Automation support in ATM service provision

Reducing area controller workload and contributing to environmental sustainability goals

Thesis

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Management summary

The European ATM Master Plan estimates that improvements in air traffic management operations could reduce CO_2 emissions by up to 6% (SESAR JU, 2024). A portion of this reduction can be achieved through the implementation of Digital ATM. For LVNL, two significant transitions are currently underway: the replacement of the AAA system with iCAS – a trajectory-based operations system – and the shift from radiotelephony (RT) to Controller Pilot Data Link Communications (CPDLC). Both developments are key pillars of the broader Digital ATM strategy.

As LVNL moves from AAA to iCAS in the coming years, changes are expected in how air traffic controllers (ATCos) are supported by automation during the assumption and handover of flights. LVNL aims to maintain, or preferably enhance, the level of system support provided to controllers. Furthermore, the transfer of communication instructions to pilots, traditionally conducted via RT, will complemented or replaced by CPDLC. The expectation is that these changes will result in a higher degree of automation and ultimately contribute to a reduction in controller workload.

However, there is currently limited insight into the net impact of these technological transitions on ATCo workload and environmental sustainability. To address this gap, the following research question was central to this thesis:

How will the transition from AAA to iCAS, and the subsequent deployment of Controller Pilot Data Link Communications, affect area controller workload in the transfer process and environmental sustainability?

The research applied a multifaceted methodology consisting of operational observations, semi-structured interviews, and voice data analysis. Observations were conducted at both LVNL and MUAC to compare ATCo task demands, with MUAC already utilizing CPDLC alongside RT. Fifteen interviews were conducted with subject-matter experts and ATCos, to gain insights into system design, operational impact, and human factors. In addition, RT recordings were analysed to assess the task load associated with voice-based communication during the transfer process.

Results
The findings reveal a nuanced impact of the iCAS and CPDLC transitions on workload and sustainability:

- The UCO-sequence behaviour in iCAS can increase controller workload due to automatic unanticipated system-driven changes, disrupting the standardized workflow of ATCos. Features like skip and bypass can help mitigate these issues. Although no direct environmental benefits were linked to the UCO-sequence, improvements in trajectory calculations through more accurate data can increase environmental sustainability.
- CPDLC is strongly desired by the majority of ATCos, especially for transfers. Voice data analysis showed that using CPDLC saves on average 7.7 seconds of RT time per flight, and significantly reduces workload during peak periods. It is also considered a safer communication method, reducing the chance of misunderstanding during critical phases such as descent and approach.
- Situational awareness (SA) impacts of CPDLC are minimal according to most participants, and are expected to diminish further as controllers gain experience. Some concerns were noted regarding the SA of pilots and the loss of shared awareness due to the silent nature of CPDLC, but the latter is manageable through interface design and clear operational procedures.

Recommendations
Based on these insights, the following recommendations are made for LVNL:

- Enhance trajectory inputs by incorporating dynamic, aircraft-specific data such as cost index, weight, and weather conditions to better align predicted and actual flight paths. This will reduce disruptive UCO-sequence changes and improve overall system accuracy. Additionally, provide clear training on skip and bypass functionalities to ensure controllers use these effectively.
- Explore the use of CPDLC for UCO procedures and assess the feasibility of enabling planner controllers to manage transfers. Promote CPDLC's safety and service benefits

to encourage adoption by controllers. Support this with an intuitive Human-Machine Interface design and training to help controllers maintain confidence and SA.
- Evaluate how the operational time saved through CPDLC can be best utilized – whether to dedicate it to the human controller or to advance environmental and capacity objectives – maximizing the benefits of the technology.

Conclusion
While the transition to iCAS introduces certain workload challenges due to disruptive system behaviour, this can be mitigated through the use of skip and bypass functionalities. In contrast, CPDLC offers a clear net benefit: reducing workload, enhancing communication safety, and potentially contributing to sustainability objectives – provided LVNL seizes the opportunity to effectively utilize the time saved. It is therefore recommended that LVNL prioritizes CPDLC implementation immediately following the iCAS transition, to realize its full operational and environmental potential.

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List of Abbreviations

Abbreviations	Definition
AAA	Amsterdam Advanced Air traffic control
ACC	Area Control Center
A-CDM	Airport Collaborative Decision-Making
ACI	Airports Council International
ANSP	Air Navigation Service Provider
APP	Approach (Control)
ASM	Air Space Management
ATC	Air Traffic Control
ATCo	Air Traffic Control Officer
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
BPMN	Business Process Modelling Notation
CONOPS	Concept of Operations
CPDLC	Controller Pilot Data Link Communications
CWP	Controller Working Position
DEVICE	Delegation through Virtual Centres
DFS	Deutsche Flugsicherung (ANSP Germany)
EASA	European Union Aviation Safety Agency
EC	Executive Controller
eFDP	European Flight Data Processor
ENAIRE	- (ANSP Spain)
FF-ICE	Flight & Flow Information for a Collaborative Environment
FIR	Flight Information Region
HMI	Human Machine Interface
HTA	Hierarchical Task Analysis
IATA	International Air Transportation Association
ICAO	International Civil Aviation Organisation
iCAS	iTEC-based Centre Automation System
iSNAP	iTEC SkyNex ATC Platform
iTEC	interoperability Through European Collaboration
KUAC	Karlsruhe Upper Area Control
LoA	Letter of Agreement
LVNL	Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)
MRT	Multiple Resources Theory
MUAC	Maastricht Upper Area Control
NASA-TLX	NASA Task Load Index
NATS	National Air Traffic Services (ANSP UK)
PAM	Pampus (waypoint in Dutch FIR)
PLC	Planner Controller
RT	radiotelephony
RVR	Runway Visual Range
SA	Situational Awareness
SDO	Strategic Deployment Objective

SES	Single European Sky
SESAR JU	Single European Sky ATM Research Joint Undertaking
SPY	Spijkerboor (waypoint in Dutch FIR)
STOC	Silent Transfer of Control
SWIM	System Wide Information Management
TBO	Trajectory-Based Operation
TID	Touch Input Device
TMA	Terminal Manoeuvring Area
TOC	Transfer of Control
TWR	Tower (Control)
UCO	Under Control

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Definition of terms

Throughout this thesis, some terms are used interchangeably for readability and variation, but they refer to the same concept:

- Radiotelephony (RT) and voice: Both terms are used to refer to verbal communication between air traffic controllers and pilots.
- Assume and Under Control (UCO): Both terms are used to refer to the task of the controller to accept control of a flight, establishing radio contact.
- Transfer of communication, release, and hand-over: These terms are used to the task of the controller to hand-over a flight to the next sector, disconnecting radio contact.
- ACC (Area Control Centre): After the abbreviation ''ACC'' is introduced in Section 1.4, the terms "Area Controller" and "ACC-controller" are used interchangeably to refer to the same role.
- ATCo (Air Traffic Controller) and Controller: From Chapter 3 onwards, ''ATCo'' and ''controller'' generally refer to an Area Controller or ACC-controller, unless otherwise specified.

Gender-neutral language

Throughout this thesis, gender-neutral language – pronouns such as ''they'' – is used when referring to participants to protect their anonymity, and because gender is not a relevant factor in this research.

1 Introduction

The primary responsibility of an air traffic controller is to coordinate aircraft movements to ensure safe separation between them (U.S. Bureau of Labor Statistics, 2025). However, the role of the air traffic controller is becoming increasingly demanding due to growing challenges in Air Traffic Management (ATM), as a result of increased traffic complexity, climate change, and environmental regulations

The European ATM Master Plan says that improving how air traffic is managed could lower CO_2 emissions by up to 6% (SESAR JU, 2024). A great share of this reduction can be realized through the adoption of Digital ATM, which uses digital technologies to increase the safety, efficiency and capacity of air traffic control. A central component of this approach is automation.

Automation plays a crucial role in supporting air traffic controllers by offloading routine tasks, allowing them to focus on complex, high-stakes decisions. This not only helps reduce the risk of human error but also enhances overall safety and efficiency in air traffic management (Falk, 2024; Westerveld, 2024). Various automated systems assist controllers through advanced features such as conflict detection and route optimization, thereby improving decision-making capabilities (Langford et al., 2022).

In the Netherlands, the air navigation service provider (LVNL) is preparing to replace its core support system in the coming years (LVNL, 2024b). A significant challenge is to provide the same system support on the basis of a new platform. The new system comes with the promise of increased levels of automation and subsequent lower workload in the future, but in the transition controllers will have to do without the modernization that the new platform enables.

As part of this modernization, LVNL will also begin transitioning from traditional voice radio communication to a new system called ‘datalink’. Datalink enables digital communication through text messages exchanged between pilots and controllers, offering a more efficient and reliable alternative to voice transmissions.

These changes -both in the core support system and communication methods- will influence the automation support of, and the tasks performed by, air traffic controllers. This may, in turn, affect their task load, system capacity, and contributions to environmental sustainability. Therefore, gaining a thorough understanding of both the current and future systems, along with their respective communication modes, is essential for identifying differences in automation support and assessing their impact on controller workload and sustainability outcomes.

1.1 Background

Since June 1998, LVNL (Air Traffic Control the Netherlands) has been using the Amsterdam Advanced Air traffic control (AAA) system to support its Air Traffic Controllers (ATCos) in providing Air Traffic Management (ATM) services (Rijksoverheid, 2016). While LVNL also makes use of other systems, AAA is by far the largest and most important operational information system. It provides the processing of flight plan and radar information, handles the display of relevant information on the operational work positions and contains warning functions and planning functions (Deleu et al., 2015). The AAA system is the main system which enables LVNL’s ATCos to handle traffic at the fourth busiest airport in Europe (based on yearly number of passengers) (ACI Europe, 2024).

As the Schiphol operation is a complex one, due to a high peak-hour demand, relatively small airspace, complex environmental regulations and complex runway structure, specific demands are put on the Air Traffic Service (ATS) system of LVNL. High standards are set for operational reliability, flexibility, availability and continuity of the system, also by the users and the government. Furthermore, the system has to be simple to use for the ATCo, so that controller workload is either reduced or remains the same (Deleu et al., 2015).

Experience showed that the development of a new ATS system takes 5 to 10 years and that the total lifetime of a system is approximately 20 years (Deleu et al., 2015). Because of this, the replacement of AAA has been studied since 2008. It was found that, besides the AAA system approaching the end of its lifespan, there were additional reasons for the required replacement of the system. First of all, the AAA system couldn't comply with three out of six ATM functionalities that the Single European Sky (SES) regulation of June 2014 required to be implemented. This was in part a consequence of the lack of interoperability that the AAA system has with other European FDP systems, provided by the Thales and Indra FDP duopoly. Those functionalities are the Extended Arrival Management, Initial System Wide Information Management and Initial Trajectory Information Sharing. Secondly, the computer hardware the AAA system operates on is no longer in production. Furthermore, LVNL's development capacity is limited, as a result of a reduction of technical support staff in 2010. Finally, there is a risk of system instabilities caused by technical hardware developments and added functionalities to the system in the past years. Due to these reasons, it was concluded that a full replacement of the AAA system would be necessary and that joining one of the European partnerships to develop a new 'core engine' for an ATS system, the so-called European Flight Data Processor (eFDP), would be the best step (Deleu et al., 2015).

This conclusion led LVNL to joining the interoperability Through European Collaboration (iTEC) consortium in March 2011 (Indra, 2021). The iTEC consortium was set up in 2007 and initially consisted of the Air Navigation Service Providers (ANSPs) of Germany (DFS), Spain (ENAIRE) and United Kingdom (NATS), and the technical partner and supplier Indra (iTEC SkyNex, n.d.; Indra, 2021). The joint ambition of iTEC is to deliver improved operational performance and increase cost efficiency through the introduction of a common:

- Concept of operations (CONOPS) based on Single European Sky ATM Research (SESAR), including 4D-trajectory management;
- Trajectory-based operation (TBO) to reduce flight diversions, flight time, fuel consumption and CO_2 emissions;
- System architecture that features improved interoperability via Flight Objects and System Wide Information Management (SWIM);
- ATS system with interchangeable ATS components supported by open standards (iTEC SkyNex, n.d.).

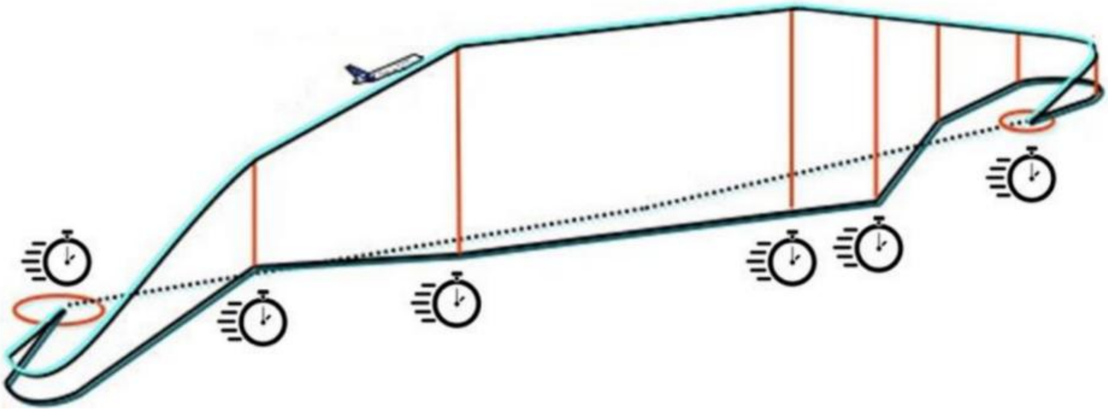
Regarding the last point, the ATS system that LVNL will implement in the upcoming years is a trajectory-based operations system. As LVNL has bought the same system as its iTEC partner DFS, the system is called iTEC-based Centre Automation System (iCAS). iCAS is developed by Indra and there have been multiple versions of this system. The first version was deployed in 2017 in the Karlsruhe Upper Area Control (KUAC) (Indra, 2023). This is an en-route system with medium-term conflict detection. The second version, deployed in the control center of Munich in 2023, was specifically adjusted and designed for Air Traffic Control (ATC) with a lower center. This version includes new functionalities such as Controller Pilot Data Link Communications, (partly) replacing radiotelephony. The third version is called iTEC SkyNex, and is a further development of the second version. It is built upon the SESAR projects iSNAP and DEVICE and it includes support for Flight & Flow Information for a Collaborative Environment (FF-ICE) and SWIM, amongst other things (iTEC SkyNex, 2024).

The idea was that the transition from AAA to iCAS would be a one-on-one transition, as it was deemed unacceptable that the capacity of the operation would be reduced for a longer period of time and risks would be minimal (Deleu, 2023). This meant that the AAA rules engine had to be rebuilt on the basis of the new iCAS platform. The rebuilding of the rules engine, which provides flexibility in configuring the Controller Working Position (CWP) turned out to be a very complex endeavour, because iCAS is built on the basis of different principles. Although LVNL made steady progress in building the set of rules initially, it became evident that more time was needed due to various factors, including the complex way of working at LVNL, the large number of rules and the differences in rules and principles between AAA and iCAS (Deleu, 2023). While the goal was to implement iCAS around 2023, the current plan is for the system to be operational between 2026 and 2028 (LVNL, 2024a).

A key feature of iCAS is that it employs 4D-trajectory management, which allows for precise tracking of an aircraft's position over time (Figure 1.1). This 4D-trajectory is initially constructed by the airspace user during the flight planning processes, but updated and enriched by other stakeholders during the lifecycle of the trajectory (Tielrooij et al., 2022).

Figure 1.1

4D-trajectory



Note. From 'Transition to Trajectory Based Operations (TBO): Components of the future ATM system in the Netherlands,'' by M. Tielrooij, R. Kok, T. De Jong, F. Dijkstra, T. Dufourmont, E. Lap, A. Okina and R.A. Vos, 2022, *KDC Mainport Schiphol*, p. 16. Copyright 2022 by KDC Mainport Schiphol.

On December 12th 2024, the SESAR Master Plan 2025 was published (SESAR JU, 2024). This document sets out the vision and priorities for the Digital European Sky, and for making Europe the most efficient and environmentally friendly sky to fly in the world by 2045. One of the Strategic Deployments Objectives (SDOs) of the Master Plan is 'Increased Automation Support'. This SDO aims to pave the way for TBOs by allowing ATCos to focus on complex rather than on routine activities (SESAR JU, 2024).

One of those routine activities is radiotelephony (RT), which has been a reliable means of communication between pilots and ATCos for decades (De Gelder et al., 2022). In spite of that, with the increase in air traffic, RT is approaching its limits. Issues such as frequency congestion at busy airports, miscommunication and bad quality of transferred messages are becoming more prevalent (De Gelder et al., 2022). Additionally, RT often contributes to ATC sectors reaching their maximum capacity, resulting in high workloads for ATCos (Falk, 2024).

Controller Pilot Data Link Communications (CPDLC) is the technology to complement and potentially replace RT in the future, answering to these problems with RT (De Gelder et al., 2022). CPDLC allows direct exchange of standardized (pre-formatted), non-urgent messages between a controller and a pilot (Franklin, 2023; ICAO, 2022). A CPDLC message sent from a ground system (i.e. ATCo) is an uplink message, while a CPDLC message sent from an aircraft (i.e. pilot) is a downlink message (ICAO, 2013). Uplink messages can be divided into six categories: level changes, route changes, speed changes, heading changes, instructions and transfer of communications (Franklin, 2023). The latter, transfer of communication, supports automated ATCo-pilot communications hand-off from one sector or centre to another (Eurocontrol, n.d.).

Transfer of communication should not be confused with Transfer of Control (TOC). When a flight approaches another sector, or Air Traffic Service Unit (ATSU), it is handed over from the previous ATSU (Deleu, 2023). If this transfer adheres to the Letter of Agreement (LoA) or internal procedures, a silent transfer (STOC; transfer without coordination) is often performed. The transfer is completed when the new controller assumes the flight Under Control (UCO). As the flight reaches the boundary of the ATSU, the controller releases it to the next ATSU. The system aids in identifying the correct counterpart using the UCO-sequence. This is a sequence of ATSUs that will have responsibility over the flight during its trajectory. The flight crew is informed to contact the next ATSU on a different radio frequency (transfer of communication), and the system notifies the next controller that the previous controller has released the flight, allowing it to be assumed (Deleu, 2023). In short, transfer of communication is realised before the TOC takes place. Thus, transfer of communication involves the pilot, while TOC is only amongst ATCos. Section 4.1 elaborates further on this.

1.2 Problem statement

As LVNL transitions from the AAA system to the iCAS system, changes are expected in the way ATCos are supported by automation when they assume responsibility of flights and hand-over flights to the next sector. It is LVNL's intention to maintain the same level of automation in support of controllers. Furthermore the transfer of communication instruction to pilots by RT will be complemented or replaced by CPDLC. Overall it is expected that the level of automation and system support will be increased with, as a result, controller workload reduction. The problem addressed in this research is the lack of insight in the net impact of these changes on ATCo workload and environmental sustainability.

1.3 Research Questions

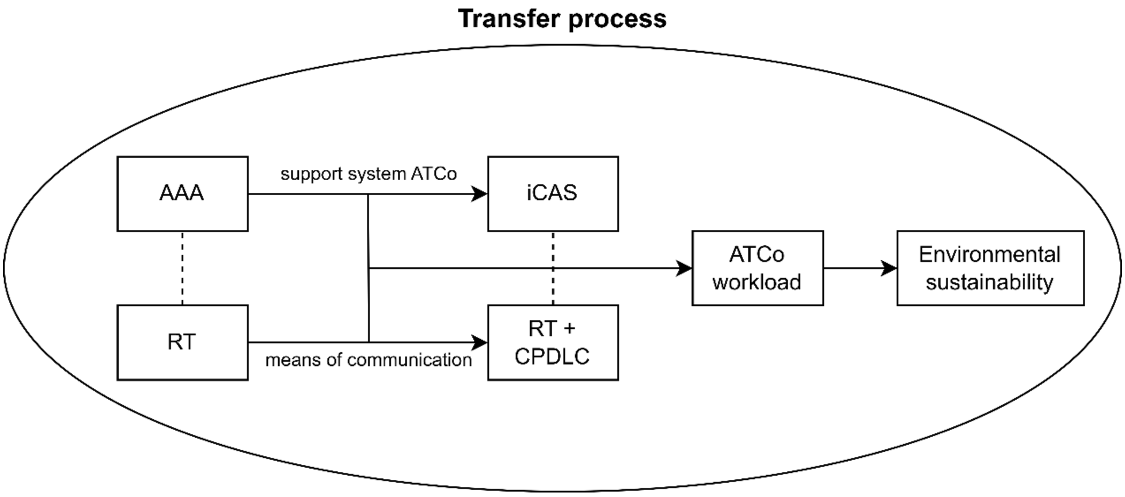
To tackle this problem, the main research question guiding this study is:

How will the transition from AAA to iCAS, and the subsequent deployment of Controller Pilot Data Link Communications, affect area controller workload in the transfer process and environmental sustainability?

This research question is presented as a framework in Figure 1.2.

Figure 1.2

Visual representation of the research question



To break down this main question into more manageable parts, the following sub-questions have been formulated:

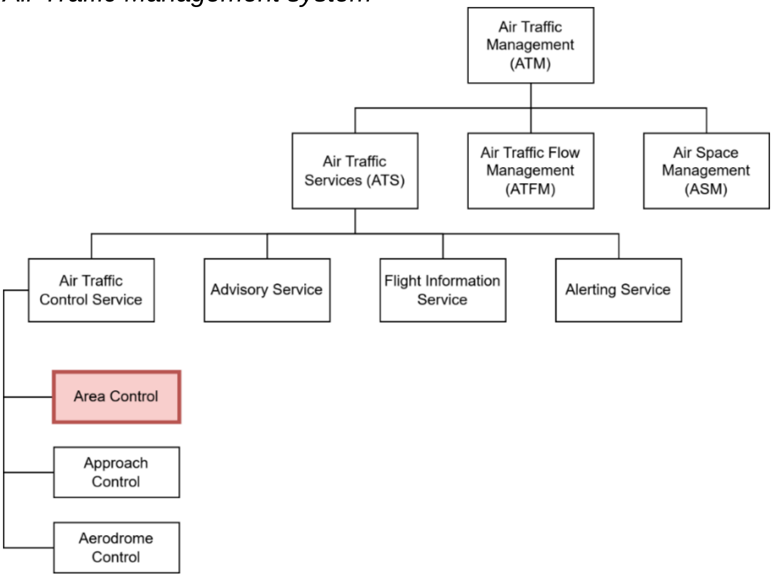
1. *What specific tasks does the area controller perform when assuming and handing over flights?*
2. *How are the UCO-sequence and transfer process currently managed in the AAA system, and what is the associated workload for the area controller?*
3. *How will the UCO-sequence and transfer process be managed in iCAS, and what will the associated workload for the area controller be?*
4. *What is the impact of the changes in core support system and means of communication on environmental sustainability?*

1.4 Research scope

As became clear from the research questions, the thesis will focus solely on the area controller. Figure 1.3 shows the placement of Area Control within the ATM system. All other elements of the ATM system are out of the scope of this thesis.

Figure 1.3

Air Traffic Management system



Note. Adapted from ''Air Traffic Management System Business Process Analysis for the Development of Information Exchange Interoperability Framework,'' by A. Awang Man, A.R. Che Hussin and O. Saktioto, 2023, *International Congress on Information and Communication Technology*, p. 919-930. Copyright 2023 by ICICT.

To clarify the focus on Area Control rather than Approach or Aerodrome Control, it is helpful to first outline the responsibilities of each department within ATC, in the order of an inbound flight:

- (Maastricht Upper Area Control Centre (MUAC) handles traffic above the altitude of approximately 8 kilometers (flight level 245), managing high-level en-route operations across multiple countries.)
- Area Control (ACC) is responsible for managing traffic beneath this altitude. It ensures safe and efficient transitions between airways and coordinates with both lower and upper airspace sectors.
- Approach Control (APP) takes over inbound traffic from ACC, guiding aircraft within a broader terminal area using radar to sequence and prepare them for landing.
- Aerodrome or Tower Control (TWR) manages aircraft in the immediate vicinity of the airport – typically within a 15-kilometer radius – handling take-offs, landings, and ground movements (LVNL, n.d.).

For outbound flights, the process is reversed: TWR hands over to APP, which then transfers control to ACC, and eventually to MUAC if the flight continues at higher altitudes.

This research focuses on ACC due to its pivotal role in managing traffic flows near the airport. By optimizing operations at this level – particularly in terms of planning and sequencing – ACC can significantly improve the structure and predictability of inbound traffic. This upstream efficiency reduces complexity and workload for both APP and TWR, who benefit from receiving better-organized traffic streams. As a result, improvements at the ACC level can enhance the overall safety, efficiency, and sustainability of the entire ATM system.

While sustainability in this thesis is primarily scoped to environmental sustainability – including both CO_2 and non-CO_2 emissions as well as aircraft noise – social sustainability is also inherently addressed. This is reflected in the focus on ATCo workload, which is a key component of social sustainability, as highlighted by Umstätter et al. (2022).

1.5 Structure

The structure of this thesis is as follows: Chapter 2 presents a literature review, discussing relevant concepts and theories. Chapter 3 details the methodology, outlining the chosen research methods and the rationale behind these choices. The results are provided in Chapter 4, and key findings and recommendations are noted in Chapter 5. Chapter 6 discusses the results, while Chapter 7 draws a conclusion of the research. Chapter 8 presents a reflection on Semester 2.

2 Literature review

In this chapter, the definition and various levels of automation, human-machine teaming and the pros and cons of automation in ATM are explored first (Section 2.1). Subsequently, Section 2.2 examines the key findings, limitations and methods used in previous research related to the impact of automation on ATCo workload.

2.1 Automation in Air Traffic Management

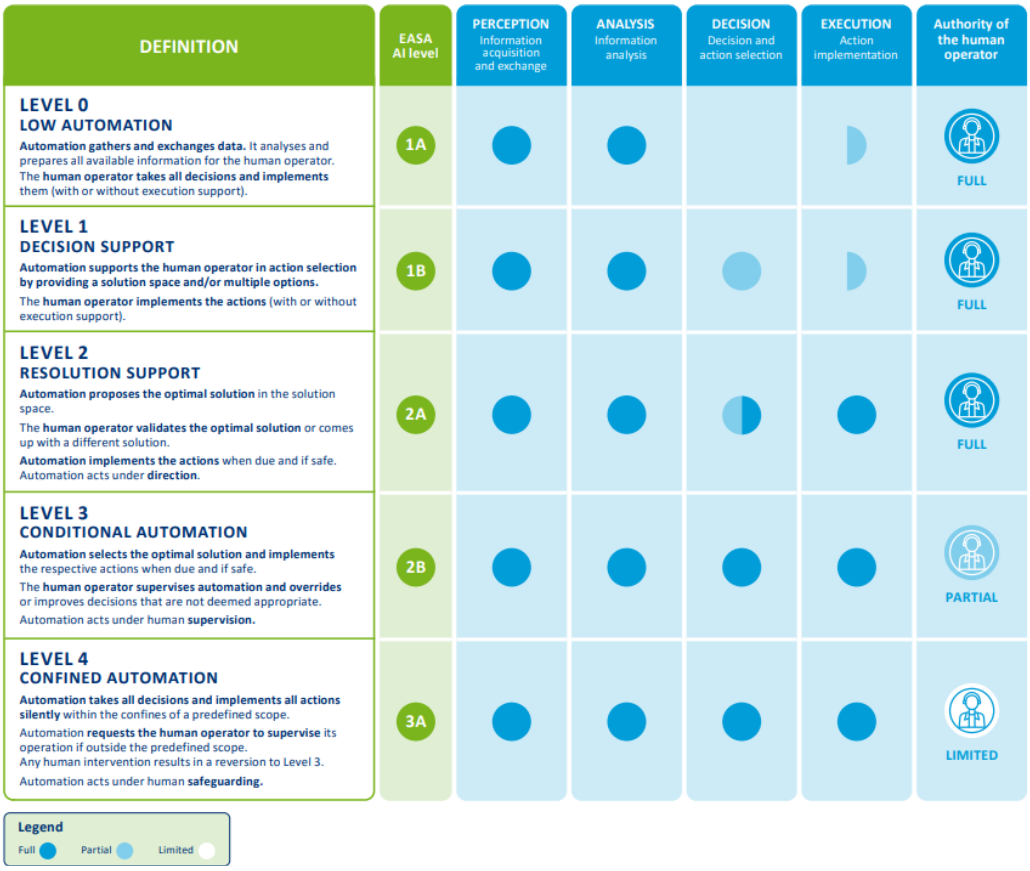
Automation refers to the use of machines and systems capable of operating with minimal human intervention. According to the Cambridge Dictionary (n.d.-a), automation is defined as ''the use of machines and computers that can operate without needing human control''. Groover (2025), writing for Britannica, describes it as ''the application of machines to do tasks once performed by human beings or, increasingly, to do tasks that would otherwise be impossible''. From a more positive perspective, the Oxford Dictionary Reference (n.d.) highlights that automation reduces manual labour. However, not all interpretations are optimistic; Van Dale (n.d.) points out that automation is sometimes associated with job loss and displacement.

It is important to differentiate between automation and digitization. While automation deals with task execution by machines, digitization involves converting information into digital formats. The Cambridge Dictionary (n.d.-b) defines digitization as ''to put information into the form of a series of the numbers 0 and 1, usually so that it can be understood and used by a computer''. In this context, digitization is a foundational step required to enable automation.

Looking more specific to ATM, SESAR JU (2024) distinguishes several levels of automation in accordance with EASA's (2023) artificial intelligence levels (Figure 2.1). Currently, ATM in Europe operates at automation level 0. It is expected that ATM in Europe will operate at level 2 by 2035, and will reach level 4 by 2045.

Figure 2.1

Levels of automation



Note. From 'European ATM Master Plan: Making Europe the most efficient and environmentally friendly sky to fly in the world,' by SESAR JU, 2024. Copyright 2024 by SESAR JU.

Due to increased automation, new roles and functions for the human operator will emerge and existing roles and functions will change (SESAR JU, 2024). Human-machine teaming will become highly important. The different levels of human roles are as follows:

- **Level 1 – Enhanced decision-maker**: The human is responsible for making all decisions, relying on automation to provide a comprehensive overview of all possible options to assist the decision-making process.
- **Level 2 – Director**: The human evaluates the optimal solution suggested by automation and makes improvements as necessary. While the human has the final authority, automation handles all the necessary calculations to support the decision.
- **Level 3 – Supervisor**: The human determines which tasks or situations should be managed by automation and which should be handled personally. The human oversees the system and can override automation if its decision is deemed unsuitable, based on operational knowledge that automation lacks.
- **Level 4 – Safeguarder**: The system operates fully autonomously under human supervision. If the system detects that it is at risk of operating outside its designed parameters, it suggests moving back to a lower level for human intervention (SESAR JU, 2024).

This increased human-machine teamwork, where automation will take over tasks from the human controller, requires a great extent of trust and acceptance from the ATCos side. As argued by Chien et al. (2019), trust is influenced by system characteristics such as reliability and transparency. Other studies reinforce this, showing that high automation reliability fosters trust and acceptance, which in turn enhances performance (Miramontes et al., 2015; Mirchi et al., 2015). When ATCos lack trust in automation, they may choose not to rely on it, limiting its potential benefits for their performance. Conversely, overtrust in automation can be dangerous – if the system fails, it may result in a significant decline in performance (Metzger & Parasuraman, 2017; Timotic & Netjasov, 2022).

The development of trust in automation depends not only on the ATCo's confidence in the system but also on their direct interaction with it, highlighting the importance of effective human-machine collaboration. Trust can be shaped by individual factors such as personality, age, experience, culture, motivation, job satisfaction, and health. Operational challenges – like high traffic volumes, adverse weather, or staffing shortages – can also influence trust, especially under complex conditions. System characteristics, particularly reliability and transparency, are critical in shaping trust during such scenarios. As controllers gain experience and familiarity with automated systems, their understanding of system behaviour improves, reinforcing trust. Ultimately, trust formation is a dynamic process influenced both by the ATCo's perception of the system and the quality of interaction between human and automation (Timotic & Netjasov, 2022).

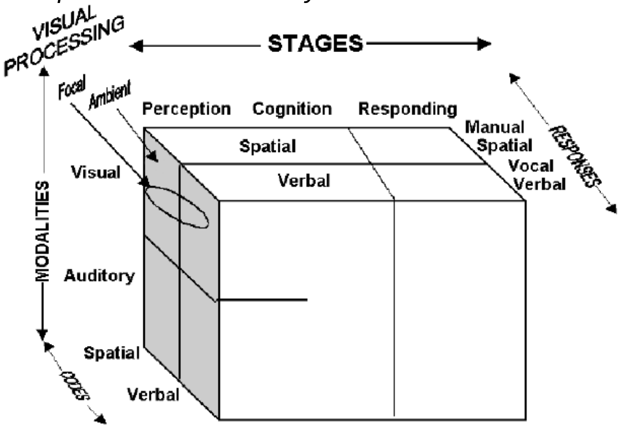
A critical component linking workload and trust is situational awareness (SA) – the operator's accurate perception, comprehension, and projection of system and environmental states (Endsley, 1995). Automation can unintentionally reduce SA by promoting passive monitoring, diminishing mental engagement, and obscuring critical information during system failures (Parasuraman et al., 1993). This degradation of SA contributes to out-of-the-loop issues, delayed reaction times, and decreased trust when automation falters. Therefore, maintaining an optimal balance is essential: automation must reduce workload without reducing SA. This balance is foundational to preserving both system resilience and operator trust in high-stakes ATM environments.

Another critical consideration in designing automation for ATM is human cognitive capacity. Wickens' (2002) Multiple Resource Theory (MRT) provides a framework to understand how simultaneous tasks interact based on the cognitive resources they require. MRT breaks down human cognitive processing into four key dimensions (see Figure 2.2):

- Processing stages: Perceptual/cognitive vs. response execution.
- Perceptual modalities: Auditory vs. visual input.
- Visual channels: Focal (detailed) vs. ambient (motion/orientation).
- Processing codes: Spatial vs. verbal information.

Figure 2.2

Multiple Resources Theory model



Note. From ‘’Multiple resources and performance prediction’’ by C.D. Wickens, 2002, *Theoretical issues in ergonomics science, 3(2)*, p. 163. Copyright 2002 by Theoretical issues in ergonomics science.

Tasks that draw on distinct resources across these dimensions are less likely to interfere with one another, enabling more efficient multitasking. Conversely, tasks that compete for the same resource (e.g., two visual-spatial tasks) are more likely to degrade performance.

In the context of ATC, this model has profound implications. Controllers must simultaneously monitor radar screens (visual-spatial), communicate with pilots (auditory-verbal), and make rapid decisions (cognitive-response) – often simultaneously. If automation adds complexity using overlapping sensory or processing channels, SA can decline. Thus, MRT provides guidance for designing systems that complement rather than overload the human operator, helping maintain SA and improve trust.

Overall, automation in ATM presents significant benefits, including increased efficiency as ATCos can focus on more complex tasks, leading to improved capacity (SESAR JU, 2020). By enabling ATCos to concentrate on higher-order tasks, automation contributes to reduced human error and facilitates cost savings through optimized flight trajectories and fewer delays. Automated systems also provide consistent performance, unaffected by fatigue or stress. However, these advantages must be weighed against critical challenges. Over-reliance on automation can lead to skill degradation among ATCos, making manual intervention difficult during system failures. Additionally, technical malfunctions and cyber-security vulnerabilities pose serious risks in an increasingly digital operational environment. The transition to higher levels of automation also demands substantial investment in infrastructure, training, and cultural adaptation within ATM organisations. Therefore, a balanced integration of automation that supports, rather than replaces, human expertise is essential (SESAR JU, 2020). This balance should aim to preserve SA, maintain trust, and enhance system resilience – ensuring that automation acts as a partner, not a substitute, in the delivery of safe and effective air traffic services.

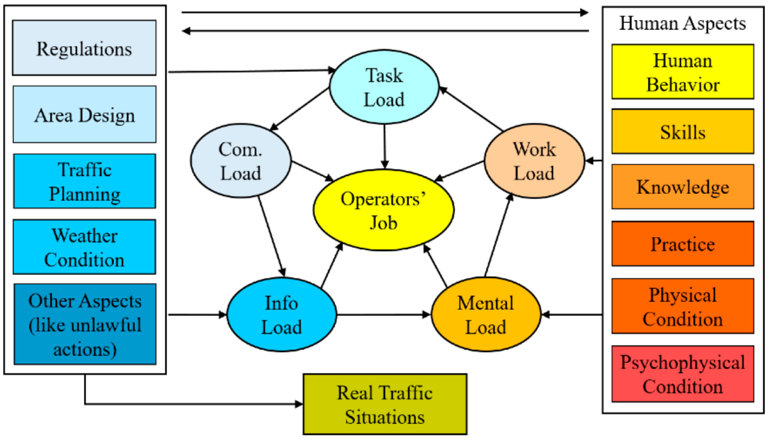
2.2 Impact of automation on Air Traffic Controller workload

Before exploring the impact of automation on ATCo workload, it is crucial to understand the term ‘’workload’’ clearly. Kale et al. (2020) distinguished five types of load affecting the operators’ job that are influenced by human (right) and external (left) factors, as presented in Figure 2.3:

- **Workload** – The total amount of work performed by an operator within a specific time period.
- **Task load** – The degree of difficulty and effort required to execute a particular task.
- **Information load** – The increasing volume of information from complex systems that can cause confusion among operators.
- **Communication load** – The level of understanding between operators, influenced by language, cultural norms and social relations.
- **Mental load** – The physical and psychological condition of operators while executing a task.

Figure 2.3

Operator load model



Note. From ''Operators' Load Monitoring and Management,'' by U. Kale, J. Rohács and D. Rohács, 2020, *Sensors*, 20(17), 4665, p. 6 (https://doi.org/10.3390/s20174665). Copyright 2020 by Sensors.

Additionally, according to Loura (2014), task load is generally distinguished from workload, as task load is defined as the demand imposed by the ATC task, while workload is the controller's subjective experience of that demand. This aligns with the statements from Di Mascio et al. (2021) and Suárez et al. (2024), who noted that workload varies from person to person and depends on the context in which the controller operates (e.g. air traffic and work environment), personal factors (e.g. experience, age, motivation), and physical conditions (e.g. health and mood). However, a key factor impacting ATCo workload, not clearly depicted in Figure 2.3 and only implicitly mentioned earlier, is the state of the equipment and the interaction between the ATCo and the equipment – essentially, human-machine teaming (Svensson, 2020). This teamwork, considering automation, has been extensively researched in recent years and is expected to remain a significant area of study in the future (Suárez et al., 2024).

With a clearer understanding of the term "workload," attention now turns to research exploring its relationship with automation in ATM. Across the literature, a combination of survey-based, simulation-based, and hybrid methods has been used to examine how automation affects ATCos' workload, SA, and performance. A key trend across these studies is that automation tends to reduce task-related workload – particularly under high-traffic or high-demand conditions – by supporting routine actions and expediting decision-making (Metzger & Parasuraman, 2017; Wang et al., 2021). However, this benefit is often offset by trade-offs such as diminished SA, increased information load, and a shift toward passive monitoring roles (Edwards et al., 2017; Wang et al., 2021; Jazzar et al., 2021). For example, when automation replaces rather than supports the ATCo, concerns emerge around skill degradation, disengagement, and lower trust in the system (Langford et al., 2022; Svensson & Peukert, 2022).

Rogošić et al. (2021) further reinforce this concern by identifying human factors such as mental workload, trust, and SA as central to automation performance. Their findings underscore that both overload and underload impair human performance, and that degraded SA – often a byproduct of excessive automation – can lead to delayed recovery responses, out-of-the-loop phenomena, and eventual skill decay. Importantly, adaptive automation techniques, such as real-time surveillance monitoring tools, were proposed to dynamically adjust automation levels to better match operator capacity, thereby mitigating these risks.

Moreover, several studies emphasize that ATCos' trust in automation is not static, but shaped by dispositional, situational, and learned factors (Wang et al., 2021; Jazzar et al., 2021; Langford et al., 2022). Undertrust can lead to disuse and elevated workload, while overtrust may foster complacency and reduced vigilance. These dynamics point to a critical need for interfaces that actively engage the operator and maintain appropriate levels of SA and skill use (Materne & Friedrich, 2025).

The literature also reveals generational and experiential divides: while most controllers acknowledge the potential for increased efficiency through automation, many express unease about future roles, the adequacy of training, and the risk of being pushed to the periphery of the control process (Svensson et al., 2021; Langford et al., 2022). These perceptions are crucial in shaping acceptance, operational readiness, and safety in next-generation ATM environments.

Table 2.1 provides a comparative overview of the ten most related articles to the scope of this research, outlining their objectives, methods, key findings, and limitations. It highlights the diversity of methodological approaches and offers insight into how workload and automation interact in ATC contexts. The papers are listed based on the number of citations and/or in alphabetical order.

Table 2.1

Overview of related publications regarding the impact of automation in ATM

Reference	Objective	Method and participants	Key findings	Limitations
(Metzger & Parasuraman, 2017)	Examine how decision aid reliability in automated ATM affects ATCo performance and mental workload.	Simulation and NASA-TLX (eye-tracking in different paper): 12 (experiment 1) and 20 (experiment 2) active en-route ATCos from Washington.	Reliable automation improved conflict detection and reduced workload; unreliable automation impaired detection, showing controllers performed better manually when automation failed.	Reliable automation was always presented before unreliable conditions, potentially confounding results.
(Edwards et al., 2017)	Investigate the relationship between workload, situation awareness, and controller performance in ATC, particularly how these factors interact under varying levels of automation.	Simulation: 8 retired en-route ATCos who had worked in Oakland.	Workload reduced when automation is increased, this trend is not seen with SA; weak relationship between workload and SA.	Median split method reduced data variance, increasing risk of Type II error; small sample size may limit statistical power.
(Wang et al., 2021)	Investigate the effects of three automation levels (manual, attention-guided, and automated) on air traffic controllers' eye movements, situation awareness, and mental workload.	Eye-tracking and NASA-TLX: 14 participants total from China – 6 professional ATCos and 8 senior ATCo students.	Higher automation reduced workload and stabilized eye movement patterns, but decreased search efficiency and situation awareness under high traffic due to passive monitoring roles.	Task complexity was not controlled; eye movement data were not analysed per interface area; the environment differed from real-world ATC; participants' working attitude changes since they know that

				mistakes are allowed in simulation
(Hoskova-Mayerova et al., 2022)	Develop a comprehensive methodology for evaluating the workload of ATCos within the Czech Republic.	Simulation testing: 10 exercises with Czech military ATCos. Questionnaire: 20 Czech military ATCos Continuous training analysis: 15 Czech military ATCos with 158 assessments analysed.	A validated methodology assigns workload weights to ATC tasks, enabling objective workload assessment and supporting training, staffing, and safety in military ATC.	Not presented.
(Langford et al., 2022)	Investigate Australian Air Traffic Controllers' perspectives on increasing automation in ATM systems, focusing on tool acceptance, situational awareness, and safety risks.	Questionnaire: Current and former Australian ATCos.	ATCOs valued supportive automation but rejected role-replacing tools; key concerns included inadequate training, skill loss, and evolving roles impacting trust in automation.	Relatively small sample size; No distinguishment between the different types of ATCos.
(Žvinys & Rudinskas, 2023)	Investigate the application of CPDLC technology in aerodrome air traffic control procedures.	Simulation: 5 ATCos, some of whom were students.	CPDLC reduced workload from 20.8% to 32.6%, saved monitoring time, and decreased language errors, especially in high-traffic aerodrome environments like Vilnius Airport.	Accuracy is limited due to low number of tests and simulation environment.
(Jazzar et al., 2021)	Investigate the impact of automation levels on the roles and total loads (work, task, information, communication, mental) of pilots and ATCos.	Questionnaire: 62 participants total from 27 different countries – 35 pilots, 16 ATCos, 6 ATCos and pilots and 5 other professions with pilot licenses.	Automation reduces task load but increases information load; operators fear deskilling, prefer automation support over control, and stress the need for better training.	Not reported.
(Svensson et al., 2021)	Investigate ATCos’	Questionnaire: 249 licensed	Participants believe the	Uneven country representation.

	perceptions of automation and safety in current and future ATM systems, focusing on teamwork in human-human and human-automation collaboration.	ATCos from six different countries.	grade of automation will be higher in the future, that workload will stay the same, and that SA and safety will both decrease in the future.	
(Materne & Friedrich, 2025)	Evaluate a new ATC interface for supervising multiple remote tower centres, focusing on mental workload and eye tracking.	Eye-tracking and NASA-TLX: 15 professional tower ATCos from ANSPs Oro navigacija and PANSA.	Unscheduled events increased search behaviour and workload; eye-tracking revealed key interface areas, informing layout improvements for efficient supervisor planning tools.	Repeated runs could influence participant behaviour despite randomization; some eye-tracking metrics were excluded due to data quality or environmental sensitivity.
(Svensson & Peukert, 2022)	Investigate ATCos' experiences and expectations regarding automation in air traffic control, focusing on perceived impacts on safety, situation awareness, and workload.	Questionnaire: 113 licensed ATCos from Sweden. Semi-structured group interviews: 35 operational ATCos.	Participants believed that the grade of automation will be higher, that safety and SA will decrease, and that workload will increase in the future.	Not presented.

In accordance with Yazgan et al. (2021), common types of workload measurement techniques include eye tracking as a physiological method and the NASA Task Load Index (NASA-TLX) as a subjective method. Table 2.1 shows that these two methods are often combined in the same study (Metzger & Parasuraman, 2017; Wang et al., 2021; Materne & Friedrich, 2025), aligning with the recommendation of Yazgan & Erol (2013) to use multi-method approaches to counter the limitations of single-measure techniques. Meanwhile, questionnaire-based studies were prevalent among research exploring ATCos' attitudes and perceptions toward automation (Jazzar et al., 2021; Svensson et al., 2021; Langford et al., 2022; Hoskova-Mayerova et al., 2022), while simulations were often used to study real-time task performance (Edwards et al., 2017; Metzger & Parasuraman, 2017).

The methods used in related work (Table 2.1) are most often quantitative in nature. Quantitative research is generally preferred due to its scientific rigor, objectivity, speed, and replicability (Mulisa, 2022). Still, according to Sardana et al. (2023), qualitative research offers unique advantages – such as contextual depth, flexibility, and rich insight into operator experience – though it may lack generalizability and be more time-intensive. Notably, the divide between these approaches is less rigid in practice: qualitative data can be quantified through rating scales or coding schemes, and quantitative data can be explored qualitatively through contextual or interpretive analysis (Ahmad et al., 2019). The widely cited[4] overview of advantages and disadvantages of the various qualitative and quantitative methos by Queirós et al. (2017) played a part in selecting appropriate methods for this thesis, as elaborated in Chapter 3.

[4] 3951 citations (June 22nd, 2025)

3 Methodology

The purpose of this chapter is to provide a detailed explanation of the methodology employed in this research. It begins by outlining the overall methodological approach. The chapter is then structured around the three primary methods used: observations (Section 3.1), interviews (Section 3.2), and voice data analysis (Section 3.3). Each section describes the sampling method and sample characteristics, procedures for data collection, data processing, and justifies the methodological choices made throughout the research process.

Section 2.2 revealed that studies on workload in ATC frequently employ methods such as eye-tracking, the NASA-TLX, and simulation-based experiments. While these approaches are valuable in many contexts, they were not suitable for the present study. Eye-tracking, for instance, would have required access to controllers proficient in both CPDLC and traditional RT. However, as CPDLC has not yet been implemented at LVNL, it was not feasible to recruit participants with the necessary experience. Although it would have been possible to conduct this method with controllers at MUAC, where controllers are used to working with both RT and CPDLC, this approach was not pursued. The operational differences between MUAC and LVNL posed a significant limitation, as MUAC operates as an upper area control centre, while LVNL is responsible for lower airspace operations. These fundamental differences in airspace structure, traffic characteristics, and operational procedures would have made it difficult to meaningfully extrapolate the findings to the LVNL context. Similarly, the NASA-TLX was not considered appropriate, as isolating specific tasks – such as the coordination and transfer of flights – to assess their individual workload contributions would have been challenging within the operational complexity of live ATC environments.

Given these constraints and the exploratory nature of this research, which aimed to understand how the implementation of iCAS and CPDLC will affect both controller workload and environmental sustainability, a predominantly qualitative approach was deemed most appropriate. This allowed for a more nuanced understanding of controller perceptions, system interaction, and operational context (Queirós et al, 2017). Nonetheless, the study incorporated an objective quantitative element through the analysis of recorded voice communication data (Section 3.3), offering supplementary insights into task load. This mixed-methods approach enabled a grounded and practical investigation of the research questions, tailored to the constraints and realities of the Dutch ATC environment. Figure 3.1 provides an overview of the research methods that have been used to answer each sub-question and corresponding section numbers.

Figure 3.1

Overview of the research methods per sub-question

<table>
<tr><th>Sub-questions</th><th colspan="4">Methods</th></tr>
<tr><td>1. What specific tasks does the area controller perform when assuming and handing over flights?</td><td colspan="4">Observation of three ATCos at LVNL and MUAC
Section 3.1</td></tr>
<tr><td>2. How are the UCO-sequence and transfer process currently managed in the AAA system, and what is the associated workload for the area controller?</td><td>Interview with three AAA experts at LVNL
Section 3.2.1</td><td>Interview with eight ATCos at LVNL
Section 3.2.3</td><td>Interview with one WLM expert at LVNL
Section 3.2.4</td><td>Voice data analysis
Section 3.3</td></tr>
<tr><td>3. How will the UCO-sequence and transfer process be managed in iCAS, and what will the associated workload for the area controller be?</td><td colspan="2">Interview with two iCAS experts at LVNL
Section 3.2.1</td><td colspan="2">Interview with three CPDLC experts at MUAC
Section 3.2.2</td></tr>
<tr><td>4. What is the impact of the changes in core support system and means of communication on environmental sustainability?</td><td colspan="2">Interview with four AAA and/or iCAS experts at LVNL
Section 3.2.1</td><td colspan="2">Interview with eight ATCos at LVNL
Section 3.2.3</td></tr>
</table>

3.1 Observations

To clearly understand the tasks an ATCo must perform when assuming and handing over a flight, a task analysis was conducted through naturalistic observation of ATCos at LVNL and MUAC in cross-sectional studies. Observing ATCos at both LVNL and MUAC enabled the comparison of the way of working at LVNL, using RT, with the way of working at MUAC, using predominantly CPDLC. However, it must be noted that the operation of MUAC differs a lot from LVNL, as MUAC is upper area control (en-route), while LVNL is a lower center.

Sample description and selection

The participants were selected through convenience sampling. For observations at LVNL, three area controllers were selected based on the researcher's connections through their supervisor. For observations at MUAC, one ATCo was selected based on reference of one of the observed ATCos at LVNL, while the other two were appointed by the contact person from MUAC who organised the visit. All participants were male and experienced controllers. Assuming and handing over flights are relatively easy tasks for the ATCo and they receive the same training. Therefore, the hypothesis was that there would not be significant differences in how ATCos perform these tasks, and that a small sample size would be sufficient. To account for slight differences in area controllers' workstyles and to be able to address questions that arose after an observation, three observations were deemed optimal.

Data collection

Table 3.1 shows the date and time the observations took place. At both LVNL and MUAC, most information was gathered during the first observations and only a few new insights were gathered during the third observations, showing that a sample size of three was sufficient. Data was collected through note-taking. A comment should be made on the observation of ATCo LVNL 2, as the ATCo had switched shifts and was performing a desk role instead of an operational one. Because of this, naturalistic observation was not possible. Instead, the ATCo explained verbally how they perform those tasks and questions were discussed.

Table 3.1

Date and time of observing participants

Participant	Date	Time
ATCo LVNL 1	March 24th, 2025	07:40 – 13:30
ATCo LVNL 2	March 25th, 2025	09:30 – 10:15
ATCo LVNL 3	April 3rd, 2025	09:00 – 11:00
ATCo MUAC 1	May 1st, 2025	09:20 – 10:20
ATCo MUAC 2	May 1st, 2025	11:00 – 12:00
ATCo MUAC 3	May 1st, 2025	12:00 – 12:30

Data processing

The information derived from the observations was processed and visually represented in swimlane diagrams, using Business Process Model and Notation (BPMN). BPMN is a flow chart method that models the steps of a process from end to end. It visually depicts a detailed sequence of business activities and information flows needed to complete a process. BPMN is a standard and reliable method, widely used in other research (Kocbek, 2015). The swimlane diagrams were created in the online program draw.io. Common flowchart symbols were used.

3.2 Interviews

A total of fifteen semi-structured interviews were conducted with various individuals and groups, each serving different purposes. To enhance clarity, this section is divided into subsections based on the type of interview. The purpose of the interviews, sample selection and description and data collection are discussed separately. Data processing, which followed a consistent procedure across all interviews, is described in a dedicated section (3.2.5). In the expert interviews (Sections 3.2.1, 3.2.2, and 3.2.4), demographic characteristics such as age or gender were not considered, as the focus was primarily on technical expertise, where these factors were unlikely to affect the findings. However, in the interviews with ACC-controllers (Section 3.2.3), demographic details were included to ensure the representativity of the sample, given the more subjective nature of these interviews and the potential influence of individual perspectives.

3.2.1 AAA and/or iCAS experts at LVNL

The purpose of the interviews with AAA and/or iCAS experts at LVNL, was to gain insight into the operation of the UCO-sequence in the AAA system and iCAS, and its impact on ATCo workload and environmental sustainability.

Sample description and selection
The participants possessed extensive knowledge on either or both AAA and iCAS, and specifically the UCO-sequence. Two out of four participants were ACC-controllers. The participants were selected through purposive sampling based on their professional expertise.

Data collection
Table 3.2 shows the date and time the interviews took place. The interview questionnaire consisted solely of open questions. It discussed three topics, being the operation of the UCO-sequence in the system(s), the impact of that on the workload of the area controller and the effect on environmental sustainability. Data was collected using a mobile phone recorder in addition to recording with Microsoft Teams.

Table 3.2

Date and time of interviewing AAA and/or iCAS experts

Participant	Date	Time
AAA expert	April 24th, 2025	15:00 – 15:45
iCAS expert	April 28th, 2025	09:00 – 12:00
AAA & iCAS (ATCo) expert	May 21st, 2025	15:00 – 16:00
AAA (ATCo) expert	May 28th, 2025	13:00 – 13:45

3.2.2 CPDLC experts at MUAC

The purpose of the interviews with CPDLC experts at MUAC, was to gain insight into the transition from RT to CPDLC at MUAC, and its impact on ATCo workload and environmental sustainability.

Sample description and selection
The participants possessed extensive knowledge on CPDLC. CPDLC experts 1 and 2 were ATCos. The participants were selected through purposive sampling by the contact person from MUAC based on their professional expertise.

Data collection
Table 3.3 shows the date and time the interviews took place. The interview questionnaire consisted solely of open questions. It discussed five topics, being the transition from RT to CPDLC at MUAC, the use of CPDLC for the transfer process, the impact of CPDLC on ATCo workload and situational awareness, the effect on efficiency and environmental sustainability and their perspective on some concluding items. Data was collected using a mobile phone recorder in addition to recording with Microsoft Teams.

Table 3.3

Date and time of interviewing CPDLC experts

Participant	Date	Time
CPDLC expert 1	May 1st, 2025	13:00 – 13:45
CPDLC expert 2	May 1st, 2025	13:45 – 14:30
CPDLC expert 3	May 1st, 2025	14:30 – 15:00

3.2.3 ACC-controllers at LVNL

The purpose of the interviews with ATCos at LVNL, was to gain insight into their perception on the contribution of RT on their workload and what the impact of the implementation of CPDLC would be.

Sample description and selection
The participants were selected through systematic sampling. Recent and often cited[5] research found that saturation can be achieved with a sample size between 9 and 17 interviews, particularly in studies with relatively homogenous study populations and narrowly defined objectives (Hennink & Kaiser, 2022). Due to limited research time, a sample size of nine (n=9) area controllers was chosen. According to an online list of colleagues at LVNL, the number of ACC-controllers was 55, while the number of ACC-supervisors was 27, resulting in a total number of 82 (N=82). Therefore, every 9th controller from the list was selected and invited to participate in the interview. In selecting the participants, the ratio of ACC-controllers and ACC-supervisors was taken into account, resulting in three out of nine participants being ACC-supervisors.

One participant replied that they were very busy and did not have the time to participate in the interview. In their email, they shared in short their perspective on experienced workload of RT and the expected impact of CPDLC. It has been chosen to use their information in this thesis, but to exclude them from the sample (Table 3.4), as the information from the other interviews was far more extensive. In addition, one female participant also replied being too busy, and the other female didn't respond at all. To maintain representativity, replacements with similar position, age, and experience were sought, as they were the only females in the sample.

To see how well the sample represents the population, the male/female distribution, average age and average years of experience of the population and sample were compared and are shown in Table 3.4. Data on the population characteristics were shared by the Human Resources department at LVNL, while the sample characteristics needed to be gathered individually, for privacy reasons. As can be seen, the total population is 80 instead of 82, meaning that there is a slight difference in administration between the online list of colleagues and the data of HR. As the HR data was thought to be more reliable, this is included in the table.

Table 3.4

Comparison of population and sample characteristics

Parameter	Population (N)	Sample (n)
Male/female distribution	59/21	6/2
Average age	42,00	42,88
Average years of experience	18,26	19,22

Table 3.4 shows that the sample represents the population well, as the male/female distribution is almost alike and the average age and average years of experience differ less than one year.

Data collection
Table 3.5 shows the date and time the interviews took place. The interview questionnaire consisted of open and closed questions. The closed questions included questions on Likert scale, where participants had to rate the workload. The questionnaire discussed three topics, being the experienced workload of transfers with RT, the expected impact of CPDLC on that workload and the relation between workload and environmental sustainability. Data was collected using a mobile phone recorder in addition to recording with Microsoft Teams.

Table 3.5

Date and time of interviewing ACC-controllers

Participant	Date	Time
ACC-controller 1	May 21st, 2025	13:00 – 13:30
ACC-controller 2	May 21st, 2025	16:15 – 16:45
ACC-controller 3	May 26th, 2025	16:30 – 17:00
ACC-controller 4	May 27th, 2025	14:30 – 15:00
ACC-controller 5	May 28th, 2025	13:00 – 13:45
ACC-controller 6	May 30th, 2025	13:00 – 13:30
ACC-controller 7	June 3rd, 2025	16:30 – 17:30
ACC-controller 8	June 6th, 2025	12:30 – 13:00
ACC-controller 9	Sent email on May 20th, 2025	N/A

[5] 5648 citations (June 22nd, 2025)

3.2.4 WLM expert at LVNL

The purpose of the interview with the WLM expert at LVNL, was to gain insight into the workload model of LVNL, to understand the role of the under control and transfer of communication processes in the model, and the contribution of radiotelephony.

Sample description and selection
The participant was an ACC supervisor with extensive knowledge of LVNL's workload model. They were selected through purposive sampling based on their professional expertise.

Data collection
The interview took place on May 8th, 2025, between 9:00 and 10:15. The interview questionnaire consisted of open and closed questions. It discussed three topics, being the workload value of the WLM, the contribution of the UCO and transfer of communication processes and the expected impact of CPDLC. Data was collected using a mobile phone recorder in addition to recording with Microsoft Teams.

3.2.5 Data processing

The recordings of the interviews were transcribed using Microsoft Teams, but mainly manual labour due to the many errors Teams made. The interviews that were conducted in Dutch were translated using DeepL Pro, as this program doesn't keep the data after translations (DeepL, n.d.). Subsequently, the transcripts were coded through thematic analysis in Excel. Columns with the participant pseudonym, the specific quote, and the theme, code and sub-code that quote belonged to were included. In this way, a qualitative database was created from scratch. Appendix XVIII shows a screenshot of the database. The transcripts, in English as well as in Dutch, can be found in Appendices I – XVII. The codebook can be found in Appendix XIX.

3.3 Voice data analysis

To get a better understanding of the ATCos' task load of doing the transfer process via RT, voice data was analysed. This served as additional support to the interviews with the ACC-controllers.

Sample description and selection
Week 16 (April 14-20) of year 2025 was taken, as this was the most recent data available at the time. Due to expert judgement, a sample size of seventy (n=70) was chosen. The expert was of the opinion that a greater sample size would not alter the results. Systematic sampling was used, meaning that the samples were distributed over the week, and over each day, starting at 4:00 and ending at 22:00, with a time interval of two hours (4:00, 6:00, 8:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00 and 22:00). This time interval was chosen to ensure listening to various ATCos, as one shift generally takes about two hours.

Data collection
The analysis included manually timing (as automation was not possible) how long it takes for the ATCo to give the transfer of communication clearance and for the pilot to do the read-back thereafter. The recording was started at the specific times, and the first transfer of communication clearance that occurred was included.

Data processing
A database was created in Excel, including the date, day, start of the clearance time, end of the clearance time and end of the read-back time (screenshot can be found in Appendix XX). Start of the read-back time was excluded, as read-backs almost always occurred directly after the clearance was given. Exceptions and abnormalities were noted as comments in the database. The data was used to create a boxplot and calculate measures of central tendency.

4 Results

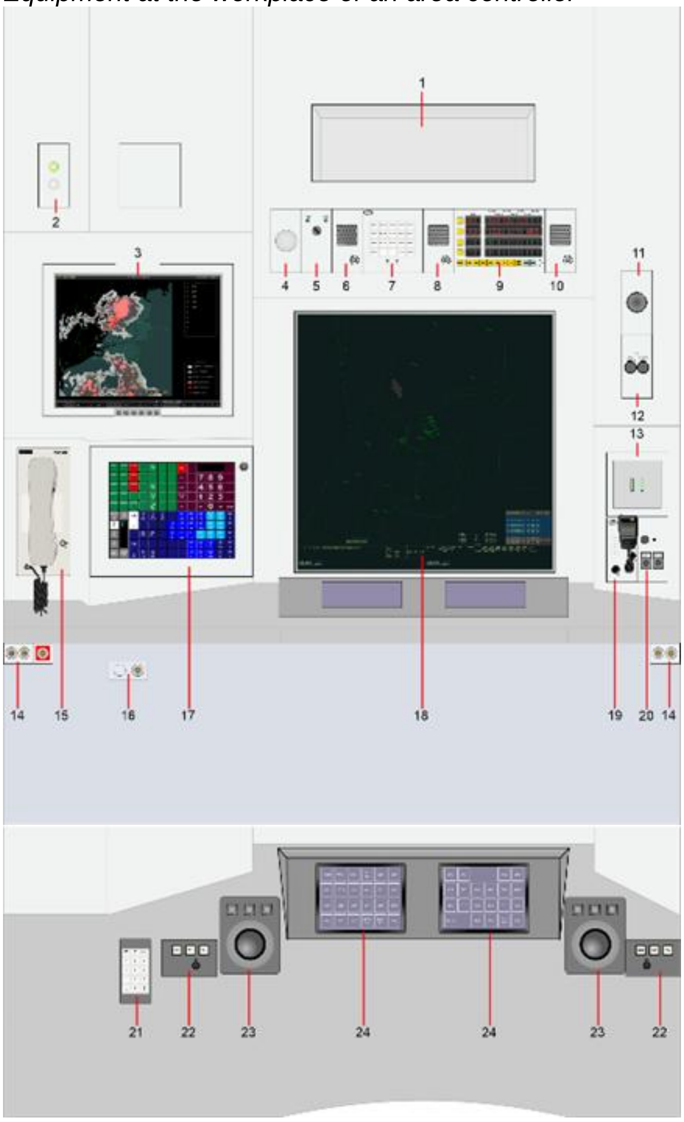
This chapter presents the results of the research, organized according to a combination of the sub-questions introduced in Chapter 1 and themes emerging from the thematic interview analysis. Section 4.1 outlines the tasks of the area controller, providing foundational context for the subsequent analysis. Section 4.2 investigates the anticipated impact of the transition from the AAA system to iCAS on controller workload. Section 4.3 examines how the shift in means of communication – from solely RT to a combination of RT and CPDLC – affects workload, and addresses the transition from RT to CPDLC at MUAC. Finally, Section 4.4 evaluates how changes in both core support systems and communication technologies influence environmental sustainability. Each section concludes with a summary of key findings, presented as bullet points to highlight the main insights and conclusions.

4.1 Area controller tasks in the transfer process

Before presenting the results of the observations, Figure 4.1 is included to provide a visual overview of the working position of an area controller. This serves to support a better understanding of the subsequent task analysis. Throughout this section, references are occasionally made to specific numbered elements in the figure to indicate the location of particular equipment within the workspace.

Figure 4.1

Equipment at the workplace of an area controller



Note. From "Operations and Instructions Manual (OIM) Amsterdam ACC-controllers," by LVNL, 2012. Copyright 2012 by LVNL.

Firstly, it is important to distinguish between the roles of the planning controller (PLC) and the executive controller (EC), who typically operate in pairs at LVNL. The PLC is primarily responsible for the coordination and planning of air traffic entering, exiting, or transiting through the sector. This includes providing tactical support to the EC. In contrast, the EC is tasked with maintaining separation between aircraft within the sector, issuing instructions for conflict resolution, and monitoring aircraft trajectories (SESAR JU, n.d.).

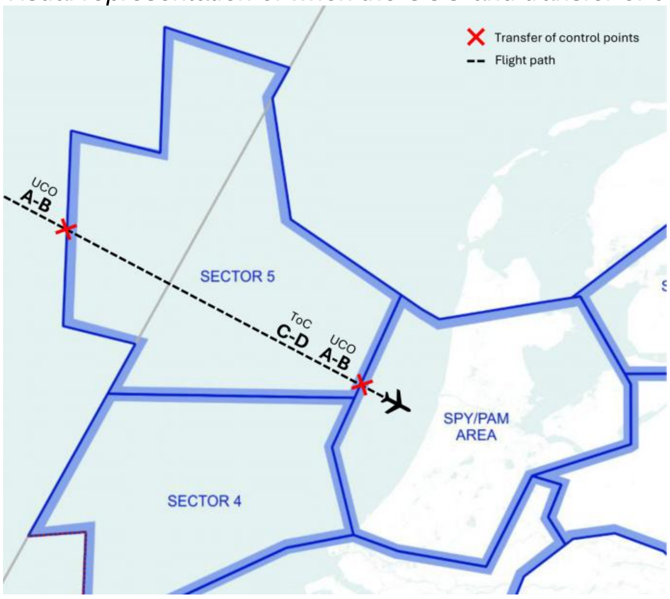
As outlined in Section 1.1, the EC assumes responsibility for a flight – referred to as Under Control (UCO) – shortly before it enters their sector. The EC releases the flight when it reaches the boundary of the sector. This process is facilitated by the system, which uses the UCO-sequence – a sequence of sectors that will successively manage the flight – to determine the appropriate downstream controller. Prior to the formal Transfer of Control (TOC), the EC initiates the transfer of communication by instructing the flight crew to contact the next sector on a different radio frequency. Once the flight is released in the system, the next controller is notified and can assume control. In essence, the transfer of communication generally precedes the TOC. This sequence is illustrated in Figure 4.2.

In the example shown, the aircraft's flight path moves through sector 5 and proceeds into the SPY/PAM area. SPY (Spijkerboor) and PAM (Pampus) are waypoints located within the Dutch Flight Information Region (FIR). The boundaries of the SPY/PAM area correspond to the lateral limits of Schiphol Terminal Manoeuvring Area (TMA) 1 and TMA 6. The TOC points – shown in red – are positioned at the boundaries of sector 5. Prior to entering sector 5, the EC assumes the flight (UCO) (this can only be done when the previous sector has released the flight). The flight is now under the responsibility of the EC of sector 5. Upon reaching the sector boundary, the EC initiates the transfer of communication, enabling the controller of the SPY/PAM area to assume responsibility and establish communication with the aircraft.

It is important to note that the exact location and timing of the UCO and transfer of communication processes may vary depending on operational circumstances. For example, the transfer of communication might be initiated earlier within sector 5 – for instance, halfway through – if no further clearances are required due to the absence of potential conflicts.

Figure 4.2

Visual representation of when the UCO and transfer of communication processes take place



Note. Adapted from "Operations Manual (OM) AMS ACC," by LVNL, 2017. Copyright 2017 by LVNL.

The UCO processes at LVNL and MUAC are illustrated in Figures 4.3 and 4.4, respectively. In both settings, the UCO process typically begins when an aircraft calls on the frequency of the relevant sector or Air Traffic Service Unit (ATSU). At LVNL, under standard operating conditions, the callsign displayed on the screen appears in white prior to and at the beginning of the radio call. This white label indicates that the aircraft is in the so-called ‘’twilight zone’’, meaning the previous ATSU has released the flight, enabling the EC of the current sector to assume control.

When comparing the UCO procedures at LVNL and MUAC, no fundamental differences are observed; the overall structure of the process is consistent across both centers. However, notable differences exist in the Human-Machine Interface (HMI) used by controllers. At LVNL, controllers interact with the system using rolling balls (Item 23 in Figure 4.1) and a Touch Input Device (TID) (Item 24 in Figure 4.1). In contrast, MUAC employs a mouse-based interface, with on-screen menus for system interaction. These interface variations reflect different operational environments but do not alter the core logic of the UCO process.

Figure 4.3

Swimlane diagram Under Control (UCO) process at LVNL

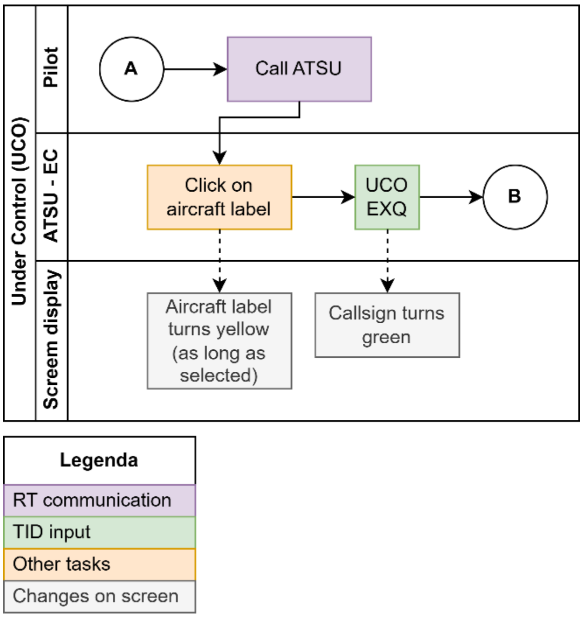
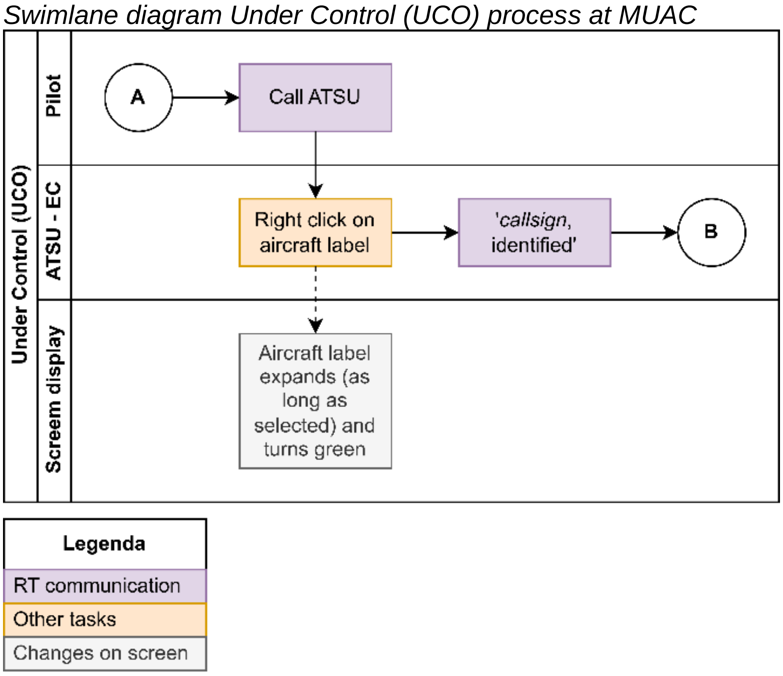


Figure 4.4

Swimlane diagram Under Control (UCO) process at MUAC



Figures 4.5 and 4.6 present the transfer of communication processes at LVNL and MUAC, respectively. As illustrated, this procedure involves more steps compared to the UCO process. At LVNL, two processes occur simultaneously during the transfer of communication. The first involves radio communication between the EC and the pilot. The EC initiates this by activating the microphone – via a switch, pedal, or button, depending on personal preference – and issuing a standard instruction to the aircraft to contact the next ATSU. The process is completed once the pilot reads back the instruction. If no immediate readback is received, the EC repeats the instruction until confirmation is obtained.

Meanwhile, the second process takes place via the HMI: the EC selects the aircraft on the screen and inputs either *TOC EXQ* – the most commonly used option – or *TOC* via the TID. The *TOC EXQ* command allows the system to determine the next logical sector, enabling that sector to assume control of the flight. Alternatively, *TOC* permits manual sector selection. These actions result in changes to the aircraft label and track symbol on the display.

The HMI differences between LVNL and MUAC are also evident when comparing the transfer of communication task (Figures 4.5 and 4.6). However, a key functional distinction is that MUAC controllers can choose between using voice or CPDLC to perform the handover. As the voice-based procedure at MUAC closely resembles that at LVNL, it is not discussed further here.

In the CPDLC procedure, illustrated in blue in Figure 4.6, the controller initiates the handover by right-clicking the aircraft callsign in the label and selecting the *CONTACT* command from a menu. This action uplinks the CPDLC message to the pilot and simultaneously starts a timer. These mouse-based interactions are designed to be intuitive and efficient.

The message handling and timing works as follows (CPDLC expert 2, personal communication, 24 May 2025):

- If the aircraft successfully receives the message, it downlinks a LACK (Logical Acknowledgement). This must be received by the ground system within 40 seconds.
- If the LACK is not received within 40 seconds, a light yellow warning appears on the controller's interface, indicating that the acknowledgement is missing. If no LACK is received after two minutes since uplink time, the message turns yellow and the ATCo must reset the message and either resend it or contact the pilot by voice.
- If the LACK arrives after 40 seconds, the message is marked yellow due to a delay or rejection caused by network issues. In this case, the ATCo must reset the message and either resend it or contact the pilot by voice.
- After the LACK, the pilot has 100 seconds to respond with a WILCO (will comply). If the pilot sends the message within this time, the message status turns green. If not, the message will turn yellow once the 100 seconds have passed.

So 40 seconds only means that the ground system didn't get a confirmation (LACK) about the message delivery – it doesn't mean it wasn't delivered. It can be that the LACK got lost and the message is in fact delivered, then it can be the case that the light yellow warning can go to normal green once the pilot's WILCO message arrives.

Figures 4.3 to 4.6 include letters (A-B-C-D) at the beginning and end of the processes, to explain their sequence. The interaction between the EC of sector 5 and the pilot in Figure 4.2 starts with the UCO process (A-B). After the EC has issued clearances and resolved any potential conflicts, the transfer of communication process (C-D) is performed, releasing the aircraft. There is only a brief interval between this and the moment when the pilot calls on the frequency of the next sector – in this case the controller of the SPY/PAM area – initiating the UCO process (A-B). Consequently, D and A follow each other, marking the handover between two different ATSUs.

Findings

- The UCO process is largely the same at LVNL and MUAC, as pilots are still required to check in on the frequency; CPDLC does not yet replace the initial call-in. The differences lie in the HMI of both organizations.
- The transfer of communication processes differs notably: MUAC controllers can choose between RT and CPDLC, offering greater flexibility based on traffic conditions and personal preference.
- While CPDLC may result in longer pilot response times compared to RT, it reduces RT usage and actions that need to be taken by the ATCo.

Figure 4.5

Swimlane diagram transfer of communication process at LVNL

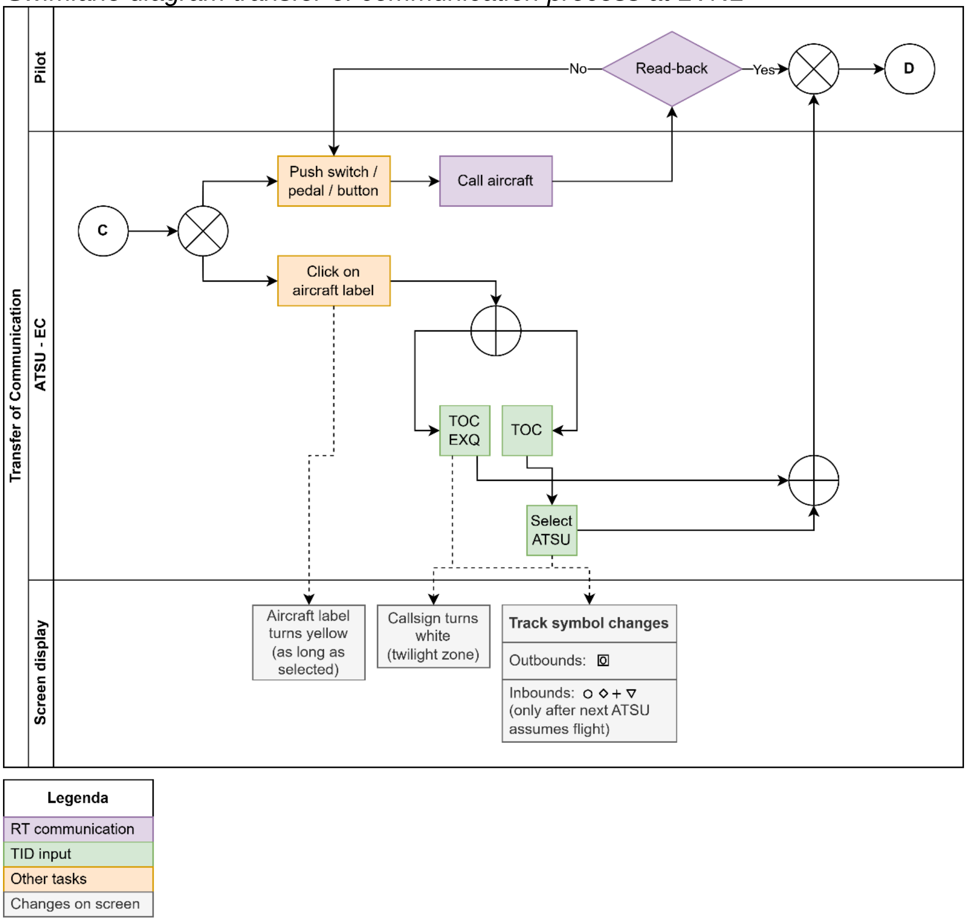
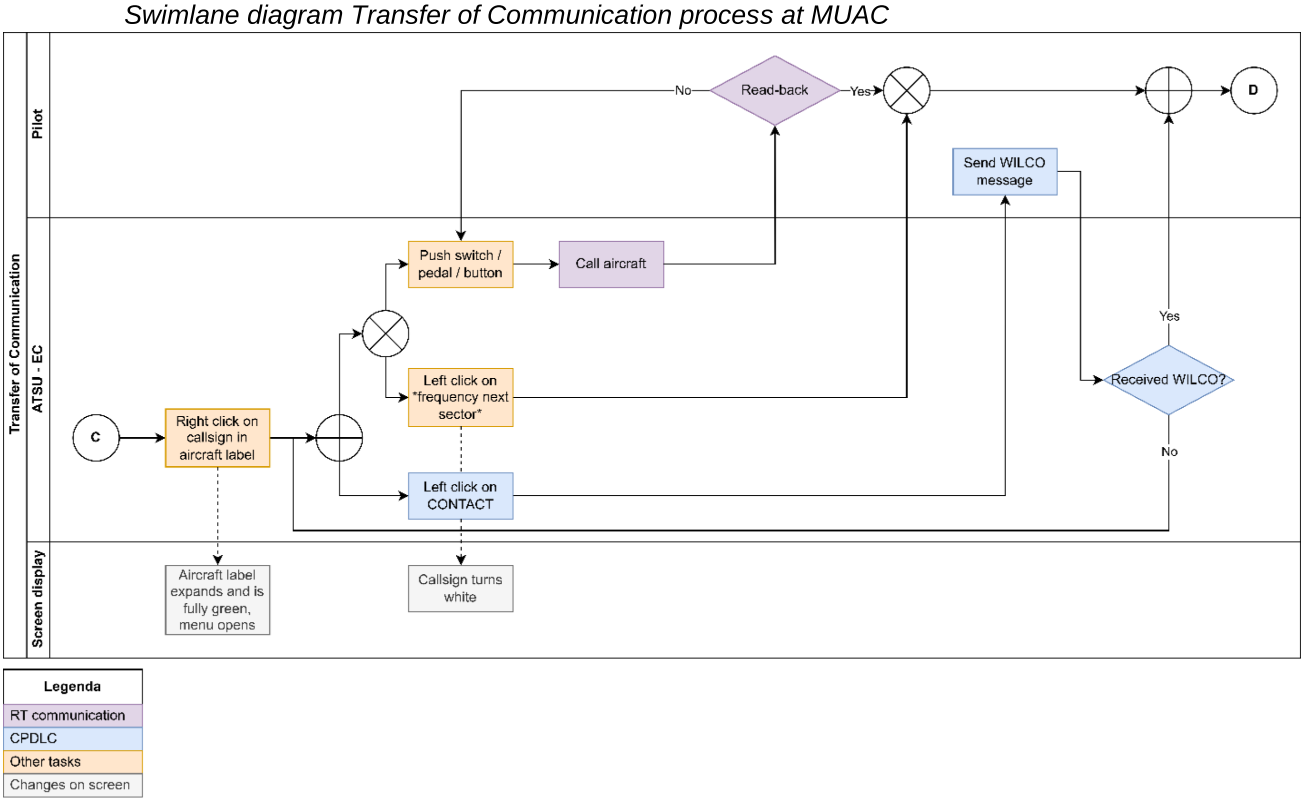


Figure 4.6

Swimlane diagram Transfer of Communication process at MUAC



4.2 Impact of system change on controller workload

This section analyses how the UCO-sequence functions within the current AAA system (Section 4.2.1) and the upcoming iCAS system (Section 4.2.2), with a focus on how these systems influence ATCo workload. These insights are based on expert interviews and documentation.

4.2.1 UCO-sequence in AAA and workload

In AAA, airspace crossing is a process that determines which airspace segments a flight traverses (LVNL, 2012). This involves evaluating both the horizontal route and the vertical profile – the trajectory – of a flight based on data from the System Flight Plan (SFPL). The outcome is a series of airspace crossings, which are used to generate the UCO-sequence – the ordered list of ATSUs responsible for the flight. If changes are made to the flight route or altitude, the UCO-sequence is automatically recalculated (LVNL, 2012).

AAA applies specific rules in addition to route analysis when creating the UCO-sequence. For instance, sector crossings trigger the inclusion of the corresponding sector controller, while crossing a holding area adds a stack controller. AAA also distinguishes between military and standard flight plans (LVNL, 2012).

According to the AAA experts, the UCO-sequence plays a critical role in determining label visibility on radar displays. Labels are shown only to the controller currently responsible for the flight and to future controllers in the sequence. In some operationally relevant cases, an information label may be displayed even if the controller will not directly work with the flight.

Predictability emerged as a central theme in the interviews. Direct routings, which are commonly issued at LVNL, do not affect the UCO-sequence – AAA continues to use the filed route for its calculations. In cases where significant deviation occurs, controllers must coordinate manually or update the system. Despite this, AAA generally adheres to standard procedures to ensure consistency.

Experts described AAA as highly tailored to controller needs, refined through 27 years of operational feedback. As one AAA expert stated, the system has become ‘’a very expensive Italian tailored suit’’ (AAA expert, Appendix I, April 2025).

In non-nominal situations, however, controller workload can increase. Diversions or system errors (such as a missed transfer in the system despite an RT handoff) require manual intervention. According to the AAA (ATCo) expert, these cases occur a few times a week and introduce only a minor increase in workload.

Findings

- In normal situations, the UCO-sequence runs smoothly and adds no extra workload, due to AAA's predictability and user-centered design.
- In non-standard situations, such as diversions or failed transfers, manual action is needed, causing a small, occasional increase in workload.

For supporting quotes and detailed references, see Appendices I-IV.

4.2.2 UCO-sequence in iCAS and workload

While AAA has been highly tailored over time to LVNL operations, iCAS introduces a different approach to trajectory prediction and system interaction. According to both iCAS experts, the fundamental logic behind the determination of the UCO-sequence in iCAS is comparable to AAA: the sequence is based on the trajectory of the aircraft, determining which sectors will be crossed and assigning the relevant controllers accordingly. However, there are several key differences between the two systems that significantly affect usability and workload.

The most notable distinction lies in the way the trajectory is determined. iCAS relies on a theoretical performance model, the Base of Aircraft Data (BADA), which considers aircraft type, detailed wind data, and other performance characteristics (iCAS expert). Furthermore, besides being updated based on controller inputs like in AAA, the trajectory in iCAS is also updated based on real-time flight positions. This makes the trajectory – thus the UCO-sequence – in iCAS more accurate. However, according to the AAA & iCAS (ATCo) expert, the trajectory in iCAS is not as accurate as it pretends to be, as it is an average – no aircraft actually flies an exact average trajectory.

Automation is another major difference. iCAS automates many tasks that require manual input in AAA. While this reduces routine workload, it can lead to unanticipated system-driven changes. These changes are not always clearly visualized in the iCAS Human-Machine Interface (HMI), which disrupts the standardized workflows that ATCos rely on. When deviations from the route occur, iCAS may update the trajectory – and the UCO-sequence – automatically, often causing confusion and requiring additional coordination.

Moreover, the opportunities to adjust the UCO-sequence using rules are in AAA better and more extensive compared to iCAS. Incorrect UCO-sequence determinations, through infrequent, do occur and can increase workload. This often happens when a trajectory briefly intersects a sector, triggering a handover that deviates from the standard way of working at LVNL (an example of this is provided in Figures XXI1 and XXI2 in Appendix XXI). AAA is better at optimizing these situations by excluding negligible sector crossings from the UCO-sequence. In contrast, iCAS includes every sector in a straightforward manner. While iCAS provides a ‘’skip’’ function – allowing controllers to skip themselves (exclude themselves from the UCO-sequence) – and a ‘’bypass’’ function – allowing controllers to determine to skip another ATSU – these manual inputs, though ultimately workload-reducing, temporarily increase controller workload.

AAA & iCAS (ATCo) expert explained that LVNL is not the only one facing these issues with iCAS. The challenges appear more prominent in lower airspace operations. They argued that the reason for this is that aircraft behaviour is less predictable at lower altitudes due to frequent changes in speed, altitude and heading. In upper airspace, most aircraft fly level and predictably, making trajectory prediction less error-prone.

In contrast to AAA being compared to a ‘’tailored suit’’ in Section 4.2.1, iCAS was described as a ‘’C&A suit’’, indicating the difference in quality and custom fit of both systems.

Findings

- iCAS demonstrated greater trajectory prediction accuracy compared to the AAA system, but there is still room for improvement regarding the quality of data.
- Increased automation in iCAS can disrupt controller workflows and lead to higher workload.
- Manual override functions like skip and bypass exist but do not fully compensate for the reduced flexibility compared to AAA.

For supporting quotes and detailed references, see Appendices I-IV.

4.3 Impact of change in means of communication on controller workload

This section shifts the focus from the core support systems to the two types of communication: RT and CPDLC. It explores how both means of communication impact ATCo workload and identifies key differences. It begins with an analysis of the experienced workload of RT by ACC-controllers at LVNL (Section 4.3.1). Then, a section is dedicated to the Workload Model (WLM) of LVNL, to comprehend the view of LVNL on ATCo workload (Section 4.3.2). Following this, the transition from radiotelephony to CPDLC at MUAC is examined to understand implementation experiences (Section 4.3.3). Next, the experienced workload of CPDLC by MUAC controllers is investigated (Section 4.3.4), followed by the expected workload of CPDLC by ACC-controllers at LVNL (Section 4.3.5). In both Sections, the impact on situational awareness is included. Finally, the section concludes with a SWOT analysis of CPDLC, providing a structured overview of its strengths, weaknesses, opportunities and threats (Section 4.3.6).

4.3.1 Experienced workload of RT

Table 4.1 presents how ACC-controllers rated the workload associated with assuming and handing over a flight, as well as how much they believe RT contributes to that workload.

Table 4.1

Rating of the experienced workload by ACC-controllers

Category	Assuming a flight	Handing over a flight	Contribution of RT
Very low	12.5%	12.5%	0.0%
Low	62.5%	62.5%	25.0%
Average	25.0%	25.0%	25.0%
High	0.0%	0.0%	37.5%
Very high	0.0%	0.0%	12.5%

It must be noted that participants interpreted the process of assuming a flight differently: some considered it to include the first clearance, while others viewed it only as acknowledging a flight. Despite these interpretative differences, the reported workload levels were largely consistent. When asked whether assuming or handing-over a flight is more demanding, answers varied: some controllers considered both actions equally demanding, others found handing over more complex due to the chance of incorrect frequency read-backs, while a few said assuming was more difficult because of issuing the first clearance.

As shown in the table, most controllers rated the contribution of RT to workload as ‘high’. One participant, ACC-controller 1, gave an ambiguous answer, stating: ‘’So you could say, again, not much. But it’s cumulative’’ (Appendix VIII, May 2025). Their response was categorized as ‘low’, but with the note that under high-traffic conditions, the RT load may be perceived as higher.

The ACC-controllers described various operational situations that increase their workload during the assumption or handover of a flight. These have been grouped and ranked by how many controllers mentioned them.

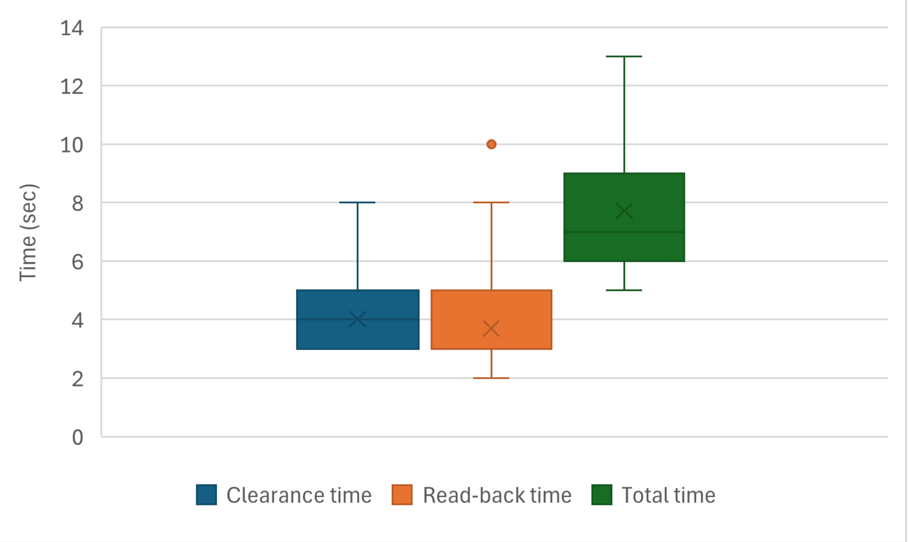
- Language barriers and communication style differences (ACC-controllers 2, 3, 6 & 7);
- Multiple aircraft checking in at once (ACC-controllers 1 & 8);
- Frequency congestion (ACC-controllers 2 & 3);
- Bad weather conditions (ACC-controllers 5 & 6);
- Transfer clearances requiring additional pilot instructions (ACC-controllers 6 & 7);
- Unresponsive pilots (ACC-controller 2);
- Previous sector forgets to transfer a flight (ACC-controller 3);
- ATCo must initiate call because aircraft hasn’t checked in (ACC-controller 3);
- Another frequency in use than normally (ACC-controller 3);
- Transfer of communication with sectors outside the UCO-sequence (ACC-controller 4).

These operational challenges can result in communication errors, incorrect or incomplete read-backs, and the need to repeat clearances – all of which contribute to higher perceived workload during the transfer process.

The voice data analysis, which provided quantitative support for the interviews, showed that issuing a transfer of communication clearance takes an average of 4.0 seconds, while the read-back takes about 3.7 seconds. This results in an average RT time of 7.7 seconds per flight (see Figure 4.7). As illustrated in Figure 4.7, this duration can vary significantly depending on whether additional instructions are given along with the clearance or if any errors occur, such as incorrect read-backs or the need for repetitions.

Figure 4.7

Boxplots of the transfer of communication process via RT



Findings

- Although assuming and handing over a flight were generally rated as low in workload, 50% of controllers rated RT's contribution as either 'high' or 'very high'.
- The most commonly cited factor increasing RT workload was language barriers and differences in communication styles between pilots and controllers.
- Based on voice data, the average RT time per flight is 7.7 seconds, but this can increase due to various factors mentioned by controllers.

For supporting quotes and detailed references, see Appendices VIII-XVI.

4.3.2 Workload Model of LVNL

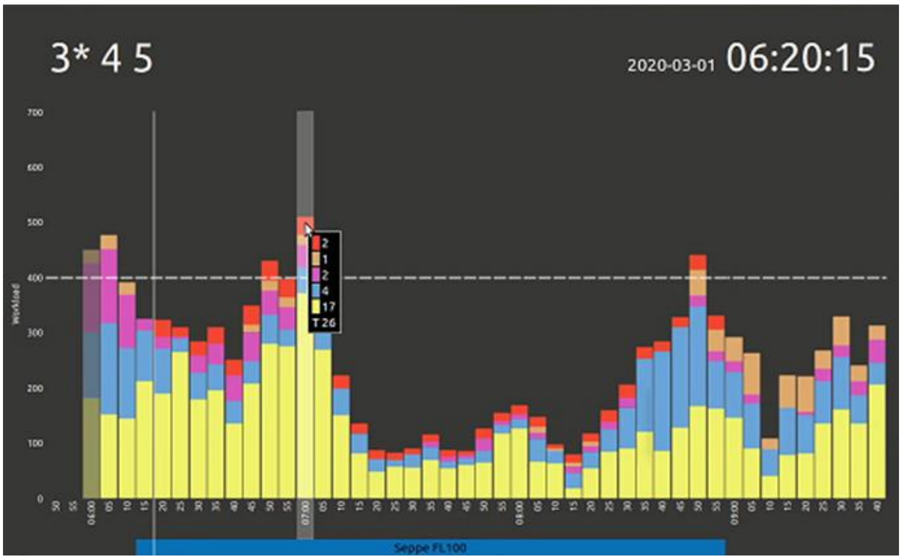
To quantify ATCo workload, LVNL employs a dimensionless Workload Model (WLM). This model provides a standardized, numeric representation of workload that supports operational planning and sector capacity management. Rather than capturing subjective experience directly, the WLM is structured around objective, quantifiable parameters associated with traffic complexity, geometry, and task demand.

At the core of the model lies an interaction-based scoring system. This system evaluates the interactions between aircraft trajectories within a sector. Specific types of interactions – such as crossing, converging, or opposing traffic flows – are assigned different weights based on their complexity. For example, opposing interactions typically receive a higher score (e.g., a weight of 4) due to the increased procedural attention they require. The model then considers factors such as route geometry, proximity of aircraft, and climb or descent constraints to generate a complexity score.

These individual interaction scores are mathematically compiled using formulas. The workload score is computed over a rolling 20-minute window and updated every 5 minutes. The result is a dimensionless value, typically ranging between 400 and 500 during periods of high workload, used as a quantitative indicator of sector busyness. Figure 4.8 shows the workload model, with a striped line at value 400. The colours in the graph represent the type of traffic: inbounds Schiphol (yellow), outbounds Schiphol (blue), inbounds and outbounds other airports in the Netherlands (pink), overflights (light orange) and paragliders (orange).

Figure 4.8

Workload Model LVNL



Note. From "Operations and Instructions Manual (OIM) Amsterdam ACC-supervisor," by LVNL, 2012. Copyright 2012 by LVNL.

In addition to traffic interactions, the model incorporates static task load factors to reflect structural and procedural complexities within a sector. These factors include sector size, available manoeuvring space, and constraints such as military airspace usage. For instance, a sector with limited lateral deviation options is considered more demanding and therefore receives a higher base workload score.

To ensure reliability, the model was calibrated and validated using subjective workload assessments provided by controllers on a scale of 0 to 10. These ratings were normalized – typically compressing high ratings (e.g., 8 or 9) into a score of 4 – to align them with model output. Validation also involved comparing the model's results with historical radar and traffic data, confirming that the numerical scores correlated reasonably with controller-perceived workload.

However, some routine tasks are not explicitly modelled in the WLM. Processes such as taking a flight UCO and transferring communication to the next sector are considered part of the standard task load but are not independently quantified, according to the WLM expert. Similarly, RT – despite its contribution to cognitive and communication load – is excluded from the model due to high variability among controllers (e.g., some speak more frequently or use different phrasing styles). Although CPDLC is seen as a potential reducer of communication workload, there is currently no established method for incorporating it in the WLM.

Overall, LVNL's model is designed to prioritize measurable, physical aspects of workload, such as aircraft count, flow geometry, and temporal clustering. While cognitive dimensions – like mental effort or spatial scanning across large sectors – are acknowledged as relevant, they are not directly measurable and therefore remain outside the model's scope. The dimensionless value produced by the WLM serves primarily as a consistent, data-driven baseline, rather than a comprehensive reflection of human task saturation. Still, thresholds such as a score of 400 are used in practice as indicators of high workload, guiding operational decision-making.

Findings

- UCO and transfer of communication are considered standard procedural tasks and are not separately quantified in LVNL's workload model.
- RT, despite contributing to cognitive workload, is excluded from the model due to high variability in controller communication styles and the challenge of standardizing verbal interactions.
- The potential workload-reducing effect of CPDLC is recognized, but there is currently no method for incorporating it in the WLM.

For supporting quotes and detailed references, see Appendix XVII.

4.3.3 Transition from RT to CPDLC

The transition from RT to CPDLC at MUAC was gradual and faced multiple challenges, as highlighted by three interviewed CPDLC experts. Initially, adoption was slow due to a low number of CPDLC-equipped aircraft. CPDLC expert 2 remarked that without local requirements, pilots were often not logging on, and CPDLC was seen by many ATCos as a toy to play around with. To quote CPDLC expert 2:

> There was supposed to be a European Commission datalink mandate, it's also known as the DLS IR, Data Link Service Implementing Regulation. So initially the plan was that from 2009 everybody should have datalink. Then that got delayed for different reasons. But when it was first announced, that really boosted the equipage levels. So we had a lot of aircraft coming in from different suppliers, which was really great, but due to the lack of performance standards, all kinds of avionics came online. Which meant that some of the aircraft which did log on were having really old or not correct software versions or hardware versions, and they were jamming up the datalink frequency for somebody else.
> *(CPDLC expert 2, Appendix VI, May 2025)*

According to CPDLC experts 1 and 2, this performance inconsistency led to resistance and frustration in the OPS room. Messages often failed to reach pilots, forcing ATCos to do it by voice – double work. To mitigate this, MUAC introduced a logon list, enabling MUAC to filter out aircraft with poor connections. System reliability was the key factor in gaining ATCo acceptance. If voice communication was perceived as more reliable or faster, ATCos would naturally default to it.

Even now, although pilot logon is mandatory, not all pilots comply, and ATCos must often ask them to do so. CPDLC expert 1 explained: ''The difficulty lies in convincing them [the ATCos] that it will take a few extra seconds to ask them [the pilots] to log in, but then you gain so much more'' (Appendix V, May 2025). Initial resistance among controllers – due to scepticism and stubbornness – began to fade once they experienced firsthand how CPDLC could speed up routine communication and reduce workload.

How new technology is implemented at MUAC

CPDLC expert 3 emphasized MUAC's culture of innovation, citing their slogan: ''Performance through innovation'' (Appendix VII, May 2025). MUAC strives to be at the forefront of adopting and implementing new technologies. Their implementation process is collaborative and user-centered, involving multiple steps:

1. Initiation by ATCos – New technology usually comes from the end users, the ATCos, who come together in SMART groups (System Monitoring And Revision Team).
2. Design and feasibility – The SMART group defines design and functional requirements, which are then assessed by engineers for feasibility.
3. Prototyping – If feasible, engineers develop a prototype.
4. Assessment and training design – Human Factors Analysis and other evaluations determine the appropriate training approach (e.g. e-briefs, Computer Based Training, simulations).
5. Operational validation – The prototype undergoes OPS room testing and validation.
6. Implementation – Upon successful validation, the technology is deployed into operational use.

The duration and depth of the process depend on the scale of the change. While minor updates may require only a digital briefing or short video, larger implementations can involve years of development and training. Experienced workload of CPDLC

Findings

- System reliability is the most important factor for CPDLC adoption among ATCos – if it's unreliable, they will default to voice.
- As MUAC has been using CPDLC for over 20 years, many issues are already resolved, such as the creation of the logon list, which Is promising for LVNL.

For supporting quotes and detailed references, see Appendices V-VII.

4.3.4 Experienced workload of CPDLC and impact on situational awareness

All three CPDLC experts at MUAC reported a significant reduction in ATCo workload following the implementation of CPDLC, particularly for the transfer process. This reduction stems not only from decreased use of RT but also from the ability to delegate transfer tasks to the planner controller, allowing for a more efficient division of responsibilities.

CPDLC is described as a major capacity enabler at MUAC, contributing to an estimated 16-20% increase in capacity. CPDLC expert 2 illustrated this impact with an example:

> I had a one hour session in the Jever sector, which is our north sector, so that's north of the Dutch airspace and the German airspace. That's a sector with 74 aircraft TMV. That's the Traffic Monitoring Value declared to NM [Network Manager]. (…) I had 96 aircraft going through that airspace with 74 maximum declared to Network Manager, and I used 15 minutes on the radio and 260 something CPDLC messages. All the time 30 aircraft and (…) I didn't feel busy. That was a really cool part. It's like, yeah, I see that it's a lot of green but it's good.
> *(CPDLC expert 2, Appendix VI, May 2025)*

Efforts are ongoing at MUAC to extend CPDLC use to the UCO process. According to CPDLC expert 1, implementing UCO via CPDLC could further reduce RT load but presents two key challenges: ICAO requirements and the risk of pilot errors.

On the pilot side, workload is also reduced, especially in Airbuses and modern Boeing aircraft, as well as some business jets. These aircraft can automatically load the next sector frequency in the Flight Management System, requiring pilots to confirm the transfer with just a click or two.

Regarding SA, CPDLC experts 1 and 2 noted that a potential risk arises if planner controllers initiate transfers unexpectedly, particularly if the executive controller still intends to take further action on the flight. CPDLC expert 1 recommended not delegating transfer tasks to planners during the initial phase of CPDLC usage until ATCos are familiarized with the technology. All CPDLC experts expressed that MUAC has good visualization on the HMI, and CPDLC expert 3 noted that transfer messages via CPDLC pose no significant problem, though other types of clearances may present challenges.

Findings

- CPDLC significantly reduces controller workload, especially for routine tasks like transfers, and is a capacity enabler – increasing capacity at MUAC by 16-20%.
- Delegating transfer tasks to planner controllers and future use of CPDLC for the UCO process offer further potential to reduce RT load.
- SA is generally maintained with CPDLC during transfers, but close coordination between planner and executive controllers is essential.

For supporting quotes and detailed references, see Appendices V-VII.

4.3.5 Expected workload of CPDLC and impact on situational awareness

Table 4.2 presents how ACC-controllers rated their knowledge of CPDLC and their expectations regarding the impact on assuming and handing over flights, as well as whether they believe it will reduce ATCo workload. The question about their CPDLC knowledge served to provide context and nuance for interpreting their responses.

The question on the expected impact of CPDLC on assuming flights was intentionally designed as a test of understanding. As pilots are still required to check in via voice during the UCO process – as outlined in Section 4.1 – CPDLC currently has no impact on flight assumption. Controllers who were aware of this responded accordingly, while others assumed potential future uses, which influenced their answers.

Table 4.2

Rating of ACC-controllers' knowledge on CPDLC and the expected impact on assuming and hand-overs

	Knowledge on CPDLC	Impact on assuming flights	Impact on handing over flights	Reduces workload?
ACC-controller 1	Excellent	No impact	Average to much	Yes
ACC-controller 2	Fair	No impact	Average	Partly
ACC-controller 3	Bad	No impact	Average to much	Yes
ACC-controller 4	Good	Average	Very much	Yes
ACC-controller 5	Good	Average to much	Little to average	Yes
ACC-controller 6	Bad	Much	-	Partly
ACC-controller 7	Good	Average	Very much	Yes
ACC-controller 8	Fair	Much	-	Yes

The responses from the ACC-controllers reveal varying levels of familiarity with CPDLC. Three controllers correctly understood that CPDLC does not currently impact the assumption of flights. However, the other controllers misjudged this aspect, suggesting that they were either unaware of this limitation or thinking ahead to potential future implementations where the UCO process might be supported by CPDLC.

There was a notable knowledge gap among controllers, particularly ACC-controllers 2, 3, 6 and 8, whose responses included uncertain language or hesitancy in their answers. These indicators of limited understanding were taken into account when weighing their input against that of their peers.

Despite this variability in understanding, all controllers expected CPDLC to reduce ATCo workload to some extent. In addition, ACC-controller 9 echoed the comments of the CPDLC experts on the potential of delegating transfer tasks to the planner controller:

> For us, CPDLC is not suitable for standard clearances, as those are too ad hoc and require immediate follow-up. However, for transfers, it would be very useful – especially because the PLC could handle them, which would relieve the EC when things get really busy. In that case, the EC wouldn't need to do anything, unlike with RT, where they normally have to issue a message and receive a read-back (if it even goes right the first time).
> *(ACC-controller 9, Appendix XVI, May 2025)*

However, not all controllers were fully convinced of CPDLC's effectiveness in all scenarios. For example, ACC-controller 2 was more cautious, questioning whether CPDLC could be relied upon for quick exchanges, particularly when coordinating with Approach. Furthermore, ACC-controller 6 admitted to not knowing how the CPDLC transfer process would function in practice, which relates to their lack of knowledge of CPDLC. Regarding the longer-term implementation of the UCO process via CPDLC, ACC-controller 1 noted that this will likely take time due to the need for additional safety assurances and approval from EASA.

ACC-controllers 5 and 7 indicated during the interviews that they would prefer to use CPDLC for additional types of clearances, including en-route clearances, expected approach times, and Runway Visual Range (RVR) information. These types of clearances were described as RT-intensive yet non-time-critical, making them particularly suitable for delivery via pre-formatted CPDLC messages.

The opinions of ACC-controllers on the impact of CPDLC on SA were divided. While some believed that CPDLC would have no effect or only a temporary one as controllers adjust to the technology, others expressed concerns about how reduced voice communication might influence both controller and pilot awareness. For example, ACC-controller 3 speculated that with less verbal communication required, there is a risk that controllers might become less actively engaged with the flight, potentially handling it with less attentiveness. ACC-controller 4 and 7 focused on the pilot's perspective, pointing out that without hearing the level of busyness over the radio, pilots may not be able to assess whether it is an appropriate time to ask a longer or more complex question. Additionally, ACC-controller 7 highlighted a team-level concern: with RT communication, other controllers in the room are able to overhear instructions and maintain a shared sense of the traffic situation. In contrast, CPDLC interactions are not audible to others, potentially reducing this shared SA among colleagues. While these concerns are not necessarily barriers to CPDLC implementation, they underscore the importance of addressing human factors and communication dynamics during the transition phase.

ACC-controllers identified several key requirements for a successful implementation of CPDLC at LVNL. These have been grouped and ranked by how many controllers mentioned them:
- Clear and intuitive visualization on the HMI, enabling efficient use without adding cognitive load (mentioned by ACC-controllers 1, 3, 4, 5, 6, and 7);
- A reliable and stable system, with dependable connectivity to aircraft that support the message types (ACC-controllers 4, 5, 7, and 8);
- Defined boundaries for CPDLC use, specifying when it must be used and when it may be used at the controller's discretion (ACC-controllers 1 and 4);
- Pilot readiness, including sufficient awareness and familiarity with the system and message formats (ACC-controllers 5 and 7);
- Comprehensive training for controllers, ensuring they understand how to effectively use the system (ACC-controllers 1 and 6);
- System feedback showing adjacent center control assumption, to maintain SA during handovers (ACC-controller 2).

Findings
- CPDLC is widely expected to reduce workload, particularly for hand-overs, and is seen as especially beneficial when transfer tasks are delegated to the planner controller.
- Situation awareness impacts varied, with some concerns about the loss of voice communication and its implications for both controllers and pilots.
- The most important identified requirements for implementing CPDLC at LVNL are clear and intuitive visualization on the HMI and a reliable and stable system.

For supporting quotes and detailed references, see Appendices VIII-XVI.

4.3.6 SWOT analysis of CPDLC

Strengths	Weaknesses
Reduces radio frequency usage, freeing up time for other essential tasks (CPDLC experts, ACC-controllers, WLM expert). *Enhances pilot workload and safety*, as miscommunication is reduced and modern aircraft can automatically load frequencies (CPDLC expert 2, ACC-controllers 5, 6, 7 & 9, WLM expert). *Significantly increases airspace capacity*, with an average gain of 16–20% reported at MUAC (CPDLC expert 2). *Lowers the rate of lost communications*, with a reduction of approximately 30% at MUAC (CPDLC expert 2). *Effectively simplifies complex airspace*, allowing quicker and more efficient traffic management (CPDLC expert 2). *Streamlines transfers*, requiring just two intuitive mouse clicks at MUAC (CPDLC expert 1).	*Not ideal for time-critical scenarios*, such as urgent transfers or instructions requiring immediate clarification (CPDLC expert 3, ACC-controllers 1, 2 & 4). *Some controllers prefer traditional voice communication*, as it provides a greater sense of situational control (CPDLC expert 2). *Requires continuous visual monitoring*, as controllers must ensure message receipt via interface indicators (CPDLC expert 1).
Opportunities	**Threats**
Transfer responsibilities could be shifted to planner controllers, allowing more efficient division of tasks (CPDLC experts 1, 2 & 3, ACC-controller 9). *Eliminating voice call-ins* could further reduce radio frequency time (CPDLC expert 3). *Future updates to CPDLC standards* may offer enhanced features and improved system reliability (CPDLC experts 1 & 2). *Increased pilot adoption will boost familiarity and confidence*, leading to more effective system use (CPDLC experts 1, 2 & 3). *Extending CPDLC to lower airspace* could streamline logon processes and further enhance operational efficiency (CPDLC experts 1, 2 & 3).	*Message delays or failures present potential safety hazards*, especially in high-density or time-sensitive environments (CPDLC experts 1, 2 & 3, ACC-controllers 1, 2 & 3). *Temporary loss of CPDLC*, and having to do everything by voice (CPDLC expert 1). *Reduced pilot SA,* due to the loss of hearing instructions to other aircraft (ACC-controllers 4 & 7).

4.4 Effect on environmental sustainability

This section explores the potential impact of the introduction of iCAS and CPDLC on environmental sustainability. Based on interviews with experts and ATCos, it examines whether and how these changes may lead to reduced CO_2 emissions, either directly through improved trajectories or indirectly via reduced controller workload and more flexible operations. The findings are discussed in two parts: one focused on the core support system (4.4.1) and one on the change in means of communication (4.4.2).

4.4.1 Impact of change in core support system

The two ATCos highlighted the simplicity of Dutch airspace, with Schiphol Airport centrally located and five surrounding sectors forming a star-like structure. According to them, this layout means that a route would need to be significantly altered to result in a substantially different UCO-sequence. Even issuing a direct (DCT) route would have limited impact on the UCO-sequence.

Both the AAA and AAA & iCAS (ATCo) experts noted a potential relationship between reduced controller workload and more optimal – and potentially more sustainable – flight trajectories. However, they emphasized that quantifying this relationship is extremely challenging. Notably, AAA expert (ATCo) stated explicitly that they do not see a direct link between the UCO-sequence and environmental sustainability.

Instead, the iCAS and AAA & iCAS (ATCo) experts pointed to optimal trajectory planning as the key to achieving environmental benefits. This includes enabling direct routes, minimizing fuel burn, and allowing aircraft to fly at their most efficient altitudes. The AAA & iCAS (ATCo) expert also questioned the effectiveness of the BADA model in this context, noting that it does not account for airline-specific cost indices, which are crucial for accurate trajectory optimization.

Findings
The interviews suggest that:

- There is no clear link between the UCO-sequence and environmental sustainability.
- A potential link exists between controller workload and sustainability, with iCAS possibly increasing workload (Section 4.2.2) and thus negatively affecting sustainability.
- The greatest sustainability gains are likely to come from optimizing flight trajectories and using more accurate data.

For supporting quotes and detailed references, see Appendices I-IV.

4.4.2 Impact of change in means of communication

The CPDLC experts at MUAC unanimously agreed that integrating CPDLC into the transfer process has led to more efficient and sustainable air traffic management. CPDLC expert 2 highlighted the increase in capacity, while CPDLC experts 1 and 3 emphasized that it saves considerable time, which can be allocated flexibly to different operational needs.

At LVNL, ACC-controllers were asked whether they perceived a link between reduced workload and increased environmental sustainability. Opinions varied significantly. ACC-controllers 1, 2, 5 and 6 acknowledged a relationship between the two. ACC-controller 6 provided an analogy:

> Look, with inbound flights to Schiphol, what you're essentially doing is stringing all those aircraft together like beads on a necklace, having them fly one after the other. Sometimes you're so busy that you can't make the space between those beads small enough. That means there's a lot of space between them, and aircraft further back have to fly longer and take less direct routes, instead of being tightly sequenced. So anything that reduces my workload gives me more space to string those beads together more efficiently. That’s why I truly believe that the more you reduce the workload, the more efficient and sustainable the operation becomes.
> *(ACC-controller 6, Appendix XIII, May 2025)*

This illustrates a direct operational link between workload and sustainability. Others pointed to indirect links. For example, ACC-controller 1 identified benefits in training: currently, staff shortages prevent ATCos from taking part in projects aimed at improving sustainability. With a lower workload, training could be completed more quickly, freeing experienced ATCos to contribute to such initiatives. ACC-controller 5 echoed this, emphasizing that freed-up time could also be used to develop improved system support tools.

However, ACC-controller 6 offered a critical view, arguing that workload reduction does not necessarily lead to faster training, as ATCos still need to be prepared for high-complexity, high-workload scenarios, especially when CPDLC fails and manual processes take over.

ACC-controller 1 also noted that a reduced workload could enable a small increase in sector capacity – even just one or two flights – allowing more aircraft to fly shorter, more direct routes during peak periods. ACC-controller 2 added that a reduced workload could support outbound traffic efficiency, particularly by enabling aircraft to maintain their preferred speeds and climb profiles (OptiClimb), which is often not feasible under high workload conditions.

ACC-controller 5 summarized the flexibility of reduced workload:

> I think it will free up capacity, and you can allocate that to the human side, meaning we'd have a bit more breathing room and it would be easier, for instance, to free people up. You could also allocate it to system implementation. We know certain things won't work yet, so the human can step in to handle those. We could also say: reduced workload equals more capacity, so let's allow more aircraft in a given time frame. Of course, that ties into sustainability aspects as well – that could be translated into sustainability. So there are various ways to use that capacity. But right now, it's extra bargaining power we don't have. *(ACC-controller 5, Appendix XII, May 2025)*

On the other hand, ACC-controllers 3, 4, 7 and 8 were sceptical of any link between workload reduction and sustainability. They described the connection as ''far-fetched'' or said it felt like ''looking for an answer''. ACC-controller 3 pointed out that individual work styles vary, with some always giving direct routings and others only doing so when absolutely necessary. This was confirmed by ACC-controller 1, who observed that many ATCos are used to issuing directs, and ACC-controller 4, who described a more cautious approach.

Additionally, several ACC-controllers raised questions about the definition of sustainability in operational contexts. ACC-controller 2 explained that they do not consider sustainability while working but rather focus on operational efficiency, for themselves and the airlines. ACC-controllers 3 and 6 stated that efficiency does not always equate to sustainability. ACC-controllers 7 and 8 expressed uncertainty about what sustainable action entails in the OPS room. ACC-controller 7 noted that there are no clear guidelines and suggested investigating the CO_2 impact of radiotelephony versus CPDLC communications.

Interestingly, no correlation was found between a participant's knowledge of CPDLC and their views on its environmental impact or the impact of reduced workload.

Findings
The interviews suggest that:

- CPDLC is viewed by experts as contributing to more efficient and sustainable operations.
- Some controllers see direct and indirect links between workload reduction and sustainability, depending on how the freed-up capacity is allocated – for example, to better sequencing, efficient routing or the development of systems and procedures.
- Others are sceptical, pointing to the variability in controller work styles and lack of operational sustainability guidelines.

For supporting quotes and detailed reference, see Appendices V-XVI.

5 Key findings & recommendations

- The UCO-sequence in iCAS increases ATCo workload due to automatic unanticipated system-driven changes, disrupting the standardized workflow of ATCos, but is expected to improve with better data and can be mitigated with features like skip and bypass.
    - Recommendation: Identify the most relevant trajectory data for accurate UCO-sequence prediction and provide clear training for ATCos on the skip and bypass functionalities.

- Despite transfer workload was rated as low, most participants find CPDLC especially useful for transfers, reducing workload and saving on average 7,7s RT time per flight.
    - Recommendation: Explore the feasibility of using CPDLC for the UCO process and decide on whether planner controllers can handle transfers, to reduce the workload of executives even more.

- LVNL's Workload Model emphasizes objective traffic complexity metrics, but excludes separate contributions of RT, and lacks a method to account for future technologies such as CPDLC, limiting its ability to fully reflect communication-related workload.
    - Recommendation: Develop an approach to integrate communication-related workload – starting with RT – and prepare the model to incorporate CPDLC effects through scenario testing.

- CPDLC helps LVNL provide safer and calmer service by reducing communication errors and easing pilot workload during critical phases like descent and approach.
    - Recommendation: Make ATCos aware of the benefits for safety and service provision, to enhance acceptance and use of CPDLC in the future.

- While most participants believe that implementing CPDLC for transfers does not significantly affect ATCo SA, some concerns were raised about potential impacts on the SA of pilots and fellow controllers.
    - Recommendation: Ensure that CPDLC implementation is supported by intuitive HMI design and provide good training, to build confidence and familiarity.

- The UCO-sequence has no direct impact on sustainability, but iCAS holds more potential if better aligned with reality.
    - Recommendation: Improve the alignment between iCAS trajectory predictions and real-world flight behaviour by incorporating more dynamic and aircraft-specific data, to support more sustainable routing.

- Workload reduction from CPDLC can directly and indirectly support environmental sustainability, depending on ATCo workstyles and the purpose the extra time is used for.
    - Recommendation: Identify how LVNL can most effectively use the time saved through CPDLC, to enhance operational efficiency or support sustainability goals.

6 Discussion

This chapter reflects on the findings presented in Chapters 4 and 5 by comparing them to the existing literature introduced in Chapter 2. Section 6.1 discusses how the results of this study align or diverge from previous research, while Section 6.2 highlights the key methodological and contextual limitations. Since implications have already been discussed in Chapters 4 and 5, they will not be revisited here.

6.1 Comparison to literature

The findings of this study align with and expand upon existing literature on automation and workload in ATM. To begin with, the study's finding that CPDLC contributes to workload reduction and improved safety is consistent with conclusions by Žvinys & Rudinskas (2023), who reported reductions in RT congestion and improvements in communication clarity. This research extends previous work by quantifying average time savings (7.7 seconds per flight) and highlighting the potential environmental benefits of reduced communication time – an angle that remains underexplored in existing literature.

Regarding the theoretical framework of Multiple Resources Theory by Wickens (2002), which posits that operators can perform better when tasks draw from different resource pools, the findings are two-sided. CPDLC, by shifting communication from the auditory-verbal RT channel to a visual-text-based format, redistributes task demand across different cognitive modalities. This can reduce overload in one channel – namely auditory communication – and promote more efficient multitasking, particularly during high-traffic periods. However, there is a possibility that CPDLC might lead to a visual overload, resulting in a potential reduction in SA.

In terms of SA, most participants in this study reported minimal impact from CPDLC implementation, aligning with findings from Wang et al. (2021), who emphasized that the influence of automation on SA is strongly tied to task complexity and interface design. However, this study also revealed concerns about a possible decline in pilots' SA due to CPDLC use – an issue less commonly addressed in previous research.

Both the literature (Metzger & Parasuraman, 2017; Wang et al., 2021) and this study highlight that automation – through iCAS – can introduce challenges when system-driven changes are unpredictable or poorly communicated. This was reflected in participant responses, where experts reported discomfort with unexpected changes initiated by the system, which affected their trust and perceived control.

Finally, as also noted by Langford et al. (2022) and Jazzar et al. (2021), trust in automation appears to be conditional – dependent on factors such as system reliability, transparency, and adequate training. While CPDLC has the potential to enhance operational efficiency, poor performance or limited clarity can reduce trust, resulting in increased workload. This concern was particularly evident in the early stages of the transition from RT to CPDLC at MUAC.

6.2 Limitations

This research faced several limitations that may have influenced the findings:

- **Participant bias** – As is often the case with interviews, subjectivity plays a role. Some participants may have been biased in their responses, particularly the ACC-controllers at LVNL who are strong advocates for CPDLC. Their enthusiasm might have led to overly positive responses. For example, ACC-controller 4 stated: ''The more time you have, the more fun things you can do. If you have to use this argument to get CPDLC at LVNL, please, the answer is 100% yes, it will be incredibly sustainable if we get CPDLC.'' (Appendix XI).
- **Researcher bias** – The researcher selected which parts of the interview transcripts to include, based on perceived relevance to the research question. This subjective selection process might have led to the omission of relevant insights that another researcher might have included.
- **Interview design** – Some interview questions were not phrased sharply enough, which led to varying interpretations by participants, as described in Sections 4.3.1 and 4.3.5. Additionally, follow-up questions varied across interviews, resulting in inconsistent data coverage across participants.

- **Coding limitations** – Due to time constraints and the late scheduling of interviews, coding was done in the final weeks of the research process. This limited the depth and accuracy of the coding. Furthermore, the inclusion of different types of interviews made it challenging to maintain a consistent overview and apply uniform coding across all data.
- **Methodological limitations** – As mentioned in Section 2.3, literature suggests that eye-tracking is a reliable method for workload research. However, due to lack of prior experience with this technique and limited time to gain familiarity, it was not used. Moreover, as explained at the start of Chapter 3, conducting such research with experienced CPDLC users, such as those at MUAC, would have made it difficult to generalize the findings to LVNL due to differences in operational environments.
- **Translation errors** – Some Dutch interview transcripts were translated into English, and certain aviation terms were inaccurately translated due to the informal nature of spoken language. For example, the Dutch term ''kist'' (aircraft) was translated as ''crate'' or ''coffin''. Although the translations were not fully checked for errors, this did not impact the results, as the coding was done using the original Dutch transcripts and all quoted material in the thesis was double-checked.

Despite these limitations, a key strength of this research lies in its multifaceted methodology. By combining direct observations, extensive interviews with relevant experts and ATCos, and quantitative support through voice data analysis, the study offers a comprehensive perspective on the issues at hand. This integrated approach has provided LVNL with valuable insights into the system transition, the implementation of CPDLC, and the resulting implications for controller workload and environmental sustainability.

7 Conclusion

The European ATM Master Plan estimates that improvements in air traffic management operations could reduce CO_2 emissions by up to 6% (SESAR JU, 2024). A portion of this reduction can be achieved through the implementation of Digital ATM. For LVNL, two significant changes are underway: the replacement of the AAA system with iCAS – a trajectory-based operations system – and the shift from radiotelephony to Controller Pilot Data Link Communications (CPDLC). Both initiatives are core elements of Digital ATM.

This thesis aimed to explore the impact of these changes on area controller workload and environmental sustainability, with a focus on the transfer process. The findings suggest that the shift from AAA to iCAS may slightly increase controller workload due to disruptive system behaviour during the transfer process. No direct link was found between the UCO-sequence operation and environmental sustainability, as environmental impact is more dependent on the trajectories themselves than on the UCO-sequence.

Conversely, CPDLC is strongly desired by the majority of controllers at LVNL. It is expected to reduce workload by decreasing radiotelephony time by an average of 7.7 seconds per flight. CPDLC also enhances operational safety and service to pilots by reducing frequency congestion and the risk of miscommunication. Importantly, the associated workload reduction can create capacity for additional controller tasks, which – depending on how LVNL leverages this freed-up time – may directly or indirectly support environmental sustainability and help contribute the targeted 6% CO_2 reduction.

Given these findings, it is recommended that LVNL prioritizes the implementation of CPDLC immediately following the iCAS transition, as it offers clear benefits in terms of workload reduction, safety and potential environmental impact.

8 Reflection

Over the past twenty weeks, I had the privilege of completing my graduation internship in Aviation Operations through KDC at LVNL. I began in early February, and before I knew it, the final week had arrived. Reflecting on this period, I am grateful for the experience, the personal and professional growth, and the many lessons I will take with me into the future.

The start of my internship was marked by a slow pace, primarily due to an undefined research scope. Together with my two company supervisors, we held multiple sessions to arrive at a clear and realistic research question suitable for a twenty-week timeframe. Although this took time, the process was valuable. Through reading, discussion, and exploration, I deepened my understanding of the topic and strengthened my ability to narrow down complex challenges into concrete objectives. I appreciated the support of my supervisors, who not only shared relevant materials but encouraged me to explore further literature independently.

As I've noted in the past, the literature review has never been my favourite phase. In the reflection of my year 3 internship I wrote: ''I really had to think hard about what I disliked about my internship, but I think that would be writing the literature review. I prefer quantitative above qualitative research, and I therefore preferred doing the capacity calculations over diving into the literature. Because of this, I feel that the literature review could have been better and I would want to put more focus on that during my next internship.'' This time, I made a conscious effort to tackle the literature review with diligence and attention, and I believe I succeeded in significantly improving the quality of this section. Despite my personal preference for numbers and data, I came to appreciate the richness of qualitative research, especially through the analysis of interview quotes. This experience taught me that words, when used well, can be just as powerful as numbers in conveying insight.

That said, the project was not without its challenges. I realized somewhat late in the process that interviews with ACC-controllers would be essential to the research. This late insight impacted my timeline, forcing me to work intensively toward the end. In hindsight, I would have benefited from identifying the need for these interviews earlier on. Improved foresight and proactive planning are lessons I will definitely carry forward into future projects.

Throughout the internship, I maintained open and effective communication with both my company and AUAS supervisors. At times, their feedback differed, but I took initiative to discuss the differences, clarify expectations, and reach common ground. This experience taught me the importance of clear communication, especially when navigating multiple stakeholders with varied perspectives.

I also enjoyed working alongside my three AUAS co-interns. We created a supportive and fun environment – complete with energizing foosball matches – and were always ready to help each other out. Our collaboration and exchange of ideas were both motivating and productive.

One of my strengths during the internship was my work ethic. I was highly motivated to deliver results that would be of value to the company. Even when the workload intensified toward the end, I remained focused and committed to meeting the objectives. I was proud to create a solid, well-structured report that is both professional and persuasive.

This internship has left me with several valuable lessons:

- Allow time in the beginning for scope definition, as a strong foundation saves time later.
- Don't underestimate the value of qualitative insights.
- Plan interviews and data collection as early as possible, and leave room in the schedule for unexpected changes.
- Maintain clear, open communication, especially with multiple sources of feedback.
- Stay adaptable and reflective – even when things don't go as planned, there is always an opportunity to learn and grow.

In conclusion, I am deeply thankful for the opportunity to work with LVNL and KDC. I'd like to thank my supervisors Koos, Evert, and Catya, as well as all the people who supported me through interviews, observations, and feedback. This internship has been an incredibly valuable experience, and I am proud of the progress I've made!

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