consideration of operational contexts, making the testing process more holistic. Before testing the technology, it is important to know exactly what must be tested. The CDE enabled the process of determining the factors directly influencing the decision-making of the drivers. This helped set up the guidelines for the experiment that KLM can perform to test the autonomous system.

Testing serves as the essential validation mechanism that uncovers hidden failures that may not occur under regular circumstances and defines the limits of operational capability of autonomous systems (Schiphol, 2021). In safety-driven workflows like aircraft towing, the consequences of system failure involve potential damage to aircraft, infrastructure, and personnel safety. Testing under worst-case scenarios that drivers are not trained for reveals how autonomous technology affects human decision-making when operators face unfamiliar situations requiring critical thinking and adaptation.

11.2 Contribution

11.2.1 To Academia

Framework for LoA determination

The framework introduced combines practical, context-related factors with existing theoretical models (Parasuraman et al., 2000), creating a comprehensive manner of deriving the area and level at which autonomy can be introduced. Most of the existing research on LoA provides information on the progression of autonomy and the distribution of tasks between humans and the autonomous system. However, research does not help explain the choice of an autonomous system. This framework introduces a context-aware approach to choosing an autonomous system, especially in safety-critical contexts where interactions occur across multiple levels. A generalization to this framework could help directly apply it across contexts.

With Industry 5.0 focusing on a human-centered approach, the framework is built upon the information provided by the end-users of the technology (Xu et al., 2021), keeping them at the center of the development process. The practical insights gathered from the process and interaction maps contributed directly to the choice of the system that can be introduced. This contributes to addressing the literature research gap (refer to 1.4).

Improving the CDM

The CDM process involves an interview where the participant is asked to recall the scenarios where their decision-making was important. However, this introduces biases, since participants might not recall the scenario accurately. The CDE is performed as an initialization to the CDM in this project, allowing the towing operators to perform a setup towing operation before moving on to the interview process in the CDM. This helps eliminate biases, keeping information fresh and recent, and allowing operators to retain critical information about decision-making.

Experimental methodology to understand safety-critical contexts

The experimental setups used in the project help replicate a real-time towing scenario. Despite its limitations, it was observed that a setup helped operators evaluate the situation more effectively due to the absence of real-time stakes (time pressure (Kerstholt, 1994), asset safety), allowing them to explain their opinions in a relatively low-pressure environment (Sosnowski & Brosnan, 2023). Moreover, the setup uncovered the dynamic relationship between operators, which would have been difficult to understand in a real-time scenario due to the operators' focus on completing their tasks.

The requirement for worst-case testing would have been difficult to replicate in a real-time towing scenario, especially within the duration of the project. The experimental setup allowed for a conceptual understanding of how operators perceive these scenarios and potentially deal with them. Experimental setups can help researchers perform testing without the need for expensive infrastructure or allotted testing time in real-time scenarios.

Decision-Making Model

The decision-making model developed as a result of the CDE provides an insight into what the results of the CDM process could look like. Research on the CDM usually provides DPs and factors affecting decision-making as outputs. However, a decision-making model can help summarise the behaviour of the participant across each DP, and provide a sequential manner of understanding how decisions are made. The model also takes into consideration decision-making under worst-case scenarios, delivering rich insights into problem-solving under pressure.

11.2.2 To KLM Royal Dutch Airlines

Technological pull

The project was an example of a technological pull, which establishes user inputs during the technology introduction process (Hötte, 2021). This allows the end-user to be a part of the development process, which eventually allows for a greater acceptance rate for the technology since it addresses their specific challenge, making the project outcomes desirable.

Guidelines for testing

In the long term, KLM aims to test the perception system, which will replace the walkers in the towing process. To enable that, the project delivers key, viable guidelines that can be followed during the test. The guidelines were based on the results of the decision-making model, thus backed by a research-based approach. Additionally, the guidelines address limitations that were encountered during the CDE and might be encountered during the perception system test, which focuses on improving the feasibility of introducing the technology.

Improving the Mototok Training Program

The setup developed during the CDE was found to have potential implications for training Mototok towing drivers. The theoretical side of the training program involves providing instructions and guidelines verbally. The setup could serve as a visual aid in understanding the towing environment at H12, potentially risky scenarios in towing, and instructions on navigating past them. This improves their understanding of the context before participating in the practical towing sessions. This furthers the desirability of the outcomes at KLM.

11.3 Relevance across contexts

The findings of this study are particularly relevant for other safety-critical multi-agent environments where complex coordination between human operators and autonomous systems is essential, such as mining operations, warehouse facilities, construction sites, and maritime operations. The systematic framework for determining autonomy levels can serve as a model for similar settings where autonomous technology needs to be introduced.

Autonomous systems are becoming more relevant as companies try to improve their productivity. Innovation is a major theme in these companies, and this project could serve as a benchmark on how to target potential areas to automate, saving costs while improving productivity.

Since technology introduction in safety-critical contexts requires testing or simulation, the experimental approach utilized in this project could provide the basis for testing how the technology could work in its real-time contexts, and also help visualize the HMC aspect of it.

11.4 General limitations

While the limitations of the experimental approach have been addressed, addressing other broader limitations can help improve the outcomes of similar projects in the future.

The limited duration of the project (100 working days) set up a time constraint to deliver value to the client and to academia. This meant trying to keep up with the fixed project plan, which was at times difficult to achieve due to unforeseen circumstances. Some of these circumstances included arranging participants for the studies and obtaining context-specific insights for the project. The limited availability of operators due to their tight schedules made it difficult to plan sessions, which was difficult to deal with. An ideal way to approach this constraint might be to arrange for a larger participant pool or find participants within a similar field of expertise, thus ensuring that the contextual competence is maintained.

The towing context at KLM changes rapidly; continuous improvement is an important target to keep up with industry standards. This project captures a snapshot of current operations and immediate automation opportunities but does not examine how automation impacts evolve over time or how human-machine collaboration patterns change with experience.

The study depends on expert interviews and experiments for data. The results are derived from their experiences, which might introduce their own biases into the results. Moreover, quantitative validation through a larger sample size, with the qualitative insights, can significantly improve the confidence in the results of the study.

While the study develops novel frameworks to address the literature gaps, validating those frameworks across multiple contexts would help improve robustness and applicability.

11.5 Future work

From the outcomes of this project, testing the perception system is the natural next step that can help validate usage in real-time contexts and integrate it with the operators for effective HMC. Testing across a larger sample size could help generate broader results, which could help improve the system-level co-operation between the operators and the machine. Furthermore, the introduction of technology also implies its maintenance and storage within H12, which needs to be explored. KLM would need to provide a completed Management of Change sheet, listing the new safety requirements and standards to incorporate the technology in towing processes.

With the introduction of the technology, new and existing towing drivers would require training with the new system. For the new towing drivers, this would mean understanding the use of the technology and the safety regulations around its use, while for existing towing drivers, in addition to the education on the technology, it would also require re-training their natural relationship with the walkers and establishing a new one with the system. The initial literature review (refer to 1.3) can provide inputs into how this can be achieved.

KLM aims to continue making processes more autonomous. This project marks the first step in the incremental introduction of the technology. With the perception system, enlarging the working context could also aid the productivity, for instance, potentially using the technology for towing beyond KLM's area of authority. This can be achieved as a new project in the existing collaborative efforts with Schiphol to introduce autonomous technologies.

The next step could be to research how the process might be made more autonomous, keeping the user-centered development process in mind. A potential roadmap, with this project as the starting point, could be aligned with KLM's Back-on-track roadmap to help develop horizons across which the process could be made more autonomous.

11.6 Conclusion

Aircraft towing operations require a delicate balance between operational efficiency and safety compliance. This research investigated the integration of an autonomous technology into KLM's Mototok-based towing processes at Hangar 12, establishing a systematic methodology for determining appropriate automation levels while preserving critical human oversight.

The successful implementation of autonomous systems in aircraft towing operations relies not only on technological capabilities but also on the preservation of essential human roles that ensure safety and regulatory compliance. By employing a user-centered design approach, this study established a framework for determining appropriate levels of autonomy that complement rather than replace critical human decision-making processes. This user centered approach kept the towing operators at the center of the development process through experiments and interviews, using their experience define the operational capabilities within the towing environment, and keeping them informed about what the future of the towing process would look like.

The project delivered on two fronts: addressing the literature gap and designing for the practical opportunity at KLM. The LoA framework delivered on contributing a process through which safety-critical environments can approach introducing autonomy into their operations, which addressed the research gap. The technological pull, based on a user-centered approach, addressed the need to keep the technology users at the center of the development process, thus addressing the practical opportunity at KLM.

The process of introducing autonomous technology meant performing four tasks: maintaining the user’s experienced inputs at the center of the research process, focusing on where and at what level the technology can be introduced, assessing the type of impact that needs to be evaluated (product/system level), and finally testing the technology to understand that impact.

Further research is needed to validate the proposed Level 2 autonomous system through full-scale operational trials, assess long-term reliability under varied environmental conditions, and evaluate the broader implications of human-machine teaming on operational efficiency and safety outcomes in towing operations.

Ultimately, this study demonstrates that thoughtful integration of autonomous technologies can enhance operational efficiency while preserving essential human expertise and control. The research provides a foundation for future autonomous system implementations in aircraft ground operations and offers a systematic approach for balancing technological advancement with safety requirements and human-centered design principles.

11.7 Personal reflection

I have always been motivated by innovation. My background as an engineer allows me to think from a technological perspective, while my education in design has helped my understanding of user-focused design. While looking for an internship at the end of my first year, I came across an open position at KLM. Working at the Engine Services for five months was a unique experience, not because I was in charge of 3D printing operations throughout the department, but because I received an opportunity to work in a professional Dutch context for the first time. I had the freedom to communicate with operators across multiple working areas and attend professional career events. It was here that I discovered the problem statement for my project.

At the beginning of the assignment, I had set a target of developing a physical solution for my thesis. I have always enjoyed the physical design phase more than the research phase of projects. The broad problem statement of the project gave me the confidence to do so. However, as I made progress in my research, I came to enjoy the process of discovery; developing insights from conversations and experiments was one of the most enjoyable aspects of the study. Moreover, since the project was the first attempt at introducing autonomy in the towing process, it required a research-heavy approach. Over time, my desire to achieve a physical outcome changed to focusing on what KLM needed more.

The project came with its challenges. Working in a Dutch-heavy context meant attempting to communicate across language barriers. Adjusting the fixed project timeline to accommodate the schedules of operators meant longer working hours. Finally, some contexts of my research had few reference points, requiring me to develop my methods. I truly believe that, in addition to developing research and design skills, problem-solving has been a transformative learning experience. I am grateful to my company mentor and the supervisory team for their guidance and motivation towards my project.

The broad scope of the project required zooming in and out as required. This required changing problem statements or sometimes, not utilizing outcomes I had worked on. Over time, I had conversations with researchers and designers at other companies and fellow students to understand how they dealt with these situations. I have realized that every step taken in the project contributed directly or indirectly to my outcomes, and that every step taken is a step in the right direction.

This thesis journey has changed me as a person, not just as a designer. I've become more patient, more empathetic, and more comfortable with complexity in all areas of my life. I've learned to value different types of intelligence and expertise, and I've developed a deeper appreciation for the wisdom that comes from experience.
The skills I've developed - active listening, critical thinking, problem-solving under uncertainty, and working with diverse groups of people have applications far beyond academic research.

Moving forward, I carry with me not just the knowledge I have gained, but the confidence that I can navigate uncertainty, the humility to keep learning, and the understanding that the best research emerges from genuine curiosity and respect for the complexity of human experience. This journey has prepared me not just for future research endeavors, but for a lifetime of learning and growth.

REFERENCES

Abdelaziz, S. G., Hegazy, A. A., & Elabbassy, A. (2010). Study of airport self-service technology within experimental research of check-in techniques case study and concept. International Journal of Computer Science Issues (IJCSI), 7(3), 30.

Agudo, U., Liberal, K. G., Arrese, M., & Matute, H. (2024). The impact of AI errors in a human-in-the-loop process. Cognitive Research: Principles and Implications, 9(1), 1.

Ajoudani, A., Zanchettin, A. M., Ivaldi, S., Albu-Schäffer, A., Kosuge, K., & Khatib, O. (2018). Progress and prospects of the human–robot collaboration. Autonomous Robots, 42, 957-975.

Ancker, J. S., Edwards, A., Nosal, S., Hauser, D., Mauer, E., Kaushal, R., & With the HITEC Investigators. (2017). Effects of workload, work complexity, and repeated alerts on alert fatigue in a clinical decision support system. BMC Medical Informatics and Decision Making, 17, 1-9.

Anderson, E., Fannin, T., & Nelson, B. (2018). Levels of aviation autonomy. 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC).

Antonaci, F. G., Olivetti, E. C., Marcolin, F., Castiblanco Jimenez, I. A., Eynard, B., Vezzetti, E., & Moos, S. (2024). Workplace Well-Being in Industry 5.0: A Worker-Centered Systematic Review. Sensors, 24(17), 5473.

Aurrigo. (2025). Auto-DollyTug® aims to streamline baggage transfer with Schiphol. Retrieved from https://aurrigo.com/auto-dollytug-aims-to-streamline-baggage-transfer-with-schiphol/

Bathla, G., Bhadane, K., Singh, R. K., Kumar, R., Aluvalu, R., Krishnamurthi, R., Kumar, A., Thakur, R., & Basheer, S. (2022). Autonomous vehicles and intelligent automation: Applications, challenges, and opportunities. Mobile Information Systems, 2022(1), 7632892.

Beumer, R. (2024). The Impact of TaxiBot Operations on Ground Traffic Flow at Amsterdam Airport Schiphol.

Boos, A., Sax, M., & Reinhardt, J. (2020). Investigating perceived task urgency as justification for dominant robot behaviour. International Conference on Human-Computer Interaction.

Butler, G. L., Read, G. J., & Salmon, P. M. (2022). Understanding the systemic influences on maritime pilot decision-making. Applied Ergonomics, 104, 103827.

Causse, M., Parmentier, F. B., Mouratille, D., Thibaut, D., Kisselenko, M., & Fabre, E. (2022). Busy and confused? High risk of missed alerts in the cockpit: an electrophysiological study. Brain Research, 1793, 148035.

Chakrabarti, A., Morgenstern, S., & Knaab, H. (2004). Identification and application of requirements and their impact on the design process: a protocol study. Research in Engineering Design, 15, 22-39.

Charlton, J., Gonzalez, L. R. M., Maddock, S., & Richmond, P. (2020). Simulating crowds and autonomous vehicles. In Transactions on Computational Science XXXVII: Special Issue on Computer Graphics (pp. 129-143). Springer.

Cracco, E., Genschow, O., Radkova, I., & Brass, M. (2018). Automatic imitation of pro-and antisocial gestures: Is implicit social behavior censored? Cognition, 170, 179-189.

Crandall, B., Klein, G. A., & Hoffman, R. R. (2006). Working minds: A practitioner's guide to cognitive task analysis. Mit Press.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1), 32-64.

Filippi, E., Bannò, M., & Trento, S. (2023). Automation technologies and their impact on employment: A review, synthesis and future research agenda. Technological Forecasting and Social Change, 191, 122448.

Flemisch, F., Heesen, M., Hesse, T., Kelsch, J., Schieben, A., & Beller, J. (2012). Towards a dynamic balance between humans and automation: authority, ability, responsibility and control in shared and cooperative control situations. Cognition, Technology & Work, 14, 3-18.

Fonteyn, M. E., Kuipers, B., & Grobe, S. J. (1993). A description of think aloud method and protocol analysis. Qualitative Health Research, 3(4), 430-441.

Frank, A. U., & Campari, I. (1993). Spatial Information Theory: A Theoretical Basis for GIS. European Conference, COSIT'93, Marciana Marina, Elba Island, Italy, September 19-22, 1993. Proceedings (Vol. 716). Springer Science & Business Media.

Galaz, V., Centeno, M. A., Callahan, P. W., Causevic, A., Patterson, T., Brass, I., Baum, S., Farber, D., Fischer, J., & Garcia, D. (2021). Artificial intelligence, systemic risks, and sustainability. Technology in Society, 67, 101741.

Gebetsroither-Geringer, E., & Loibl, W. (2016). Urban development simulator: How can participatory data gathering support modeling of complex urban systems. Understanding Complex Urban Systems: Integrating Multidisciplinary Data in Urban Models, 33-47.

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. Journal of Cleaner Production, 252, 119869.

Glaessgen, E., & Stargel, D. (2012, April). The digital twin paradigm for future NASA and US Air Force vehicles. In 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA (p. 1818).

Gopinath, V., & Johansen, K. (2019). Understanding situational and mode awareness for safe human-robot collaboration: case studies on assembly applications. Production Engineering, 13, 1-9.

Greenberg, J., & Liljeholm, M. (2021). Stakes and expertise modulate conformity in economic choice. Scientific Reports, 11(1), 23369.

Guest, G., & McLellan, E. (2003). Distinguishing the trees from the forest: Applying cluster analysis to thematic qualitative data. Field Methods, 15(2), 186-201.

Helle, P., Schamai, W., & Strobel, C. (2016). Testing of autonomous systems–Challenges and current state-of-the-art. INCOSE International Symposium.

Hendra, O., Kurnianto, B., & Endrawijaya, I. (2024). Collaborative governance for aviation approved training organisation: an adapted model for multi-stakeholder collaboration. Higher Education, Skills and Work-Based Learning, 14(2), 418-434.

Hertzum, M., Hansen, K. D., & Andersen, H. H. (2009). Scrutinising usability evaluation: does thinking aloud affect behaviour and mental workload? Behaviour & Information Technology, 28(2), 165-181.

Hoc, J.-M. (2000). From human–machine interaction to human–machine cooperation. Ergonomics, 43(7), 833-843.

Hötte, K. (2021). Demand-pull and technology-push: What drives the direction of technological change? An empirical network-based approach, 1-88.

Isaza, L., & Cepa, K. (2024). Automation and augmentation: A process study of how robotization shapes tasks of operational employees. European Management Journal.

Jaap Bouwer, V. K., Steve Saxon, Caroline Tufft. (2022). Taking stock of the pandemic’s impact on global aviation. Retrieved from https://www.mckinsey.com/industries/travel/our-insights/taking-stock-of-the-pandemics-impact-on-global-aviation#/

Jarvenpaa, S. L., & Leidner, D. E. (1999). Communication and trust in global virtual teams. Organization Science, 10(6), 791-815.

Kaempf, G. L., Klein, G., Thordsen, M. L., & Wolf, S. (1996). Decision making in complex naval command-and-control environments. Human Factors, 38(2), 220-231.

Kerstholt, J. (1994). The effect of time pressure on decision-making behaviour in a dynamic task environment. Acta Psychologica, 86(1), 89-104.

Klein, G. A., Calderwood, R., & Macgregor, D. (1989). Critical decision method for eliciting knowledge. IEEE Transactions on Systems, Man, and Cybernetics, 19(3), 462-472.

KLM. (2024). Annual Report 2024 - Back on Track. Retrieved from https://www.klmannualreport.com/#:~:text=Our%20Back%20on%20Track%20program,operations%2C%20and%20restoring%20financial%20resilience.

Kolahchi, Z., De Domenico, M., Uddin, L. Q., Cauda, V., Grossmann, I., Lacasa, L., Grancini, G., Mahmoudi, M., & Rezaei, N. (2021). COVID-19 and its global economic impact. In Coronavirus Disease-COVID-19 (pp. 825-837). Springer.

Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. Ergonomics, 35(10), 1243-1270.

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. Human Factors, 46(1), 50-80.

Lee, H. R., Fox, S., Cheon, E., & Shorey, S. (2025). Minding the Stop-gap: Attending to the" Temporary," Unplanned, and Added Labor of Human-Robot Collaboration in Context. Proceedings of the 2025 ACM/IEEE International Conference on Human-Robot Interaction.

Lindström, V., & Winroth, M. (2010). Aligning manufacturing strategy and levels of automation: A case study. Journal of Engineering and Technology Management, 27(3-4), 148-159.

Majid, G. M., Tussyadiah, I., Kim, Y. R., & Pal, A. (2023). Intelligent automation for sustainable tourism: a systematic review. Journal of Sustainable Tourism, 31(11), 2421-2440.

Mansikka, H., Virtanen, K., Lipponen, T., & Harris, D. (2024). Improving pilots' tactical decisions in air combat training using the critical decision method. The Aeronautical Journal, 128(1326), 1613-1626.

McBride, S. E., Rogers, W. A., & Fisk, A. D. (2014). Understanding human management of automation errors. Theoretical Issues in Ergonomics Science, 15(6), 545-577.

McCarney, R., Warner, J., Iliffe, S., Van Haselen, R., Griffin, M., & Fisher, P. (2007). The Hawthorne Effect: a randomised, controlled trial. BMC Medical Research Methodology, 7(1), 30.

Melles, M., Albayrak, A., & Goossens, R. (2021). Innovating health care: key characteristics of human-centered design. International Journal for Quality in Health Care, 33(Supplement_1), 37-44.

Meyerson, D., Weick, K. E., & Kramer, R. M. (1996). Swift trust and temporary groups. Trust in Organizations: Frontiers of Theory and Research, 166, 195.

Militello, L. G., & Hutton, R. J. (1998). Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive task demands. Ergonomics, 41(11), 1618-1641.

Moray, N., & Inagaki, T. (1999). Laboratory studies of trust between humans and machines in automated systems. *Transactions of the Institute of Measurement and Control*, *21*(4-5), 203-211.

Mototok. (2025). *How does it work?* Retrieved from https://www.mototok.com/how-does-it-work

Nhamo, G., Dube, K., Chikodzi, D., Nhamo, G., Dube, K., & Chikodzi, D. (2020a). COVID-19 and implications for the aviation sector: a global perspective. Counting the Cost of COVID-19 on the Global Tourism Industry, 89-107.

Nhamo, G., Dube, K., Chikodzi, D., Nhamo, G., Dube, K., & Chikodzi, D. (2020b). Impact of COVID-19 on the Global Network of Airports. Counting the Cost of COVID-19 on the Global Tourism Industry, 109-133.

Novák, A., Bugaj, M., Sedláčková, A. N., Kandera, B., Stelmach, A., & Lusiak, T. (2021). Use of Unmanned Aerial Vehicles in Aircraft Inspection. Advances in Science, Technology and Engineering Systems, 6(3).

Nowak, J., Emmermacher, A., Wendsche, J., Döbler, A.-S., & Wegge, J. (2023). Presenteeism and absenteeism in the manufacturing sector: A multilevel approach identifying underlying factors and relations to health. Current Psychology, 42(22), 18641-18659.

Olaganathan, R. (2024). Human factors in aviation maintenance: understanding errors, management, and technological trends. Global Journal of Engineering and Technology Advances, 18(2), 92.

Pan, M., Linner, T., Pan, W., Cheng, H., & Bock, T. (2018). A framework of indicators for assessing construction automation and robotics in the sustainability context. Journal of Cleaner Production, 182, 82-95.

Parasuraman, R., Bahri, T., Deaton, J. E., Morrison, J. G., & Barnes, M. (1992). Theory and design of adaptive automation in aviation systems.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 30(3), 286-297.

Pérez-Escamirosa, F., Medina-Alvarez, D., Ruíz-Vereo, E. A., Ordorica-Flores, R. M., Minor-Martínez, A., & Tapia-Jurado, J. (2020). Immersive virtual operating room simulation for surgical resident education during COVID-19. Surgical Innovation, 27(5), 549-550.

Pritchett, A. R., Kim, S. Y., & Feigh, K. M. (2014). Measuring human-automation function allocation. Journal of Cognitive Engineering and Decision Making, 8(1), 52-77.

Rankin, A., Lundberg, J., Woltjer, R., Rollenhagen, C., & Hollnagel, E. (2014). Resilience in everyday operations: a framework for analyzing adaptations in high-risk work. Journal of Cognitive Engineering and Decision Making, 8(1), 78-97.

Read, G. J., Cox, J. A., Hulme, A., Naweed, A., & Salmon, P. M. (2021). What factors influence risk at rail level crossings? A systematic review and synthesis of findings using systems thinking. Safety Science, 138, 105207.

Rijsenbrij, J. C., & Ottjes, J. A. (2007). New developments in airport baggage handling systems. Transportation Planning and Technology, 30(4), 417-430.

Roth, E. M., Sushereba, C., Militello, L. G., Diiulio, J., & Ernst, K. (2019). Function allocation considerations in the era of human autonomy teaming. Journal of Cognitive Engineering and Decision Making, 13(4), 199-220.

Saadati, P., Abdelnour-Nocera, J., & Clemmensen, T. (2021). Co-designing Prototypes for User Experience and Engagement in Automation: Case Study of London-based Airport Future Workplace. IFIP Working Conference on Human Work Interaction Design.

Sadraey, M. (2020). Automatic Flight Control Systems. Morgan & Claypool Publishers.

Salvucci, D. D., & Taatgen, N. A. (2008). Threaded cognition: an integrated theory of concurrent multitasking. Psychological Review, 115(1), 101.

Schiphol. (2021, February 25). Next phase of testing an Autonomous Baggage Vehicle. https://www.schiphol.nl/en/innovation/blog/next-phase-of-testing-an-autonomous-baggage-vehicle/

Seamster, T. L., Redding, R. E., Cannon, J. R., Ryder, J. M., & Purcell, J. A. (1993). Cognitive task analysis of expertise in air traffic control. The International Journal of Aviation Psychology, 3(4), 257-283.

Sharp, M., Hedberg Jr, T., Bernstein, W. Z., & Kwon, S. (2021). Feasibility study for an automated engineering change process. International Journal of Production Research, 59(16), 4995-5010.

Simmler, M. (2024). Responsibility gap or responsibility shift? The attribution of criminal responsibility in human–machine interaction. Information, Communication & Society, 27(6), 1142-1162.

Sosnowski, M. J., & Brosnan, S. F. (2023). Under pressure: the interaction between high-stakes contexts and individual differences in decision-making in humans and non-human species. Animal Cognition, 26(4), 1103-1117.

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M., & O'Connell, D. (2017). Integration: the key to implementing the Sustainable Development Goals. Sustainability Science, 12, 911-919.

Su, J., Wu, H., Tsui, K. W. H., Fu, X., & Lei, Z. (2023). Aviation resilience during the COVID-19 pandemic: A case study of the European aviation market. Transportation Research Part A: Policy and Practice, 177, 103835.

Su, Y., & Wang, L. (2021). Integrated framework for test and evaluation of autonomous vehicles. *Journal of Shanghai Jiaotong University (Science)*, *26*, 699-712.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257-285.

Szczygielski, J. J., Charteris, A., Bwanya, P. R., & Brzeszczyński, J. (2022). The impact and role of COVID-19 uncertainty: A global industry analysis. *International Review of Financial Analysis*, *80*, 101837.

Tatasciore, M., & Loft, S. (2024). Can increased automation transparency mitigate the effects of time pressure on automation use? Applied Ergonomics, 114, 104142.

Tatasciore, M., Strickland, L., & Loft, S. (2024). Transparency improves the accuracy of automation use, but automation confidence information does not. Cognitive Research: Principles and Implications, 9(1), 67.

Vagia, M., Transeth, A. A., & Fjerdingen, S. A. (2016). A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed? Applied Ergonomics, 53, 190-202
.

Vicente, L., & Matute, H. (2023). Humans inherit artificial intelligence biases. Sci Rep 13: 15737.

Walter, R. (2001). Flight Management Systems. The Avionics Handbook.

Wolf, Z. R. (2012). Ethnography: the method. Nursing Research: A Qualitative Perspective, 4, 293-330.

Woo, A., Park, B., Sung, H., Yong, H., Chae, J., & Choi, S. (2021). An analysis of the competitive actions of boeing and airbus in the aerospace industry based on the competitive dynamics model. Journal of Open Innovation: Technology, Market, and Complexity, 7(3), 192.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, *61*, 530-535.

Yang, X. J., Schemanske, C., & Searle, C. (2023). Toward quantifying trust dynamics: How people adjust their trust after moment-to-moment interaction with automation. *Human Factors*, *65*(5), 862-878.

Zhou, K., Wang, C., Xie, S., Zhou, Y., Zhang, X., Wang, Y., & Tang, H. (2024). Effect of task interruption on the situation awareness of air traffic controllers. *PloS One*, *19*(11), e0314183.

APPENDIX

A. Informed Consent Form

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
1. I have read and understood the study information dated [23/06/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves an audio and video-recorded interview which will be transcribed into text and anonymized for further analysis. These files will be destroyed after the project is completed.	☐	☐
4. I understand that this will be a one-time study lasting approximately 30-60 minutes.		
5. I understand that taking part in the study involves the following risks as it is conducted in an international organization: 1) participants feeling obligated to participate; 2) participants revealing sensitive and commercially confidential information; 3) participants' hindrances in expressing an honest opinion. I understand that these will be mitigated by 1) anonymizing the participants' identity; 2) confirmation the anonymous nature of their identity through cross-checking by the project lead; and 3) allowing the participants to withdraw from the study at any time.	☐	☐
6. I understand that taking part in the study also involves collecting specific personally identifiable information [name, email] and associated personally identifiable research data [job role, department name, previous job profiles] with the potential risk of my identity being revealed or my image being tarnished.	☐	☐
7. I understand that the following steps will be taken to minimize the threat of a data breach, and protect my identity in the event of such a breach: 1) transcribing audio and video data to text; 2) preventing data access to any other members of the organization; 3) securing the identity of the participant; and 4) destroying the recordings at the end of the study.	☐	☐
8. I understand that personal information collected about me that can identify me, such as name, email, job role, and department name, will not be shared beyond the study team.	☐	☐
9. I understand that the (identifiable) personal data I provide will be destroyed after the data collection process is complete (approximately by July 2025).	☐	☐
10. I understand that after the research study, the de-identified information I provide will be used for the final thesis report and potential academic publications aimed at improving the process of autonomous towing at KLM Royal Dutch Airlines.	☐	☐
11. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐
12. I give permission for the de-identified [name, age, job role, and department name] that I provide to be archived in the TU Delft repository so it can be used for future research and learning.	☐	☐

Signatures

Name of participant [printed] ______ Signature ______ Date ______

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Aayush Bhat

Researcher name [printed] Signature Date

B. Rational Agent Model

1. Pre-Towing Preparation Cluster

Process Step	Perception	Decision-Making	Action
A.1: The hangar and the parking area must have the space required to hold the aircraft before the process begins	Driver visually assesses hangar and parking dimensions relative to aircraft size	Driver determines if space is adequate for the specific aircraft type	Driver confirms space adequacy or requests alternative arrangement
A.2: The order for a towing process is given by the Towing Lead at the particular shift	Driver receives verbal/written communication from Towing Lead	Driver interprets priority and specific requirements of towing request	Driver acknowledges order and initiates preparation sequence
A.3: The Mototok's licensed driver is made in-charge of the towing process	Driver recognizes assignment of responsibility	Driver accepts responsibility as towing lead	Driver assumes control of the operation
A.4: The driver collects the keys for the Mototok's secure equipment cupboard and walks towards it	Driver visually identifies key storage location	Driver recalls correct key for equipment cupboard	Driver retrieves keys and approaches equipment storage
A.5: The driver collects the Mototok's radio remote control, headset, steering bypass pin and walkie-talkies from the cupboard	Driver visually inventories required equipment	Driver verifies all required equipment is present and functional	Driver gathers and checks all necessary equipment
A.6: The driver invites available technicians in the Hangar to join the towing operation	Driver visually/verbally identifies available personnel	Driver determines which technicians are needed based on qualifications	Driver communicates invitation to join operation
A.7: The driver assigns tasks to each technician	Driver assesses operator skills and requirements	Driver determines optimal role assignment based on experience and needs	Driver assigns specific roles (proximity operator, brakeman, wing walkers, tail walker)
A.8: Each operator is handed a walkie-talkie. One of the operators is handed the bypass pin	Driver visually tracks equipment distribution	Driver determines which operator should receive which equipment	Driver distributes communication devices and bypass pin
A.9: One of the operators installs the cockpit ladder	Operator visually assesses aircraft door location	Operator determines proper ladder positioning for cockpit access	Operator installs ladder at appropriate position
A.10: One of the operators opens the hangar door	Operator visually checks door clearance area	Operator determines when it's safe to open door	Operator installs ladder at appropriate position
B.1: The driver disconnects the charging cable from the Mototok	Driver visually identifies charging connection	Driver verifies Mototok is sufficiently charged	Driver physically disconnects charging cable
B.2: The driver switches the Mototok on using the start button	Driver visually checks Mototok readiness	Driver verifies system is ready for activation	Driver presses start button on remote control
B.4: The proximity operator stands next to the driver, as the main communication source if driver's communication fails	Proximity operator recognizes optimal position	Proximity operator determines appropriate standby position	Proximity operator positions self next to driver
B.5: The brakeman enters the cockpit using the ladder to take charge of the braking controls	Brakeman visually confirms access to cockpit	Brakeman verifies proper position for brake control	Brakeman enters cockpit and prepares brake systems
B.6: The two wing-walker operators take their place next to the wingtips, and a tail walker just behind the tail	Wing/tail walkers visually identify aircraft dimensions	Wing/tail walkers determine optimal positions for clearance monitoring	Wing/tail walkers position themselves at designated monitoring locations

2. Individual Mototok movement and connection cluster

Process Step	Perception	Decision-Making	Action
B.3: The Mototok is reversed out of its parking spot	Driver visually assesses clearance behind Mototok	Driver determines safe reversing path	Driver operates joystick to reverse Mototok from parking position
C.1: The Mototok is driven towards the aircraft nose	Driver visually assesses path to aircraft	Driver determines optimal approach route	Driver operates joystick to navigate Mototok toward aircraft
C.2: The Mototok is aligned with the nose landing gear, and stopped 1-2 meters from it	Driver visually assesses alignment with nose gear	Driver determines when alignment is precise	Driver adjusts position and stops at correct distance
C.3: The operator with the bypass pin attached to the nose landing gear to bypass the aircraft's hydraulic system	Operator visually identifies bypass pin connection point	Operator verifies correct attachment location	Operator attaches bypass pin to nose landing gear
C.4: One of the operators removes the cockpit ladder	Operator visually verifies brakeman is in position	Operator determines when it's safe to remove ladder	Operator removes ladder
D.1: The hydraulic automatic door gets pushed out and opens	Driver visually checks area in front of Mototok	Driver determines when it's safe to extend door	Driver presses button for hydraulic door extension
D.2: The Mototok is moved closer towards the nose landing wheel	Driver visually assesses distance to nose wheel	Driver determines appropriate speed for final approach	Driver operates joystick for precise positioning
D.3: When the wheel touches the nose wheel platform, the Mototok is stopped	Driver perceives visual/tactile feedback of wheel contact	Driver recognizes moment of contact	Driver immediately stops forward movement
D.4: The door then closes and retracts back	Driver visually verifies wheel position on platform	Driver determines when wheel is properly positioned	Driver presses button to retract hydraulic door
D.5: The paddles are brought down onto the wheels, thus securing them	Driver visually checks wheel position relative to paddles	Driver determines when wheel is centered for paddle engagement	Driver presses button to lower securing paddles
D.9: The nose wheel platform lifts the wheels above the ground	Driver visually verifies wheel security	Driver determines if connection is secure enough for lifting	Driver presses button to activate lifting mechanism

3. Safety verification cluster

Process Step	Perception	Decision-Making	Action
D.6: Driver completes a communication check with operators via an open channel	Driver receives audio feedback from all operators	Driver verifies all communication channels are functioning	Driver initiates communication check and processes responses
D.7: One of the wing walkers is instructed to remove the wheel chocks	Driver visually verifies aircraft stability; Wing walker visually checks wheel chock position	Driver determines if it's safe to remove wheel restraints	Driver directs wing walker to remove chocks; Wing walker removes wheel chocks
D.8: The aircraft tail is checked for any obstructions under or around it	Tail walker visually inspects tail area	Tail walker evaluates if tail area is clear of obstacles	Tail walker reports clearance status to driver
D.10: The brakeman is instructed to release the aircraft brakes	Driver communicates with brakeman; Brakeman confirms brake status	Driver determines appropriate timing for brake release	Driver issues brake release instruction; Brakeman releases aircraft brakes
F.4: The tail walker shifts his position to join the wing walkers close to the end of parking	Tail walker visually assesses metal plates at end of parking area	Tail walker recognizes safety hazard of metal plates	Tail walker repositions closer to wing walkers
F.5: The brakeman is instructed to apply the aircraft brakes	Driver assesses aircraft final position	Driver determines when aircraft is properly positioned	Driver instructs brakeman to apply brakes; Brakeman applies aircraft brakes
F.6: One of the wing-walkers intuitively applies the wheel chocks	Wing walker visually verifies aircraft stability	Wing walker determines when aircraft is fully secured	Wing walker applies wheel chocks
E.1: The driver announces the start of the towing	Driver assesses team readiness and path clearance	Driver determines when all conditions are met for movement	Driver verbally announces the commencement of towing
E.4: Every operator maintains their position dynamically during the towing process	All operators continuously visually monitor aircraft movement	All operators continuously evaluate clearance requirements	All operators maintain dynamic positions during movement

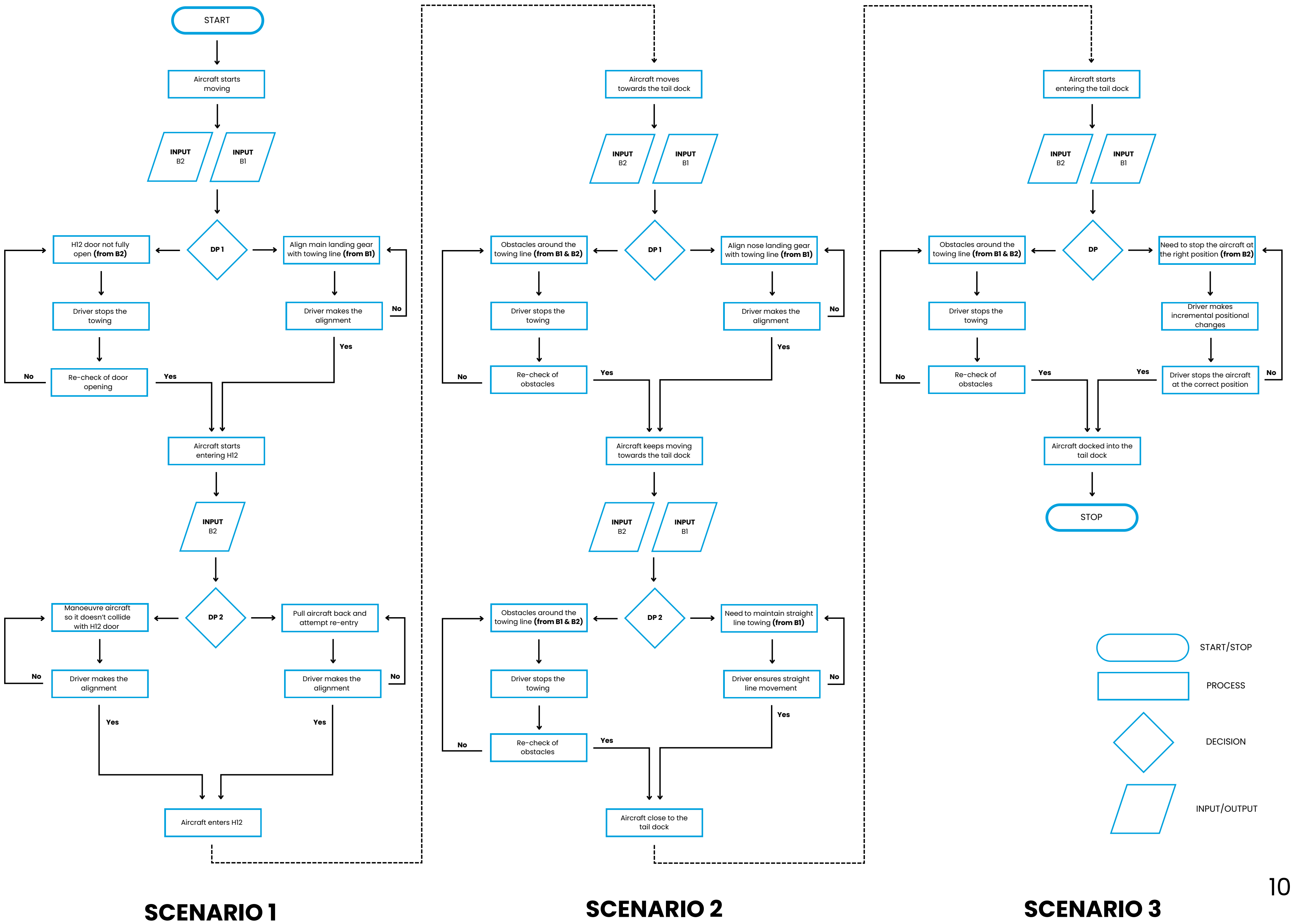
4. Aircraft Movement Cluster

Process Step	Perception	Decision-Making	Action
E.2: The Mototok either pushes or pulls the aircraft out of the hangar along the towing line	Driver visually tracks aircraft position relative to towing line	Driver determines optimal push/pull strategy	Driver operates joystick to initiate and control movement
E.3: The aircraft is moved on the straight towing line till it reaches the hangar door beyond which it is turned onto the towing line outside the hangar	Driver visually assesses position relative to hangar door and outside towing line	Driver determines optimal turning moment and angle	Driver executes controlled turn at transition point
F.1: As the aircraft approaches a parking stand, it is turned to align with the towing line of that stand	Driver visually aligns with parking stand towing line	Driver calculates turning radius and timing	Driver controls steering to align with parking stand line
F.2: If then towing was a pushback, the aircraft is parked with the tail going in first. If it was a pull, the towing changes to a pushback while entering the parking stand	Driver assesses current towing direction and parking configuration	Driver determines if directional change is needed	Driver adjusts towing direction as required for parking
F.3: The aircraft is stopped at a marker on the towing line in the parking stand, which indicates where the nose of the aircraft must be positioned	Driver visually identifies position marker	Driver judges distance and approach speed to marker	Driver controls speed and applies precise stop at marker

5. Disconnection and Wind-up Cluster

Process Step	Perception	Decision-Making	Action
G.1: The nose landing gear is lowered	Driver visually verifies aircraft stability	Driver determines when it's safe to lower platform	Driver presses button to lower nose wheel platform
G.2: The paddles get separated from the wheel	Driver visually checks wheel and paddle position	Driver determines when it's safe to release wheel	Driver presses button to retract securing paddles
G.3: The door opens and is retracted out	Driver visually assesses area in front of Mototok	Driver verifies clearance for door extension	Driver presses button to extend hydraulic door
G.4: The Mototok is reversed outwards	Driver visually checks clearance behind Mototok	Driver determines safe reversing path	Driver operates joystick to reverse away from aircraft
G.5: The door closes and retracts back into the Mototok	Driver visually verifies door position	Driver determines when door can safely retract	Driver presses button to retract hydraulic door
G.6: The steering bypass pin is removed and is kept with the operator who removes the pin	Operator visually confirms aircraft system status	Operator verifies it's safe to remove bypass pin	Operator removes and secures bypass pin
G.7: One of the operators installs the cockpit ladder	Operator visually assesses aircraft door location	Operator determines proper ladder positioning	Operator installs ladder for brakeman exit
H.1: The brakeman exits the aircraft through the ladder	Brakeman visually navigates exit path	Brakeman determines safe exit procedure	Brakeman exits aircraft using ladder
H.2: One of the operators removes the cockpit ladder	Operator visually verifies cockpit is vacated	Operator determines when it's safe to remove ladder	Operator removes and stores ladder
H.3: The driver drives the Mototok back to its parking area, and is accompanied by all other operators	Driver visually assesses path to parking area	Driver determines optimal return route	Driver operates joystick to navigate Mototok to parking spot; All operators follow
H.4: One of the operators closes the hangar doors	Operator visually checks door clearance	Operator verifies door path is clear	Operator closes hangar doors
H.5: The driver keeps all the equipment back in the Mototok closet, locks it and returns the keys to its initial location	Driver visually inventories all equipment	Driver verifies all equipment is collected	Driver stores equipment, locks cabinet, returns keys

C. Flowchart of the Critical Decision Experiment



D. Approved Project Brief

DESIGN FOR our future

TUDelft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	
Initials	
Given name	
Student number	

IDE master(s)	IPD ✓ Dfl ☐ SPD ☐
2nd non-IDE master	
Individual programme *(date of approval)*	
Medisign	☐
HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Nazli Cila	dept./section	Human Technology Relations
mentor	Garoa Gomez Beldarrain	dept./section	Designing Value in Ecosystems
2nd mentor	Serdar Cifoglu		
client:	KLM Royal Dutch Airlines		
city:	Schiphol, Amsterdam	country:	The Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Nazli Cila Date 4/March/2025 Signature [signature]

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ______ EC

Of which, taking conditional requirements into account, can be part of the exam programme ______ EC

☐	YES	all 1st year master courses passed
☐	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name ______ Date ______ Signature ______

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	☐	Supervisory Team approved
NO	☐	Supervisory Team not approved

Comments:

Based on study progress, students is ...

☐	**ALLOWED** to start the graduation project
☐	**NOT** allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name ______ Date ______ Signature ______

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student		**Student number**	

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Shaping User Interaction and Experience for Autonomous Aircraft Towing

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The COVID-19 pandemic exposed vulnerabilities in global supply chains, forcing industries to adapt through operational shifts, digital transformation, and workforce changes. Aviation was among the hardest hit, with disrupted air travel causing massive financial losses. Airlines, as key stakeholders, faced a $252 billion revenue loss and widespread job cuts. To survive and stabilize, many adopted strategic measures.

As of 2024, KLM has recovered from its dire financial position during the peak pandemic period. Despite high operating profits, the figures are still lower than those observed in 2023, due to staff shortages from the layoffs during the outbreak. The Back-on-Track program is the latest devised plan by KLM, which will seek to continue investments that contribute to sustainable operations. One of the measures within this plan is to increase labour productivity by 5 percent through automation. This would mean offsetting the shortage of manual labour with on-ground autonomous operations to achieve a more productive workforce. While KLM recognizes the initial financial and infrastructural investment required to accommodate them, it believes that laying the early foundations is a certain way of securing a profitable future.

To champion automation, The Maintenance, Repair, and Overhaul (MRO) Lab presents an automated approach to the aircraft towing and pushback process. The Lab intends to partner with external companies (Mototok, in this case) to bring this idea to life. Through a collaborative effort, KLM intends to widen its innovation circle and build on Mototok's existing technology to create new solutions that may even lead to revenue generation.

→ space available for images / figures on next page

DESIGN FOR our future

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Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The collaboration between the MRO Lab and Mototok leaves room for the development of an autonomous towing tug in two segments; a Systems Engineering segment focusing on the hardware and software requirements of developing the autonomous Mototok, and a User-Experience segment defining the interaction between the Mototok and the operator. This project focuses on the second expertise area. While the process of towing with a Mototok tug is still quite manual, KLM envisions a future where the towing becomes fully autonomous. The process of developing an autonomous vehicle, however, is procedural, requiring verification after increasing the autonomy at every stage of development. The project will visualize the user interaction and experience of the Mototok after its operational capabilities have been enhanced to a defined autonomous degree. Defining these new interactions will also influence other interactions between the operators and the product throughout the process, which will also be studied. This will be led by an iterative experimental approach, with a constant feedback loop with the operators of the tug within that stage. The results will contribute towards furthering the autonomous development of the tug, by prioritizing the understanding of user interaction as a significant requirement in the development process.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a prototype to verify and validate the user experience of interacting with the autonomous Mototok tug after investigating potential modes of interaction between the tug and the operator at a fixed level of automation to contribute to KLM's autonomous operations program targeting the increase in labour productivity thereby contributing towards the achievement of its 2030 sustainability targets.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

In this project, I will follow a Double Diamond method will the four conventional phases: discover, define, develop, and deliver. The first two phases are primarily focused on executing the research; which includes contextual research for the general topic and specifically within KLM's ecosystem, gathering product and process data through experiments and interviews with the operators, defining the research gap, and finally setting up the design challenge.

The last two phases dictate the physical and cognitive design of the product. Based on the collected data, I will design and test two concepts, with a constant improvement cycle running throughout the development stage. During this period, I will also maintain contact with Mototok, to understand if the changes/additions I propose would be feasible. Finally, within the deliver phase, I will finalize the product specifications, and complete the last testing and feedback session at KLM.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	February 27, 2025
Mid-term evaluation	April 23, 2025
Green light meeting	June 26, 2025
Graduation ceremony	July 24, 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

After completing a Bachelor's degree in Engineering, I decided to pursue the Master's program in Integrated Product Design to develop my competency in human-centered design thinking. This meant attempting to build on my design and engineering knowledge, which I have achieved through the courses offered at the department. Through this project, I aim to continue working towards achieving that objective.

During my previous internship at KLM, I worked on physical design and prototyping which would be a necessity for this project. While understanding user experience is a part of product development, this will be the first time I will execute the development cycle from end to end since the start of my Master's program. Previous working experience in the company will allow me to communicate with different stakeholders and gather data. This thesis will also allow me to explore physical testing on an industrial product in the workplace, which will be a new experience.

In addition, a few personal objectives I have are understanding the existing methods and timeline of a development process in an airline, conducting experiments with operators (who speak multiple languages), and learning to adapt to re-defining project boundaries and scoping in or out as required.