Design, evaluation and acceptance of a visual support tool for Air Traffic Control

Stephanie Wiechers

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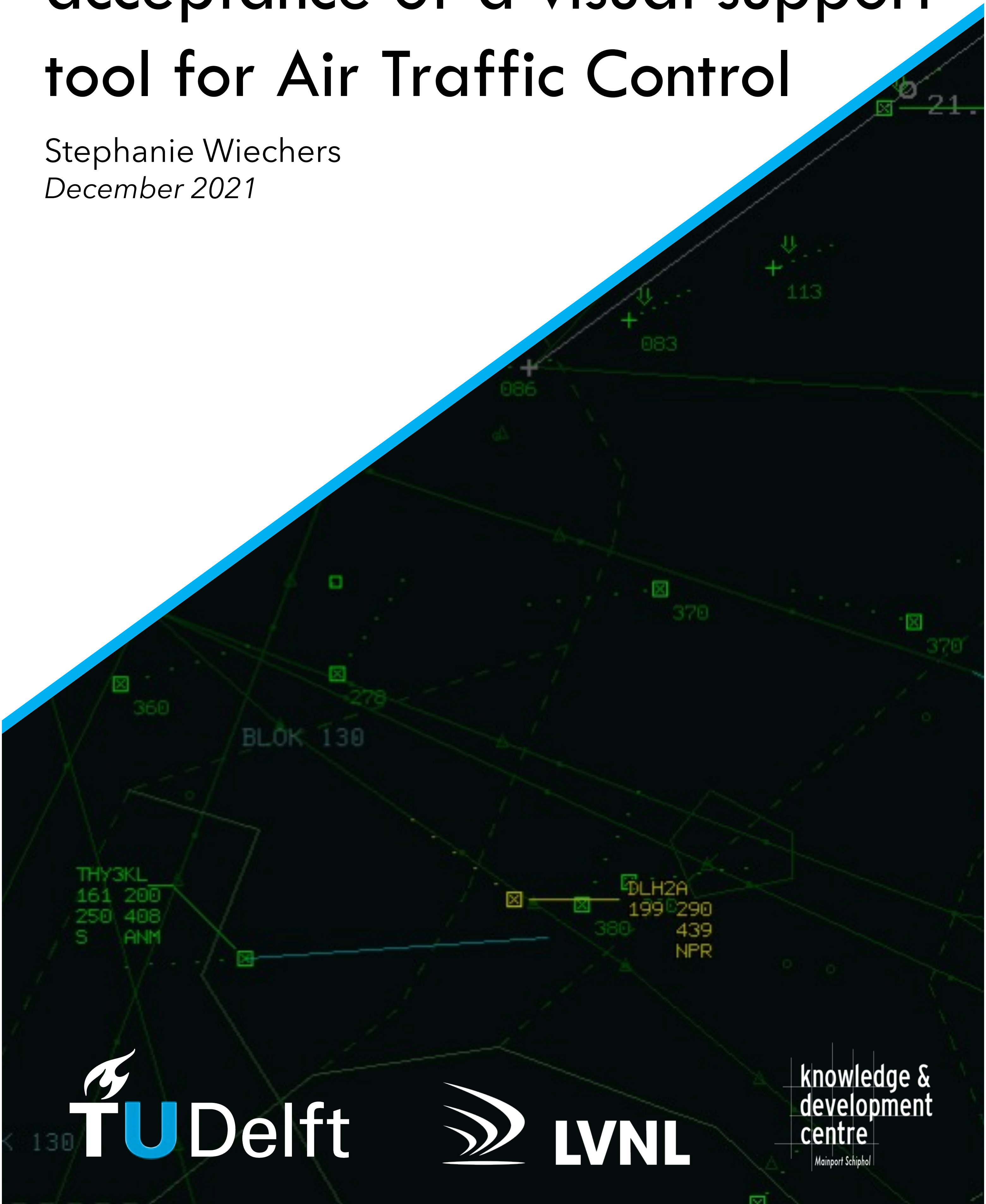

TU Delft LVNL knowledge & development centre Mainport Schiphol

The cover page photo is a radar screen image taken at LVNL. Credit: Ferdinand Dijkstra.

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Design, Evaluation and Acceptance of a Visual Support Tool for Air Traffic Control

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Preface

This report concerns the research conducted in the light of obtaining two masters at the Delft University of Technology. The project was conducted with the objective of researching the topic from two different angles and writing two theses: one for the MSc Aerospace Engineering, specialization Control and Simulation, and one for the MSc Communication Design for Interaction. The thesis project was started on September 1st, 2020 and will be defended on December 22nd, 2021. I would like to thank several people who have contributed to this project. First of all, my supervisors from TU Delft, Dr. Ir. Clark Borst, Prof. Dr. Ir. Max Mulder, Dr. Ir. Maarten van der Sanden, Ir. Gijs de Rooij, Drs. Ir. Caroline Wehrmann and Dr. Ir. René van Paassen, who have guided me though the process of writing a thesis, providing me with useful insights, feedback, cheerfulness during meetings and motivational talks at the right moments. Second, I would like to thank Ferdinand Dijkstra, for being the project supervisor from LVNL and providing me with data, information and practical knowledge. I am also very grateful for his constant support and enthusiasm, and for the opportunity to work together. Finally, I would like to thank all experiment participants from LVNL, and a special thank you to Jorien Dijkstra and Jonah Bekkers, who not only participated in the experiment but also gave me extremely valuable insights into the world of ACC and holding support.

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Summary

This study has researched what are defining factors on the attitude toward a new technology within the group of Area Control (ACC) at Luchtverkeersleiding Nederland (LVNL) and how these factors shape an Air Traffic Controller's (ATCo) attitude toward the technology in an exploratory way. The outcomes of the research suggest that dominant factors are result demonstrability, output quality, job relevance, subjective norm and (timeliness of) involvement in the development process.

First, the work domain of air traffic control and the functioning of holding patterns were researched and a description of these things was given, based on interviews with air traffic controllers and on literature. It was found that the largest challenge when holding at LVNL is adherence to Expected Approach Time (EAT), and that this is caused by two things: the first is a lack of accurate and integrated information on the impact of a control decision on EAT adherence, the second is that current practice of ATCos is to aim for a 2:00 minute deviation from the EAT, which is the current error margin they are allowed to operate on.

It was found, based on interviews with two professional area controllers and one other expert from LVNL, that in current practice an ATCo makes estimations of when to give a turn-to-IAF command based on a rule of thumb with a holding loop timing of four minutes and by extrapolating the history dots of the aircraft. However, analysis of historical holding pattern data shows that lap times often take six or seven minutes and that wind severely influences the in- and outbound ground speeds, making both the four-minute loop time and history dot extrapolation unreliable estimators. A support tool was designed that gives a prediction of the time it takes to reach the IAF from different locations, taking into account aircraft characteristics and wind. The new tool was designed such that it is in accordance with the layout and style of present LVNL systems. It involves two things. First, a prediction of the EAT adherence error upon giving an immediate turn-to-IAF command in the form of a delta-T in the aircraft label. Second, and a prediction of the turn-to-IAF locations at which an EAT adherence error of +120s, +110s, ..., 0s, 10s, ...-120s will be achieved, in the form of colored dots (ECOL dots) on the vertical view and the top view radar screen.

The social situation at LVNL was described based on interviews with two professional area controllers and one other expert from LVNL. Indications were found for two opposite things. On the one hand, that (some) ATCos are willing to innovate and actually take initiative in innovation processes, and on the other hand, that (some) ATCos have a strong resistance toward technological system innovation. Regarding collaboration between groups, it was found that the relation between ACC and Approach Control (APP) that is characterized by skepticism on the skills of the other party. Finally, it was found that ATCos take pride in the way they execute their job and are willing to work hard to achieve the goals they believe match their job description. In doing this, ATCos have indicated to value their autonomy and the idea that the effort they put in actually adds value for the full Air Traffic Control (ATC) process.

Besides interviews to describe the situation at LVNL, case studies were done to research innovation in other organizations that showed similarities to the context of LVNL. Three things were found. First, ensuring people can contribute and influence the innovation from early stages of the innovation process is a promising factor that seems to influence a person's attitude toward using the innovation in a positive way. Second, the lack of implementation of innovations has caused skepticism under ATCos. Third, the TAM is a suitable framework to further explore how area controllers at LVNL's attitude toward innovations manifests itself.

To be able to use the TAM in the framework, first, literature on the TAM has been reviewed. It has been found that there are different versions of the TAM that include or exclude several variables. For the present research, the most suitable version of the TAM was determined to be the TAM2, using the following external variables: result demonstrability, output quality, job relevance, image, subjective norm, experience, voluntariness, age. Next to the TAM in the framework, literature was reviewed on several factors surrounding the interaction with support systems, where autonomy and trust were found to be of a valuable contribution to the framework in the present research.

The operationalization of the framework was done using survey questions, a semi-structured interview, and results from letting ATCos interact with the system innovation concept (the tool). It was found that some factors of the TAM could be questioned straightforward in either the survey or the interview, while for other factors it was necessary do design multiple questions and depend on the type of answers given by the participants. Since the research is exploratory, it was decided to keep the interview setup semi-structured to ensure

participants would be able to outline defining factors for their attitude toward innovation relatively freely, instead of needing to keep them within a predefined set of factors.

From the performed case study, where 10 ATCos participated in an experiment in which they had to manage two holding scenarios, with and without the tool, the following things were learned. First, three of the external variables defined in the framework played the largest role for participants' perceived usefulness of the tool were result demonstrability, output quality and job relevance. Second, it was found that subjective norm impacts the attitude towards use for the participant group. A mismatch was found between the participants' attitude toward innovation in general and the way the participants thought their colleagues viewed system innovations. Subjective norm was also found to be of influence on the participants personal objective in the level of EAT adherence they aim to obtain in their day-to-day work. Third, participants linked the external variables not only toward perceived ease of use and perceived usefulness, as is the case in the TAM, but also to attitude towards use. Finally, it was found that participants appreciated being part of an innovation process rather than being presented with the final solution, which was further improved by the fact that the concept was visibly not perfected yet (even though it was functioning, it was clear it was still under development and showed some minor issues in e.g., the stability of the computer program).

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Nomenclature

ACC Area Control.
APP Approach Control.
ATC Air Traffic Control.
ATCo Air Traffic Controller.
ATM Air Traffic Management.
ATP ARTIP.

CTA Control Area.

DCO Departure Controller.

EAT Expected Approach Time.
EID Ecological Interface Design.

FL Flight Level.
FMS Flight Management System.

IAF Initial Approach Fix.
ICAO International Civil Aviation Association.
ID Identifier.

KDC Knowledge Development Centre.
KNMI Koninklijk Nederlands Meteorologisch Instituut.
kts Knots.

LVNL Luchtverkeersleiding Nederland.

RQ Research Question.

SPL Schiphol.
SRK Skills, Rules, Knowledge.

TAM Technology Acceptance Model.
TMA Terminal Control Area.
TWR Tower.

U.S. United States (of America).
UTA Upper Control Area.

WDA Work Domain Analysis.

1 Introduction

The final stage of flight, before arriving at the destination airport, is when the aircraft passes its Initial Approach Fix (IAF) and starts the approach phase. It has already descended and slowed down significantly at that moment, and is ready to start the landing process. However, in some cases there is no capacity for landing yet. In this case, it needs to be delayed, either by vectoring or by flying a holding pattern at the location of the IAF. In Figure 1.1 a schematic overview is given of the pieces of airspace an aircraft passes through and the trajectory it takes in the final stage of flight (after the cruise phase where it has covered the majority of the distance traveled).

Standard practice at Dutch Air Traffic Control (LVNL), operating at Amsterdam Schiphol Airport, currently avoids holding under regular conditions. When, however, extreme conditions (adverse weather, emergency, delays of +7 minutes) dictate holding as the only option left to absorb delays, the systems offer little support to their operators[1]. This results in low predictability and large deviations from the planning during an already extreme scenario. Current standard practice allows for a four-minute window in which the IAF can be crossed around the Expected Approach Time (EAT), a condition that is currently not always met in extreme situations.

The goal of an Area Controller who is responsible for managing a holding stack is emptying the stack from the bottom. Aircraft are to exit the stack at the IAF. A planning is made regarding the EAT of each aircraft by a planner (so one person is responsible for this), which is the exact moment they are to cross the IAF before continuing approach to the airport. Adhering to this planning means higher predictability in the Terminal Control Area (TMA), less need for vectoring or other means of delaying aircraft in the TMA, and a traffic flow that has been optimized for runway capacity. When the EAT is not met accurately, this comes at the cost of less predictable traffic (jeopardizing safety) and more detours and vectoring (at the cost of efficiency and increased workload for Approach Control (APP)).

Because of this, there are two main tasks when managing a holding stack: lowering aircraft, where maximum one aircraft can be present per flight level, and ensuring an aircraft turns toward the IAF at the right moment to comply with the planning. In the case of the second task, there are many factors and conditions

[1] Source: interviews with Area Controllers at LVNL (2020)

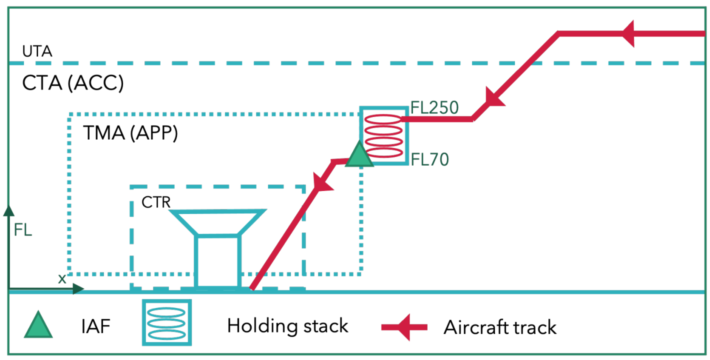


Figure 1.1: Trajectory including holding

that cause a high level of complexity. These, in turn lead to unreliable estimations of timing, causing low EAT adherence. From analyzing real-world holding data (see LVNL [2019]), it was found that the main complicating factors are wind, aircraft type and pilot delay. These factors cause the lap time of holding loops to vary considerably.

1.1. Problem Statement

The need for a decision support tool is imminent: it can give accurate estimates of time where current displays require the ATCo to make an estimation based on history dots, and provide a trigger as to what aircraft require the controller's attention. Yet a vital part of improving EAT adherence using a decision support tool is the willingness of individuals to work with this tool. From interviews with Air Traffic Controllers (ATCos) (LVNL, 2020) and people who have worked with this group (F. Dijkstra, KDC, 2020; M. van Apeldoorn, NLR, 2021) it becomes clear that the attitude ATCos have towards system innovation is generally low. In this case, system innovation refers to innovations in the technological systems (e.g., computers, radar screens) that are used within ATC, and system innovation refers to changes or additions to these computer systems that are meant to improve the way people work. People are skeptic due to long development processes (5+ years) with delays that extend over the course of multiple years, complete lack of implementation, and a disconnect between controller wishes or demands and system functionality. The reason for this is described by people within the organization as “semi-governmental organizations and technological innovations not going hand-in-hand but through a bureaucratic process” [Personal communications with Area Controllers, 2020]. This can be accounted for by shifting priorities (changing budget, time, people and other resource allocations) and the fact that every system innovation has to be tested extensively before being operative.

Earlier research in the field of holding support tooling by Mac an Bhaird et al. [2020] was geared at aligning aircraft at higher levels in the stack. However, LVNL radar data shows that the duration of a holding loop is unpredictable, meaning that the predicted EAT adherence error will increase again when lowering in the stack [LVNL, 2019]. The proposed display in this study was not an augmentation to current systems but an entirely different display concept; from interviews with F. Dijkstra, KDC (2020) it became clear that acceptance of this solution is low. Other studies conducted at LVNL have focused on other parts of flight and/or control task, e.g. turn-to-Instrument Landing System (ILS) (see Dirkzwager et al. [2019]) and strategic conflict handling (see Bakker et al. [2019], Ottenhoff et al. [2020]). These studies all show difficulties with finding ATCos who are willing to participate in proof-of-concept experiments (respectively 2, 0, 4 participants from the actual target user group on a total of 100 target users). The factors that determine the outlook of ATCos on these innovations have not been studied in these researches.

This study introduces a first concept for a decision support tool that can be implemented as a non-critical (not critical for safety) augmentation to Air Traffic Control (ATC) systems in a modular and adaptive manner. A decision support tool in this context is a technological innovation that supports the end-user (in this case, an ATCo) in the tasks they need to perform by providing additional information. With modular and adaptive is meant that it will introduce several features that can be added to the systems that can, in the final stage of implementation, turned on and off as the ATCo wishes to use them. It does this in the form of a partial solution space that hinges on an extended leg control strategy, combined with a trigger, namely a countdown timer, and an additional support element to reduce screen clutter. The main drivers of the design are increased performance, workload and solution predictability. This part of the research is identified under the technical problem in **??**. For the concept tool, the initial attitude towards use and the factors that influence an ATCos attitude toward the innovation are researched through a survey and interview (method in Figure 1.2). This is done to find out how people within the group of area control currently view the introduction of a new technology and why their attitude is such as it is. Findings from the tool evaluation (measuring performance on EAT adherence with and without tool), survey questions and interview (coded quotes), an answer to the research question (see below) is to be formulated.

The long-term goal beyond the scope of this research, is to determine how these area controllers can get a more positive attitude toward such an innovation. The factors that follow from exploring technology acceptance in this research are to be used as a starting point for reaching this long-term goal.

The concept is evaluated using an extreme yet realistic holding scenario at one of Schiphol Airport's holding fixes. The scenario involves a large amount of traffic and relatively strong winds, as to represent a situation that strongly benefits from a decision support tool; the reason for this is to let the participants first-hand experience the added benefit of the support tool. The display design is implemented in and tested using Delft University of Technology (TU Delft) developed medium-fidelity ATC simulator SectorX. Questions are asked

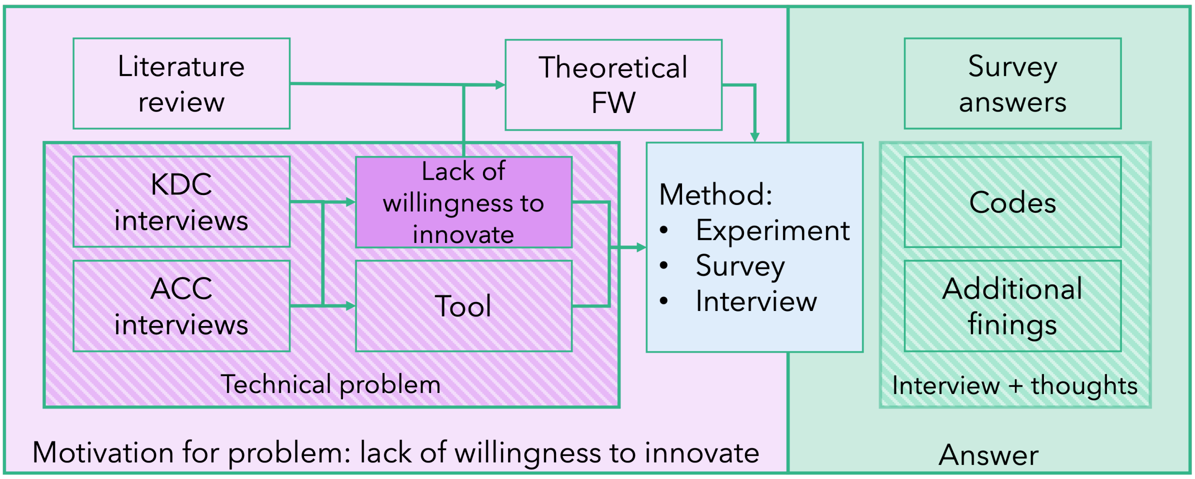


Figure 1.2: Research process: from problem definition to answer. On the left side (pink) is all preparatory research; in the striped box (pink) the approach to the technical solution or creation of the new tool; in the middle (blue) the method for evaluation of tool and factors that influence attitude toward the innovation; on the right (green) the findings that will be used to answer the research question.

throughout the course of the evaluation; at the end the participants are interviewed.

The problem that is to be solved by this research is:

> Within the group of ACC at LVNL, people are generally known to have a negative stance toward system innovations. The introduction of an innovation triggers resistance. Factors that can determine the current attitude and that can potentially contribute to a more positive outlook on system innovations are unknown.

The main objective of this research that follows is:

> To determine what factors in an innovation process shape the attitude towards the innovation and intention to use the innovation, with the objective of creating a more positive attitude towards the innovation itself and intention to use the innovation.

The research question is:

> What are important factors that determine the attitude towards a new technology within the group of ACC at LVNL and how do these factors shape an ATCo's attitude toward the technology and intention to use?

It should be noted in relation to the objective that there is a practical goal, namely improving ATCos' stance toward technological system innovations, ensuring they are more willing to collaborate in projects and in the end have a positive intention to use systems that are being developed. Even though the problem at hand might seem quite simple at first glance, the amount of variables in researching how the current interfaces can better support area controllers in doing their job while triggering the ATCo to engage with the system are endless. For example, there is the socio-technical system of LVNL, including many different technical, computer and radar systems, there are possibilities to change the way people collaborate, the structure of dividing task responsibilities, the possible control actions, communication with pilots. Therefore the scope of the research is actively focused on certain topics, from which sub-goals follow.

The first objective is to gain knowledge about current LVNL systems, procedures and practices, specifically in the context of holding patterns as that is the situation in which the tool should operate. This is important as the outcome of the research should form a basis for LVNL to improve EAT adherence within the present interfaces and systems.

Secondly, the interface should visualize the boundaries and margin of the control action possibilities, showing the implications of certain control actions, allowing the controller to stay in charge of the situation. In order to bound the scope of the research, the set of considered solutions in the visualized tool shall have the aim of being both comprehensive as well as limited to that what can be reasonably considered logical practice. The sub-goal is to determine how to predict and visualize the implications of these control actions.

The third sub-goal is to determine the context of the social problem, gaining insight in what is important to area controllers in their work, how their stance is toward EAT adherence, how they view their work domain, and understand how innovations take place in organizations like LVNL.

The fourth sub-goal is to understand how acceptance of technology is defined in literature and to operationalize this within the context of the present research.

The fifth sub-goal is to gain insights into factors that influence the ATCo's attitude toward the present innovation as well as their intention to use the proposed concept through a case study.

1.2. Research Questions

This research aims to explore how the target users (ATCos) attitude toward an innovation is shaped by these factors. This has the broader goal (beyond the scope of this research) of being able to improve it in the long term. The factors are explored through a case study, using a concept for new tool and letting the target users engage with it. In order to reach the aforementioned objective, several sub-questions need to be answered first, taking an integral approach to the research and considering the end-user to be the most important driving factor from the beginning onward.

1. What information would support an area controller in ensuring an aircraft can adhere to a desired EAT upon passing IAF?
2. How can the boundaries and margins of the control problem be best represented?
3. How can the social situation at LVNL be described in relation to aspects that are of interest to the research (innovation, EAT adherence, collaboration between groups, perception of job responsibilities and goals)?
4. How can literature support exploring the problem and how should definitions from literature be operationalized in the present research?
5. What factors have a relevant influence on an ATCo's attitude towards the proposed system innovation? (The goal is to explore relevant and dominant factors, not to generate an exhaustive list of all factors that influence an ATCo's attitude toward the innovation)

The research questions above can be used to reach the sub-goals in the way that they (1) ensure the foundations for the project are present by gaining relevant information on the work domain of LVNL and how holding stacks are controlled, (2) design an innovative concept that can be used in a case study to test for controller attitude toward the innovation, (3) determine the social context of the attitude toward technological system innovation within LVNL, (4) make sure the framework in which the final objective (explore what influences an ATCo's attitude toward technological innovation) can be met is defined using literature and operationalized, (5) evaluate the concept for the tool (innovation) from which finally conclusions can be drawn, and by that lay the foundations for improving attitude toward innovation within LVNL in the future.

As other research has already been (successfully) performed on visual support tools for ATC to improve situational awareness, workload, efficiency and performance in other phases of flight, this research is seen to be feasible as long as the scope is limited to encompass an amount of topics and parts that can be researched in the period envisioned for the research. In other words, in consideration with LVNL and TU Delft a set of realistic assumptions and essential details is composed to ensure that the research outcome is useful and complete enough, as well as delivered timely. The long-standing contribution that this research will contribute to the body of knowledge are insights in how a visual support system can improve the performance of the controller, and insights on how the Technology Acceptance Model (TAM) can be used to ensure ATCos have a more positive stance toward system innovation.

1.3. Report Structure and Reading Guide

This report is structured as follows. Every chapter starts with a method section. This contains information on how the presented information was collected. Followed by this section are findings and where relevant, an interpretation of these findings. The information in the chapters is the following. First, a description of the work domain of air traffic management in general and LVNL in specific is given in Chapter 2. A detailed explanation is given on holding patterns, both in theory and in practice, followed by the current available tooling and common control strategies. In Chapter 3, the methods, assumptions (based on literature review) and algorithms used for trajectory prediction are described, followed by the proposed interface concepts. Then Chapter 4 outlines the basis of the communications problem, providing insights into the social situation at LVNL and outlining several case studies of innovation and change at other companies that share some similarities with LVNL. Chapter 5 provides the theoretical framework of the research and its operationalization within the context of improved EAT adherence at LVNL. This is followed by the description of the case study in Chapter 6, outlining the method, study results, and interpretation of these results. A final conclusion is presented in Chapter 7, followed by a discussion on the research method, its reliability, and the broader-scale implications of this research.

2

Background: Air Traffic Control and Holding

The work environment of Air Traffic Control (ATC) has become more complex every year with increasing volumes until the Covid-19 crisis, resulting in a crowded airspace and high workloads. In this chapter, the way ATC works is explained, including the various roles people have and the way the airspace is divided. The focus here will be on LVNL and Schiphol Airport, since the research conducted aims to propose a display that LVNL can implement. The research aim is to determine how an innovation is more positively welcomed by ACC at LVNL, which is explored under the presence of an innovation in the form of a proof-of-concept of a proposed tool. The aim of the proposed tool, to increase Expected Approach Time (EAT) accuracy at the Initial Approach Fix (IAF), is a result of the extremely tight planning of Schiphol Airport caused by the high traffic density and noise constraints.

After explaining the airspace structure, the chapter starts zooming in more and more, first by narrowing down to holding patterns, then by zooming in on the objectives of air traffic control, and finally by describing in detail the functioning of LVNL and specifically the way they manage holding patterns. These sections are provided to give a complete background on the subject, in such a way that the different types of intended readers will all be knowledgeable of air traffic control and of holding stack management after reading this chapter.

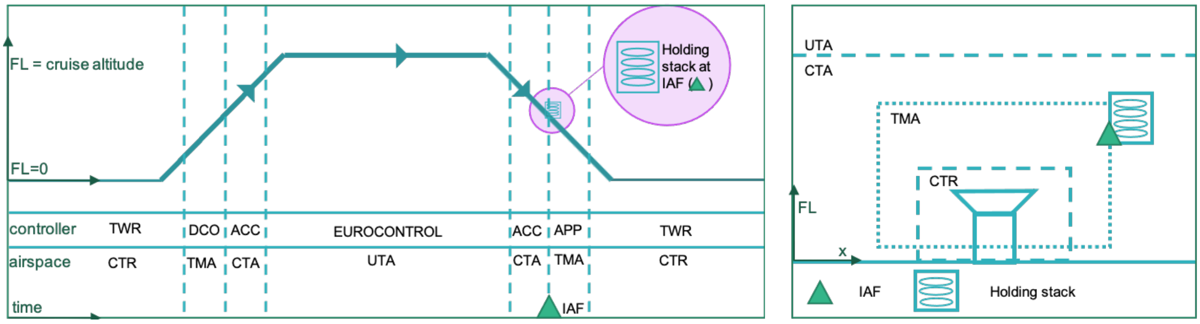
2.1. Method

The method for gathering the information presented in this chapter is the following. Unstructured interviews were held with F. Dijkstra, who has worked on many innovation projects at LVNL, to get an initial view on the problem. After that, research was done online and more interviews were held with Dijkstra as well as with three people who have previously conducted a research on support system innovation at LVNL to gain insights in how the organization works and understand the terminology, airspace structure and roles ATCos have within LVNL and their matching responsibilities. It was found that there is little literature describing the airspace above the Netherlands, as well as a lack of other sources. Therefore, the majority of the information was gathered through interviews. After clarity on the problem boundaries (airspace structure, holding pattern flow) was obtained, unstructured interviews were held with two area controllers from LVNL to determine the exact problem surrounding EAT adherence in holding.

To become more familiar with holding stack management at LVNL, an ATCo managing a holding stack in the simulator facility at LVNL was observed. Information about the present work environment and technological systems available to an ATCo was obtained by observing the technological systems present at the work environment and interviewing (unstructured) ATCos about this. Finally, screenshots of the radar screens at LVNL were analyzed to gain more information about the information currently presented on the radar screens.

2.2. Airspace Structure and Control Flow

The global airspace is divided into multiple sections, based on both their height expressed in Flight Level (FL, the aircraft's altitude at ISA pressure per 100ft) and their lateral position, considering points of interest on the



(a) Airspace division per stage of flight

(b) Airspace division around an airport

Figure 2.1: Schematic overviews of airspace division, not to scale

ground such as distance to airports and military terrain. Per country the exact limits of each boundary differ; the following numbers refer to the division in the Netherlands. First there is the Upper Control Area, which considers the airspace above FL245 and is, in the case of the Netherlands, controlled by Maastricht Upper Area Control Center, which is part of EuroControl. The airspace below is divided into Flight Information Regions, where in this case the EHAA FIR is considered, spanning the Netherlands and a piece of the North Sea. Area controllers from LVNL are responsible for this part of the airspace; it is sub-divided into five smaller regions to ensure a manageable workload. Within the FIR, surrounding any airport is the Terminal Control Area (TCA), responsible for guiding the aircraft through the approach phase, until they are handed over to the Tower (TWR) which is the control zone on the ground, responsible for taxi, landing and departure. In Figure 2.1a the different parts of airspace are shown in relation to the different stages of flight (not to scale), and in Figure 2.1b the division of the airspace around an airport is schematically shown[1].

Analogous to the different parts the airspace is divided into, different controllers are responsible for the air traffic at different locations and with that, different phases of flight. Looking at it from the perspective of a pilot going from A to B, the aircraft starts of at an airport where the Tower (TWR) is responsible. After take-off, the aircraft enters the Terminal Maneuvering Area and is controlled by a Departure Controller (DCO) during the first phases of climb. When it crosses the boundary of the TMA, it enters the CTA and an area controller is responsible for ensuring separation between aircraft in these zones. As the aircraft continues to climb towards its cruising altitude, it will exit the CTA and enter the UTA where in the case of the Netherlands and Europe, Eurocontrol takes over the responsibilities. When an aircraft is approaching its destination, the same stages are passed in the reversed order, and the same divisions between controllers are made [Borst, 2019]. However, there are two differences: first of all, a holding stack may be present at the Initial Approach Fix (IAF) where the aircraft has to wait before entering the TMA; such a trajectory is visualized in Figure 1.1. In that case, an area controller will be assigned to this holding stack, regulating traffic. Around Schiphol Airport the area controller will feed the aircraft into the TMA and therefore determines at what moment they pass the IAF. One more thing to note is that upon departure a DCO is responsible while for approach the role is called APP. However, at Schiphol these tasks are not separated; generally there will be four approach/departure controllers working at the same moment, managing the traffic in the TMA, plus one planner[2].

2.3. Around the IAF: Holding Patterns

When an aircraft is inbound to land at Schiphol, it is first guided by the responsible area controller toward its IAF. The dense air traffic and lack of support tools make it difficult for the Area Control Center (ACC) to achieve a high accuracy in EAT adherence, which currently results in a higher workload in the TMA as approach controllers have to match the incoming traffic with the landing capacity by e.g. vectoring. This section will explain how holding patterns work and how they can be used to influence the moment an aircraft passes the IAF.

There are three holding stack locations around Amsterdam Schiphol Airport, see Figure 2.2. The red lines represent the routes by which aircraft fly toward the holding, plus an indication of the holding pattern geometry. The zoom panel shows the holding at IAF ARTIP, as well as a possible route to Schiphol. A trajectory in-

[1]Source: interviews with LVNL, Knowledge Development Center (KDC) and the aeronautical information packages from LVNL, see `https://www.lvnl.nl/eaip/2021-05-06-AIRAC/html/index-en-GB.html`

[2]Source: interviews with LVNL and F. Dijkstra, KDC

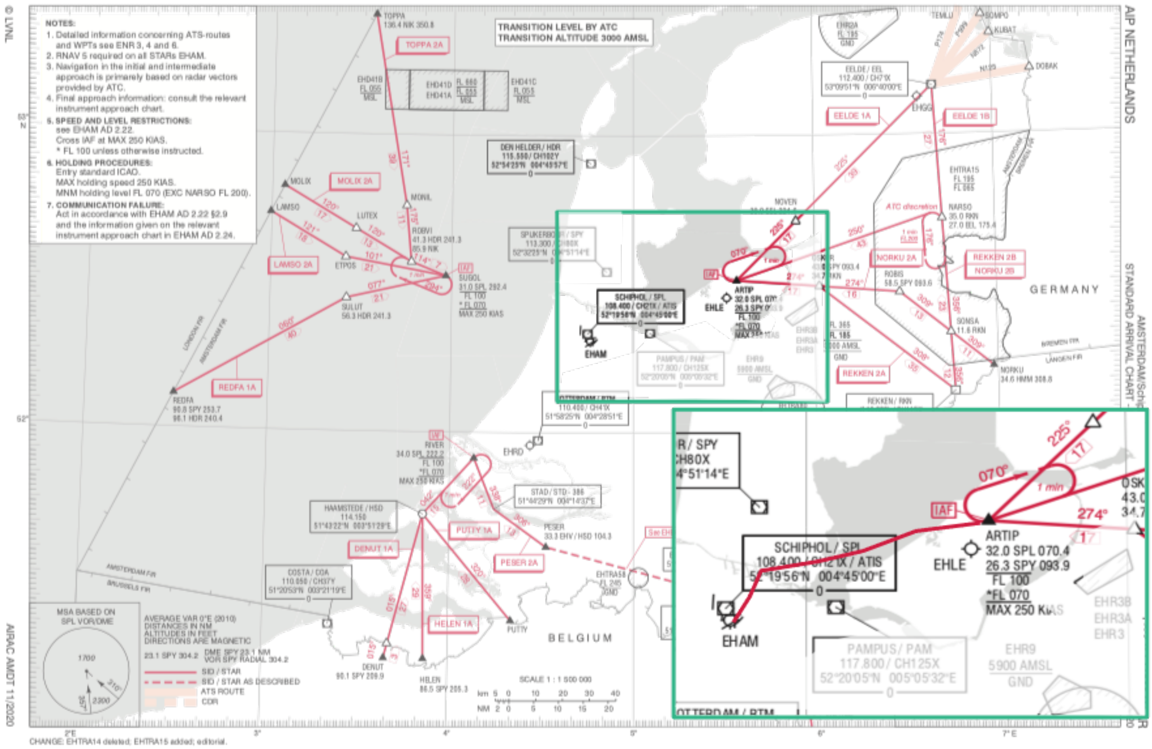
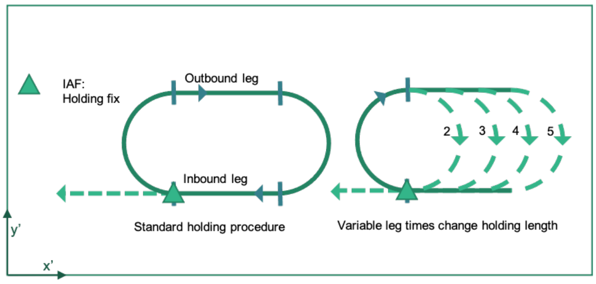


Figure 2.2: Holding stacks around Amsterdam Schiphol Airport LVNL

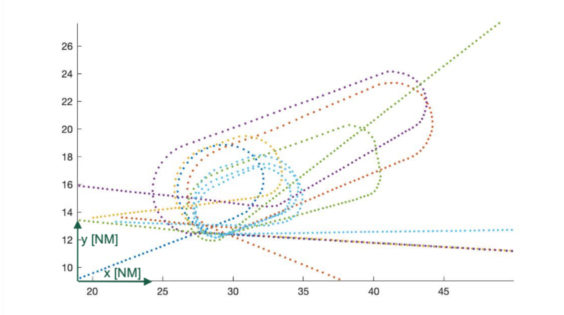
volving a holding pattern in visualized in Figure 1.1. The theoretical geometry of a holding pattern, as shown in Figure 2.3a, consists of a holding fix, two legs and two turns. Under different conditions, for example due to wind or shorter leg times, the precise shape of the pattern that is flown will vary; changing leg length can alter the total holding loop length as is visualized by the numbers in Figure 2.3a, indicating the standard loop time[3] in minutes for no leg, half legs, full legs <FL140, full legs >FL140. It is standard practice to fly a holding pattern with right-hand turns at most airports, including Schiphol. An aircraft enters the holding at the top of the holding stack. It starts flying holding loops which have a standard time of four or five minutes: one minute for each leg below FL140, 1.5 minutes for each leg above FL140 and rate 1 turns [SKYbrary]; the standard IAS flown at holdings around Schiphol is 220kts. However, each pilot is allowed to choose at what speed she flies a holding pattern and therefore not only leg time, but also turn time varies. As the assigned holding stack controller empties out the stack from the bottom, she lets the aircraft in the stack descend to lower flight levels. Aircraft leave the holding pattern at the Initial Approach Fix (IAF) between FL70 and FL100, where they enter the TMA.

As in real life holding speeds vary and winds are nonzero, the actual geometry, duration and size of holding patterns vary as well, as visualized in Figure 2.3b. Both in theory and in practice, the timing of one holding loop can be influenced by altering the leg times, while turns have a fixed duration due to bank angle constraints. This is especially relevant in the final stage of the holding, when the EAT is nearing: then the ATCo can decide to actively influence the pattern by changing the length of the outbound leg, by giving a turn to IAF command. Current EAT adherence is required to have a 2 minute accuracy, which is not met in some extreme cases[3]. From the perspective of Approach Control in the TMA, a higher level of adherence to EAT is desired most, followed by a target velocity (preferred TMA entry velocity is 250kts) and target flight level (preferred flight level is determined by IAF/runway combination)[3]. All of these things result from the short time-span aircraft spend in the constrained space of the TMA, creating limited room for deviations and flexibility.

[3]Not influenced by external factors such as wind



(a) Theoretical holding pattern



(b) Plot of actual holding patterns [LVNL, 2019]. Each color represents one aircraft.

Figure 2.3: Theoretical and practical holding patterns

2.4. Objectives of Air Traffic Control

The International Civil Aviation Association (ICAO) defines its vision for Air Traffic Management (ATM) systems as:

> To achieve an interoperable global air traffic management system, for all users during all phases of flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements [ICAO].

At LVNL these pillars are translated into their corporate strategic goal: "becoming the world's best air traffic control organization in terms of safety, people and delivery reliability [LVNL, 2020]". These objectives are actively pursued with initiatives on improving safety through encouraging employees to identify risks and develop safety and security management systems, revise departure and arrival routes to reduce noise and emission effects for the people living around Schiphol, and implement time-based separation to increase capacity and allow for higher delivery reliability [LVNL, 2020].

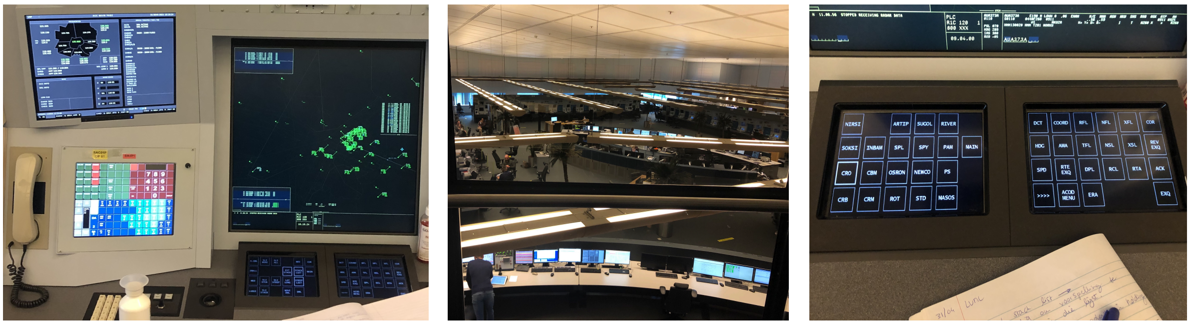
It is in line with these objectives to steer toward a higher EAT accuracy. Based on the above objectives, a support system should have several characteristics. First, it should allow air traffic controllers to identify risks, and therefore it is important that the system gives insight into the real-world situation rather than only present a solution. Second, the most important driver in ATC are people: therefore a system should always keep its end-user (Area Control) in mind, and should be designed in such a way that it triggers people to engage with it. Especially in the domain of ATC, it is known that controller acceptance is generally on the low side (see Bekier et al. [2012]). That means technology acceptance is a critical factor in the success of improving EAT adherence.

The Future of Holding at LVNL At Schiphol airport, the goal is not to turn holding into a standard practice. The main reason for this is efficiency, as holding costs additional fuel[4]. Simultaneously to this research, other research projects are executed that have the aim to improve EAT adherence in other (non-holding) situations. Together, an overall higher EAT adherence will allow for flying fixed arrival routes in the TMA, which is the main goal of LVNL[4]. These routes will allow for more efficient flight trajectories in the TMA and lower noise pollution, which is one of the main drivers for the limitations on traffic at Schiphol airport.

2.5. Work Environment

In the current situation, the Air Traffic Controller has its own workspace in the so-called "zaal" (i.e. room), shown in Figure 2.4b. The different teams, controlling different parts of the airspace all have their own physical location. On the left is approach control, sitting in a circle such that it is easy to speak to everyone else working at APP at that moment as it is such a small space where they have to manage the traffic. In the middle at the straight desks are the military controllers. Closest to the photographer is a planner workbench, just like the oval workbenches to the right of the military controllers. Finally, in the back of the room and to the right are the ACC desks. These are not positioned in a circle but next to each other, as for ACC it is more common to only need to work together with the people controlling the airspace right next to theirs.

[4]Source: interviews with F. Dijkstra, KDC



(a) ATCo workplace (b) The “zaal”: work domain of ATCos (c) Command panel

Figure 2.4: Work domain of the ATCo, photos taken at LVNL (March 2021)

Each ATCo has their own workplace, which is flexible and dependent on the part of the airspace they are managing at that moment. The amount of ATCos working at a moment in time is dependent on the occupancy rate of the airspace. At peak hours, sectors become smaller and more controllers are needed; when holding stacks are installed due to e.g. weather conditions or an emergency, separate holding stack controllers are assigned who then also get their own desk. The layout of the radar screen varies, depending on the type of activity: in a regular situation, so without holding, the radar screen only shows the top view (like in Figures 2.4a and 2.6a) and the stack list, see Figure 2.5a. When a couple of aircraft enter the holding, but the ATCo still manages those aircraft next to the other traffic in its sector, the ATCo often chooses to use the extended stack list shown in Figure 2.5b. Finally, if a dedicated holding stack is installed, the ATCo will have access to the vertical view.

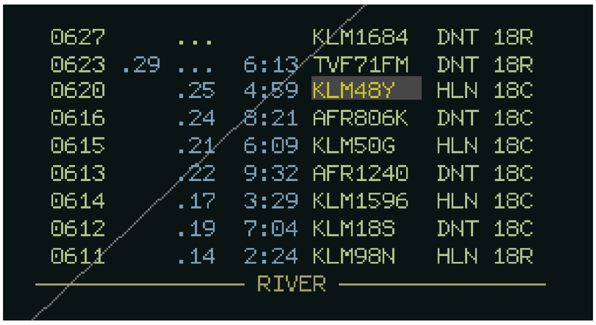
The vertical view is only available to a dedicated holding stack controller. According to ATCos at LVNL, it is not possible to manage both the sector traffic and a complete holding stack. As holding occurs in extreme situations, it requires a lot of communication with the pilots, meaning that the ATCo has to explain to all pilots entering the holding what is going on and why they have to hold. This is done for safety reasons, such that the pilots themselves can decide to either hold or deviate to another airport (e.g. considering a limited amount of fuel taken aboard for holding). Besides the workload, which could in part be improved by better support systems but not relieved completely as communication with aircraft is still of vital importance, the second argument given has to do with the space on the screen. Managing a larger sector requires quite a lot of space on the radar screen, such that the vertical view makes it more difficult to manage the traffic as part of the traffic entering the sector is seen much later, inducing additional workload. One final comment that is made regarding these considerations is that the information was obtained from interviews with LVNL and therefore contains a bias toward the limitations of the current situation.

Besides the radar screen which is explained below, the ATCo has several tools that can be used for giving commands and communicating with other Air Traffic Control Centers. Using the phone EUROCONTROL can be contacted. Many other features exist, but are not relevant to flying holdings and will therefore not be discussed here. The most relevant feature outside the radar screen is the command panel, as shown in Figure 2.4c. This is used to give all commands, for example target FL, target velocity (SPD), waypoints, but also to enable different views on the radar screen. Besides entering these commands in the command panel, the ATCo also gives the command to the pilot via radio.

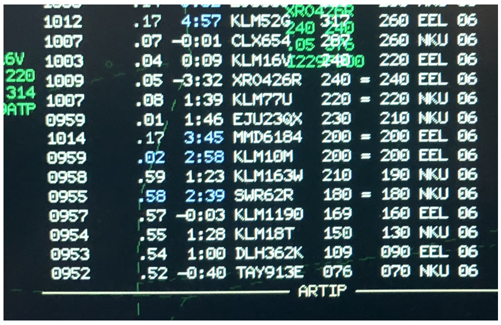
2.5.1. Features of the Radar Screen

Stack lists The layout of the stack list is normally as follows, from left to right: expected IAF crossing - EAT (planned) - EAT inaccuracy - aircraft ID or flight number - waypoint - runway. When the ATCo enables the extended stack list, the current and cleared altitude, in flight levels, are also presented in the list, in that order. Besides the addition of FLs, the major difference between both stack lists can be found in the sorting order. In the regular case, the aircraft are sorted on EAT (planned). In the case of the extended stack list, the order is based on the FL (current).

The sorting of the lists is such that the first aircraft to continue to Schiphol (SPL) is on the bottom. That means the first EAT or the lowest FL is on the bottom. The lists do not automatically re-sort; on the desk there is a button which sorts the list again when clicked. From observing ATCos it became clear that this sorting is something that they do routinely and seemingly without actively thinking about it: re-sorting the list is

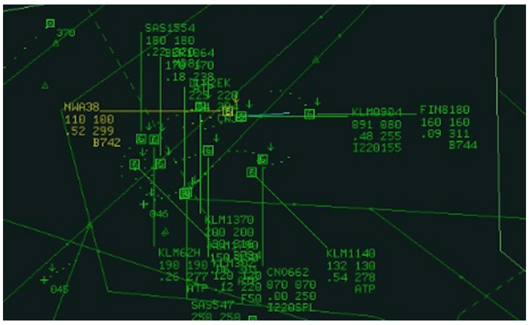


(a) Stack list at RIVER

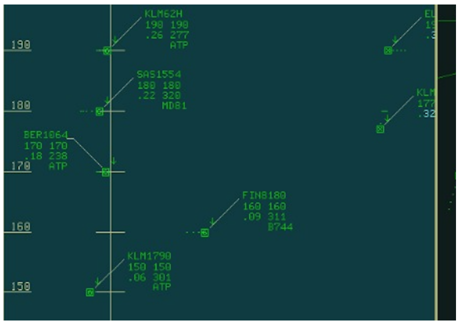


(b) Extended stack list at ARTIP

Figure 2.5: Normal and extended stack list



(a) Top view



(b) Vertical view

Figure 2.6: Radar screen close-ups when holding stack is present

therefore rule-based behavior rather than knowledge-based.

Finally, there is one very important thing that the reader should note here. The predicted IAF crossing times presented in the second column of the stack list stop updating after the IAF has been crossed. In other words: as soon as the aircraft enters a holding pattern, the prediction times are not updated anymore.

Vertical view When a dedicated holding stack controller is present, the vertical view can be made active. As seen in Figure 2.6a, the screen becomes very cluttered as the holding fills up. In fact, at the moment the still is taken, there are 17 aircraft present in the holding space. This makes it extremely difficult if not impossible to distinguish the aircraft in the top view: since aircraft are separated by height and fly a similar track, it makes more sense to look at their positions from the side. A caption of the vertical view at the same moment is shown in Figure 2.6b. This obviously gives a better overview of the situation than the top view, improving the controller's situational awareness.

History dots and speed vectors Based on radar updates (approximately 5 seconds), the ATCo has additional tools to get a better idea on the past and future trajectory of the aircraft. In Figure 2.6 one can distinguish (if looking closely) five dots behind the aircraft. These represent the last five radar positions, and can be used to get an idea on how fast the aircraft is going and whether it is e.g. descending. The ATCo also has the option to enable a speed vector, which is a line from the aircraft toward the predicted location in five radar updates based on current heading and velocity.

Label Another feature from which the ATCo gets a lot of information is the aircraft label. Its layout is given below. The EAT is the amount of minutes past the closest hour, meaning that if it is currently 8:53 .54 implies that the planned EAT is in one minute, and .01 implies it is at 9:01. The speed given is the ground speed (GS) in kts. Finally, the bottom right entry either shows the next waypoint (e.g. ATP for ARTIP or SPL for Schiphol), or the aircraft type (e.g. B737). It is possible to move the aircraft labels and make them readable again in the top view when the holding stack is full and they are overlapping like in Figure 2.6a.

Aircraft or flight ID		KLM1790	
FL (current)	FL (cleared)	132	130
EAT	GS (kts)	.54	278
	WP or type		ATP

2.5.2. Holding Stack Control Task Strategies

There is a couple of standard practices and control strategies currently used in holding. While the design of the visual support tool will not be constrained by current practices, shortcomings and limitations, it is good to be aware of the standard workflow at LVNL to gain a better understanding of the way people work.

Stack list versus vertical view The stack list and extended stack list are used as a primary measure on planning when aircraft pass the IAF. The ATCo gets an overview on who needs to pass first, EAT adherence error (not updated in holding), and in the case of the extended stack list whether the pilot has already lowered enough to continue to approach. When a dedicated holding stack controller is installed, the vertical view is enabled and the controller uses the EAT that is presented in the aircraft label as a primary source of planning.

History dots and speed vector Speed vectors are not used by all ATCos. In general, when someone is working as a dedicated holding stack controller and the vertical view is present, speed vectors are turned off as they are considered to clutter the screen at that moment. This can be further explained by the speed constraints present in holding, meaning that the different aircraft will not have an extremely large variation in speed - and an aircraft does not vary its own speed significantly during holding. For this reason, the speed vector does not give more information than the history dots, in fact, it gives less information. That is the case as the history dots also provide insights in the altitude history of the aircraft, providing insight in both speed and descent rate.

EAT accuracy The ACC planner provides an EAT planning, which comprises the exact moments in time a pilot is to cross the IAF before continuing to Schiphol. The ATCo has the freedom to ensure the pilot crosses this point within a four-minute window around the planned EAT, meaning maximum two minutes earlier or later than planned. Two different strategies are employed here by ATCos, depending on the person.

The first hinges on making worst-case estimations on the timing and then planning to be two minutes too late (-2:00). Then, if anything goes better than expected, the IAF is crossed earlier than expected which is perfectly within the four-minute window given.

The other strategy is the exact opposite, namely to use perfect-case estimations on the timing, and aim at two minutes too early (+2:00)[5]. Then, if anything goes worse than expected, the IAF is crossed later than planned which again fits in the four-minute window.

From observation in the simulator at LVNL, it was found that in fact the deviation from +2:00 minutes (too early) from EAT is relatively small and rarely gets below +1:00 minute from EAT. This implies that the EAT accuracy can be improved by providing the ATCo with better tooling, to enable them to validate their own estimates, as well as by exploring how the tool can trigger a behavioral change as to change the aim from +2:00 minutes from EAT to 0:00 minutes or exactly at EAT. The reason for flying at two minutes margin is that this is seen as standard practice by ATCos, and they do not wish to refrain from keeping this safety measure without additional support.[6]

[5] Cross the IAF two minutes too early (+2:00) means that there are two minutes to be compensated for by the ATCo, meaning there is a positive amount of time remaining

[6] Source: interviews with LVNL (2021)

3

Interface Design Concept

This chapter discusses the back-end (program functioning) and user interface of the proposed tool that is to assist the ATCo in improving EAT adherence when holding. It starts by outlining the way predictions are made and what uncertainties are accounted for in the algorithms. Then, the proposed concept is explained including visualizations of the different features of the tool. Finally, some stills from the interface are shown to give the reader a clear idea of what the experiment looked like.

3.1. Method

The method by which the interface design concept was conceived is outlined in this section. It consists of two parts: the method for designing the back-end, being the prediction algorithm, and the method for designing the user-interface.

For the prediction algorithm, the first step that was taken is analyzing the exact geometry of a holding pattern and evaluating what components it has. This was done by analyzing historical data on aircraft tracks from holding patterns, and by researching the theoretical geometry of holding patterns based on online resources and literature. Then, a literature research was performed to determine what would be required elements for the algorithm to ensure the prediction accuracy would be sufficient for the purpose. Several factors were identified based on literature, after which consecutive literature research was done to determine the relevance and impact of these factors on the present prediction algorithm. For one of the factors, pilot delay, interviews were held with ATCos, pilots and Dijkstra [Personal communications with Area Controllers, 2020, Personal communications with KDC, 2020–2021] to determine whether and if so, how pilot delay should be taken along in the prediction. Since aircraft flight management systems (FMS) also have prediction features, pilots were interviewed on how they used those and an FMS manual from KLM was reviewed [KLM, 2019]. After the algorithm was created, it was validated in Matlab using historical data.

The method for designing the interface started with the analysis of present systems as described in Chapter 2. This was followed by a literature review on previous researches in the area of holding support and support systems for LVNL in general, and interviews with area controllers to determine what type of interface would suit their needs. Then, a first concept was designed, which was presented to area controllers and at the Dutch Aerospace Institute [Personal communications with NLR, 2021] to gain feedback. Several iterations were made based on this before arriving at the final layout of the interface concept.

3.2. Prediction Algorithm

This section discusses the prediction algorithms that determine the integrated information presented to the controller. To assist the ATCo in reaching a higher EAT adherence, an approach is taken showing the margins and boundaries on the actions they can take. For larger predictability, an extended leg strategy is supported, where the ATCo actions are putting an aircraft on an extended leg and giving a turn-to-IAF command. Showing the margins and boundaries means that the interface and tool merely visualize data in an integrated, logical way such that the controller can interact with it. Essential to the problem at hand is the predicted EAT adherence based on the location at which the pilot starts to turn toward the IAF; the corresponding action is giving the pilot an instruction to make this turn and the timing at which this instruction is given. By giving a prediction about the EAT adherence, an analysis step is automated using the aircraft performance

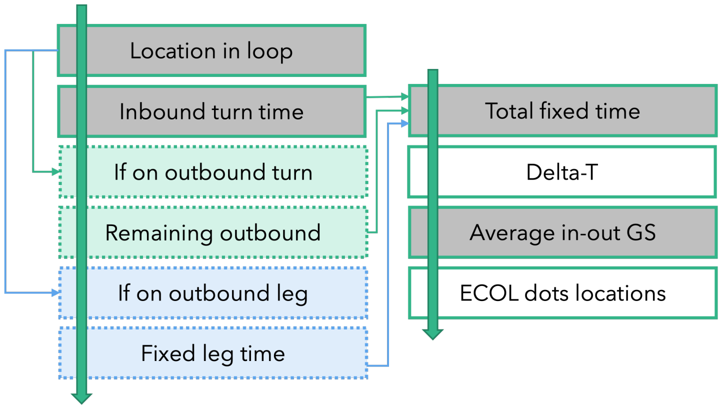


Figure 3.1: Flowchart algorithm

(speed, performance characteristics, descent path) and contextual factors (altitude, wind), relating these to constraints (planned EAT). Automating this analysis step comes at the benefit of speed (faster calculation) and accuracy (calculation over estimation).

To make that prediction, the holding loop is split into multiple components. The leg and turn times are calculated separately. For each heading, the predicted ground speed is based on the IAS and the wind field; the algorithm makes use of KNMI medium-detailed weather data which is the same as currently used in LVNL systems but can easily be adapted to facilitate using more detailed wind fields. During the turn time calculation, ground speed determines angular velocity which is numerically integrated for total turn time.

3.2.1. Algorithm Functioning

The algorithm flow is visualized in Figure 3.1. The grey boxes are intermediate steps; the green and blue boxes are optional steps; the white boxes are the end product. First, the location in the holding loop is determined, which can be outbound turn, outbound leg,

Figure 3.2a visualizes the ground speed prediction algorithm. It works as follows:

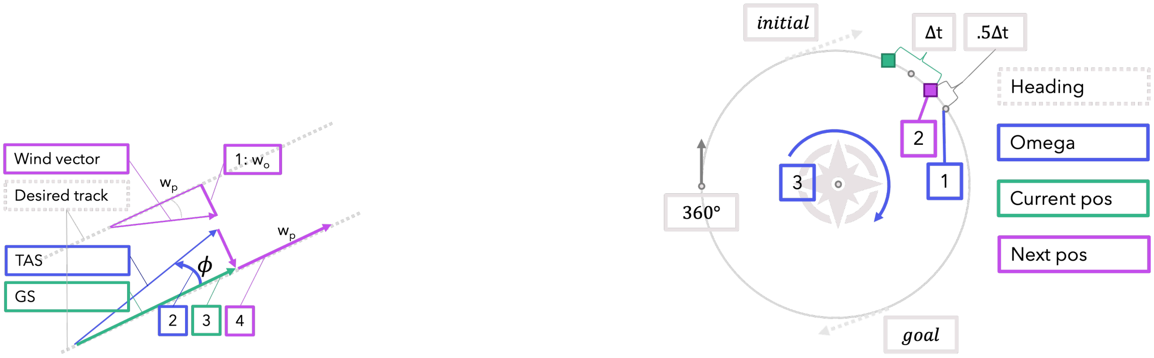
1. Wind component orthogonal to desired track is the sine of the difference between wind heading and desired heading;
2. Compute angle ϕ between TAS and GS. Assumption TAS $\gg$ wind speed yields $\phi = \arcsin\left(\frac{\text{orthogonal wind}}{\text{TAS}}\right)$;
3. Along-track component of the TAS = $\cos(\phi) \cdot$ TAS;
4. Full ground speed vector = along-track TAS (green) + along-track wind component (purple).

The turn time algorithm visualized in Figure 3.2b hinges on calculating the angular velocity based on the ground speed prediction at future locations. A numerical integration is done where $\Delta t = 5s$ (one radar update).

1. Predict heading at $1.5\Delta t$ from the current moment (i.e. predicted moment) by adding $1.5\omega\Delta t$ to the heading at the current predicted position (green);
2. Predict the next heading (purple) by adding $\omega\Delta t$ to the current predicted heading;
3. Predict the next omega, by taking the heading computed in step [1] and using $\omega = \frac{g\tan(\phi)}{V}$ and the ground speed;
4. Add Δt to the turn time prediction.

These steps are continued until the difference between next predicted heading and desired heading is smaller than the time step. The last step takes the difference between the two headings and divides them by the last predicted ω, and adds this to the turn time prediction.

Based on the current location, turn time predictions and leg time predictions, both the minimum remaining time until crossing the IAF as well as the optimal turn-to-IAF location are predicted. Figure 3.3 shows the prediction algorithm that results in the delta-T: the difference between minimum remaining time until the next IAF crossing plus the current time and the EAT, or in other words, the minimum EAT adherence error. Based on this, it is possible to extend the predicted in- and outbound leg lengths and therefore alter the predicted EAT adherence error. The predicted turn-to-IAF locations for various EAT adherence errors (+120s, +110s, ..., 0s, -10s, ..., -120s) are forecasted in this manner.



(a) Ground speed prediction

(b) Turn time prediction

Figure 3.2: Graphical representation of prediction algorithms

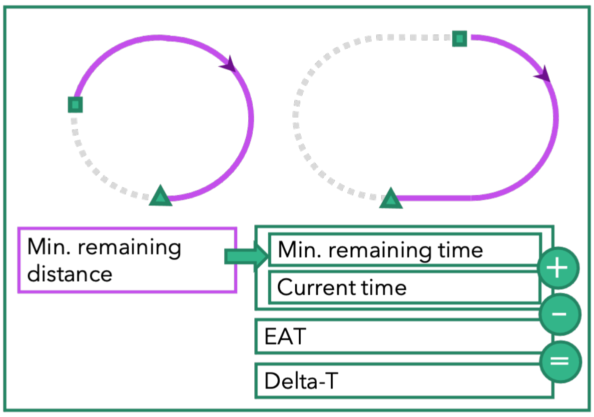


Figure 3.3: Visualization of delta-T calculation

3.2.2. Wind

Wind is a highly influential component in trajectory predictions [Magaña and Juan, 2016] and is in reality one of the most difficult things to estimate. The need for including wind in trajectory predictions is further substantiated by Bakker et al. [2019] and has been indicated as the essential factor by LVNL [Personal communications with Area Controllers, 2020]. Reynolds et al. [2013] state: "accurate wind information is of fundamental importance to some of the critical future air traffic concepts". This is especially valid for the research at hand. In the specific case of holding patterns, the influence of wind on the in- and outbound legs works in opposite directions leading to a significant change between in- and outbound ground speed. It cannot be expected of a human to memorize complete wind fields at different altitudes that change over location and time, emphasizing the potential benefit of a system that does take wind effect into account.

Two types of weather forecasts are currently used at LVNL in several support systems, where every hour a new dataset is provided with a 10-minute interval prediction for the first three hours and a 1-hour interval prediction for the following four. The most detailed forecasts include information about the wind vectors at various heights and locations, but also about other weather conditions such as temperature and prediction of rain, thunderstorms, humidity. These files contain a 4D grid such that at every point information on these factors is present. The other forecast type is simpler and more widely used. These contain wind and temperature predictions per flight level, which do not vary throughout the interval or over the, in this case, span of the holding area. Current LVNL prediction algorithms make use of the simple wind data. However, as this research is aimed at improving the systems, this is not proposed as a reason for not using the more detailed forecasts. Still, simple wind data will be used over full weather fields for two reasons.

First, using full weather fields increases model complexity as integration over each point in the weather grid is required. Since the duration of a holding leg is in the order of one minute and the spatial domain on which holding loops are flown is limited, the accuracy increase is very small (order of one second) and therefore the benefits of higher accuracy by using the full wind do not outweigh the increased complexity and computational power required.

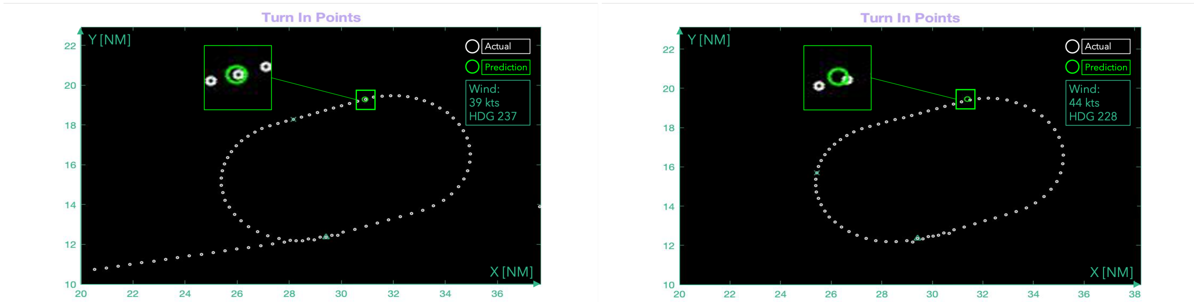
Second, even while using a highly detailed grid, the update frequency of the prediction should be considered regarding the level of weather prediction accuracy and the level of required trajectory prediction accuracy [Reynolds et al., 2013, 2015]. Main drivers in the accuracy of a trajectory prediction influenced by wind have been identified to be the magnitude and forecast latency [Robert, 2013].

Finally, an uncertainty between the predicted and actual wind (field or vector) remains, which can be modeled using a nominal wind value from the prediction combined with a stochastic variable [Casado et al., 2012]. The influence of such wind uncertainties on trajectory predictions has been evaluated in [Lee et al., 2009]; it has been shown to be very small when the forecast time and elapsed (flight) time are of the levels that are used for the holding tracks in this research. From this it will be assumed that the uncertainties in wind field prediction lead to a negligible trajectory uncertainty in holding loops.

3.2.3. Validation

The validation of the algorithm was done using real-world radar and simplified wind data. The data used was collected at August 10, 2019 by LVNL [LVNL, 2019]; in the morning from 7:00AM to 9:00AM, wind conditions were extreme which resulted in multiple holding situations. Heading of the wind over time and at different flight levels was between 228-237; intensity of the field was between 37-44kts. From this dataset, seven holding loops were isolated to use as validation data. For each loop, the time the aircraft crossed the IAF at the end of the loop was registered and stored in a list of imaginary EAT data. Then, the prediction algorithm was run for three aircraft locations per several loop. This was done for aircraft locations in the outbound turn at heading 30, on the verge of outbound turn and outbound leg and further down the outbound leg at 30% of its length; the EAT was set to the actual time over IAF and then the predicted turn-to-IAF location was compared with the actual turn-to-IAF location.

After validating the prediction algorithm on multiple holding loops, using different aircraft locations, it was found that overall the prediction error is very small. In 12 cases, the expected impact on EAT adherence error was smaller than 1 second, in 5 cases the expected impact was larger than 1 but smaller than 2 seconds; for each case the expected impact was bounded by 5 seconds. The error was expressed in the distance between the actual location where the aircraft started the inbound turn and the predicted location where the aircraft should start the turn. In order to put this into perspective, this number was divided by the distance between the two final radar updates on the outbound leg (location where turn started and the radar update before that). This fraction is then multiplied by the radar update frequency (5s) to get an estimate of the error in time. Moving the start of the inbound turn effects both the in- and outbound leg, which means that double



(a) Validation: wind 39 kts, heading 237

(b) Validation: wind 44 kts, heading 228

Figure 3.4: Validation of predication algorithm

this time estimate gives an idea of how large the impact is on EAT adherence.

In Figure 3.4 two examples of the validation of the algorithm using real-life data are shown. The EAT is set to the actual time over, the open green dot represents the turn-to-IAF location at which the EAT adherence error is predicted to be zero, the highlighted feature shows the predicted turn-to-IAF location and the actual turn in point. In Figure 3.4a, it can be seen that the predicted turn-to-IAF location and actual turning point used to reach the IAF at the set EAT are almost exactly at the same position under the following conditions: aircraft on outbound leg, wind intensity 39 kts, wind heading 237. In Figure 3.4b, it can be seen that the predicted turn-to-IAF location and actual turning point used to reach the IAF at the set EAT are slightly off under the following conditions: aircraft on outbound leg, wind intensity 44 kts, wind heading 228. The accuracy is still acceptable, as the distance between predicted location and actual location is 0.21 radar update which corresponds to 1 second in time, or an impact in the order of 2 seconds on the EAT adherence.

3.3. Proposed Concept

The different components of the tool are outlined in this section. The components are: prediction updates without control action in stack list, difference between expected approach time (planned) and expected time over IAF (Delta-T), visualization of EAT adherence for Control Operation Locations (ECOL dots) and a feature reducing screen clutter in the PVD.

3.3.1. Stack List Update

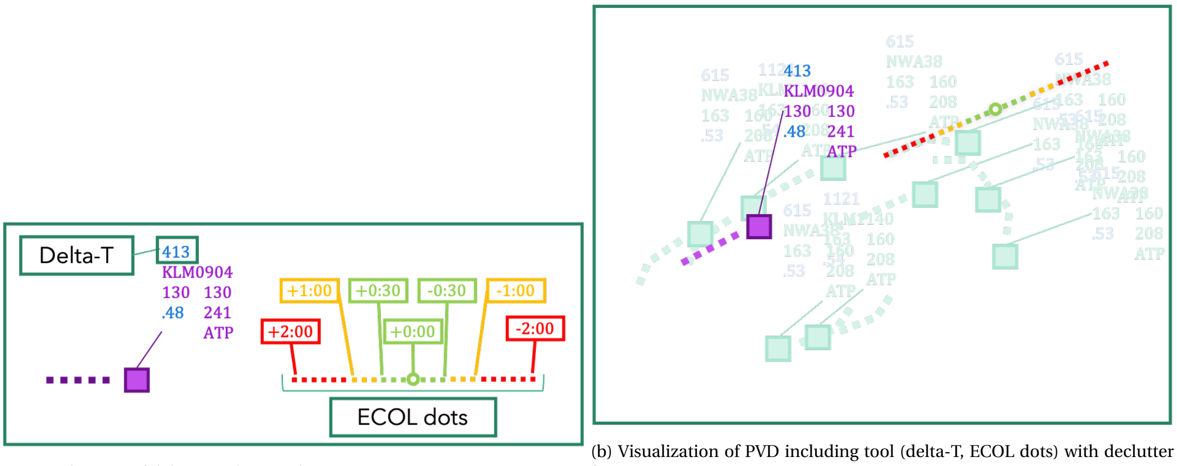
In the current systems, the next predicted time the aircraft crosses the IAF (predicted time over) is not updated. To comply with the EAT adherence times presented in the stack list in all other (non-holding) flight situations, the predicted time over IAF is the moment the aircraft is predicted to reach the IAF again at the end of the present holding loop. In other words, it represents the predicted EAT adherence without performing any control actions, giving the controller an idea of how far in the future a control action is required.

3.3.2. Delta-T

The first innovative system addition brought by the tool is the prediction of EAT adherence error when a turn-to-IAF command would be given now based on the current aircraft location, see Figure 3.3 for a visualization of the calculation. The EAT adherence error is visualized as a clock at the top line (line zero) of the aircraft label, both in the PV and VV, see Figure 3.5a. This location has been chosen as it does not take up the space of any important piece of information and because additional information is often presented in line zero [Personal communications with NLR, 2021]. The reason for depicting it as a clock or timer is that EAT adherence error is depicted in a similar manner during different flight phases and is therefore in accordance with the mental model of the controller.

The delta-T shows the difference between EAT (planned) and predicted time over IAF. In this case, a positive time means that the AC will cross the IAF too early (e.g. 1027 means that the aircraft would be 10 minutes and 27 seconds too early if turning toward the IAF and starting approach at this moment). Another way to put this is that there is a positive amount of time to be compensated for. On the other hand, a negative time indicates that the aircraft will cross the IAF later than planned.

The delta-T is always shown in the label for all aircraft because this gives an overview of how far in the future a control action is required to meet the EAT. With that it serves an additional purpose, namely to pro-



(a) Visualization of delta-T and ECOL dots

(b) Visualization of PVD including tool (delta-T, ECOL dots) with declutter feature

Figure 3.5: Visualization of tool features

vide a trigger for action in the form of showing the boundaries to the problem. It does this by showing the remaining time up to which an action needs to be performed instead of only giving a trigger when the action needs to be done immediately.

3.3.3. ECOL Dots

The other main aspect of the tool is the visualization of the EAT adherence of Control Operation Locations (ECOL dots). These dots visualize the predicted EAT adherence error at future possible turn-to-IAF locations. They are placed on the extended, extrapolated outbound leg and show the locations where the EAT adherence error will be between +120 and -120 seconds with 10-second intervals, see Figure 3.5.

The dots can be used for two purposes. The first is that the location of the dots relative to the aircraft and general holding pattern geometry can be used as a decision aid when the ATCo has to choose between putting the aircraft on an extended outbound leg or to fly another holding loop. The closer the dots are located to the standard holding pattern, the more logical it is to extend the outbound leg.

The second and main use is to determine the optimal turn-to-IAF location and therefore control action (command) location. The middle, open green dot represents the point where the inbound turn should be started for a predicted EAT adherence error of 0s. The surrounding dots give an indication of the sensitivity of the solution and the margins. Since pilot reaction time plays a large role regarding the actual turn-in location, an ATCo can use the surrounding dots to estimate how much earlier a command should be given for the best EAT adherence. If, for any reason, it is not possible to give an aircraft a turn-to-IAF command at the point optimal for EAT adherence, the ECOL dots give the ATCo the tools to know the predicted EAT adherence error at other locations on the outbound or extended leg, too, and therefore allow for bounding the EAT adherence to different levels when it is impossible to steer at 0s error.

3.3.4. Declutter Feature

Screen clutter in the PVD is already an issue while holding (see Figure 2.6a for a photo of the real-world PVD during a holding situation). Since the tool proposes to add even more elements to the PVD (delta-T in line zero and ECOL dots), screen clutter is increased even further while using the tool. This makes it difficult to use the ECOL dots, as their projection is tangled with aircraft locations and labels. To solve this, all aircraft except for the selected one are faded in the PVD. The other aircraft are still visible, but much darker, making the selected aircraft, its label, and the ECOL dots clearly distinguishable and legible. In Figure 3.5b the feature is shown, where colors have been changed for readability.

4

Social Situation and Challenge

The objective of the research is to gain insights into the factors that influence the attitude toward innovation of ACC within LVNL. This is done guided by a new system innovation concept as was presented in Section 3.3 that assists the ATCo into making sure EAT adherence window becomes smaller than the current 4-minute window. Where the previous chapters have discussed the functioning of ATC, holding, current systems and the technical solution to the EAT adherence problem, this chapter will focus on the social and communicative aspects toward introducing a technological innovation within LVNL. A driving factor for this part of the research is that in order for any innovation to valorize, the intended users will actually need to start using it. In other words: the people in the organization are a driving factor to actually reduce the EAT adherence deviation and therefore a positive stance toward innovation and willingness to work with (new) support systems is important. From interviews with air traffic controllers[1] and interviews with people who have worked together closely with ATCos[2,3], an overview of the situation has been composed, and the most promising area in which to conduct the social part of the research has been determined.

4.1. Method

The method for determining the social and communicative aspects surrounding the problem is outlined in this section. To determine the social atmosphere between the groups of ACC and APP, ATCo's attitude toward EAT adherence, and the things ATCos think are important while doing their job, unstructured interviews were held with area controllers and with people who have worked with both of these groups [Personal communications with KDC, 2020–2021] and who have done research in the area before [Personal communications with M. Ottenhoff, 2020].

To describe the context of the social situation, literature research has been done on different topics that were of potential interest. The initial topics were: learning, collaboration and mental model. While doing the literature review, in an iterative manner other relevant topics were found that were then also researched. In Table 4.1 part of the literature search, the search terms and the found articles is shown. For a larger overview including searches that generated literature that was not used, the reader is referenced to D.

For each of the topics that were researched in the literature review, an overview was created explaining the theory and a link to the research context. It was found that the most relevant theories and literature for describing the problem were mental model theory and case studies on innovation and change, and therefore these have been included in the report.

4.2. Autonomy, Responsibility and Value Within ATC

Within ATC, the different parts of airspace are controlled by different groups of people with different job titles. Each group has a highly responsible job, as the impact of a mistake in air traffic control is enormous when a collision between two aircraft would take place. In doing this job, they value their autonomy a lot: they have been trained to make the right decisions and therefore it is essential that they are completely in

[1] Source: observations made at and interviews with people from LVNL (2020–2021)
[2] Source: interviews with F. Dijkstra, KDC (2020–2021)
[3] Source: interview with NLR (2021)

Table 4.1: Literature search related to social situation and challenge

Search terms	Engine	Hits	Literature in chapter
Ironies of automation	TUD Library	3	Bainbridge [1983]
Mental model collaboration	TUD Library	258	-
Mental model innovation	TUD Library	27,235	-
Mental model teams	TUD Library	20,825	Uitdewilligen et al. [2013]
References/related articles Uitdewilligen et al. [2013]			Mohammed et al. [2010]
Perceived usefulness perceived ease of use and user acceptance of information technology	Google Scholar	7,103	TAM references pop up, no additional literature found
User acceptance social situation	TUD Library	18,151	-
Technology acceptance cognitive frame	Google Scholar	403,000	Lin and Silva [2005]
Mental model technology acceptance	TUD Library	13,398	Elbanna and Linderoth [2014]
Technology acceptance model external factors	TUD Library	40,943	Venkatesh and Davis [2000]
Innovation case study	Google Scholar	750,000	-
Organization openness change innovation	Google Scholar	505,000	Vakola [2012]
technology			Miller et al. [1994]
Organization work environment resistance	Google Scholar	304000	Vakola [2012]
change technology innovation			Wanberg and Banas [2000]
Technology acceptance intention to use	TUD Library	24753	Davis et al. [1989]
Sent by AE supervisor after discussion on TAM and ATC	-	1	Westin et al. [2015]
Articles on previous research at LVNL obtained via AE supervisor	-	3	Bakker et al. [2019], Ottenhoff et al. [2020], Dirkzwager et al. [2019]
Constructivist collaborative discovery learning	TUD Library	637	-
Constructivist learning	TUD Library	14,815	-
Learning human interaction	TUD Library	129,000	-
Innovation change emotion trust	TUD Library	1,577	-

charge of making a decision. It is for this exact reason that the introduction of new tooling and technological innovations has often not been welcomed at LVNL[2]. Reasons for this are a lack of trust in the correct functioning of the tool (e.g. uncertainty about the correctness of predictions made)[1], but also a fear that automation will take over part of their job[2] or that a higher level of automation will make their job easier, resulting in a lesser pay as the people who can do the job become less scarce[3]. Besides that, innovation projects from the past have taken extremely long and in several cases have gone unimplemented, which has reduced people's motivation to work with a new technology as they do not trust it will be implemented into the systems[2].

Besides the focus on sustaining autonomy and the value people add through their high responsibility as an air traffic controller in general, there is also some "friendly rivalry" between the different groups at LVNL[2]. Especially between the groups of APP and ACC, who are in the same room and who transfer traffic to each other (see Sections 2.2 and 2.5 for a more detailed explanation). There seems to be an atmosphere where ACC is of the opinion that APP "does not have enough to do" while APP believes that ACC is incapable of performing certain tasks (such as a higher level of EAT adherence)[2].

All of these reasons and statements come from interviews with people who work at or have worked with LVNL, and therefore compose a subjective view of the situation that has not been scientifically researched. It should also be noted that every individual has their own specific outlook on innovation within their work domain, as well as motivations for it. The subjective picture of the current social and communicative situation is a generalization, and will therefore as well as for the reasons mentioned above only be used to pose a research question and not to make any definite claims.

4.3. The Social Situation Surrounding EAT Adherence

The following section will discuss the view that people who have worked with ACC give on the social situation regarding EAT adherence. It should be noted here, however, that this picture is based on the opinions of these people and that every individual working at LVNL is different. Therefore, generalizations and statements made here do not apply to all people within the organization. That having said, a quote that has been heard a lot is in the presence of EAT adherence error is “well, good, then APP will also have something to do”, an indicator that some people at ACC actually deliberately do not reduce the EAT adherence[2]. It seems like a bold claim to make, but has been heard repeatedly. Another observation made regarding EAT adherence is that the goal of the ATCo is actually to aim for a +2:00 or -2:00 error, instead of ±0:00[1]. The common way of working is to aim at those two minutes, where statements like “This is how we always do it” and “So instead of aiming for 0:00 minutes, we always aim for +2:00 minutes error” have been overheard often[1]. A contrary view is given by ATCos who seemingly do want to improve their EAT adherence, yet claim that this is not possible as there is currently no tooling available[1].

From this follows an interesting situation: a culture where new tooling is not always welcomed for various reasons, and where the need for an improvement is not recognized by all members of the organization. Looking at the depicted situation, several factors could potentially contribute to the larger goal of this research, namely to improve EAT adherence from $\pm 120s$ to $\pm 30s$. For this, not only is a support system needed, but the system also needs to be regarded more positively by the end-user and be accepted. The first factor that can potentially contribute to this is that when a support tool is introduced, it should both make accurate predictions that truly offer support, as well as convince people of the accuracy and correctness of these predictions. In other words, the usefulness, demonstrability of results, and the way this is perceived by the end user play a role here. Secondly, a person’s autonomy in performing their job should stay intact and automation should have a supporting rather than determining role. A factor that potentially complicates the introduction of tooling is the fear of job complexity, which indicates that a mitigation of these fears through communication about the impact of the tool on one’s job is a potential factor that improves tool acceptance. Finally, regarding the social situation where the need for improved EAT adherence is not always recognized, convincing people by outlining the potential positive impact rather than forcing them to work with new tooling can make a contribution to this improved EAT adherence.

It follows then that an understanding of users’ cognitive frames should be a key factor in managing the adoption of information systems.

4.4. Innovation in Accordance With Mental Model of Work Domain

Theory A mental model is defined as the way concepts are structured and defined in the mind of a person [Mohammed et al., 2010, Uitdewilligen et al., 2013]. Mental model theory consists of many aspects, but for this research some parts of it are especially relevant. The way mental model theory plays a role in this research is outlined here. For innovation to take place within a social network, it is important that it takes place in exactly the right moment: it should strike the right balance between being conservative (completely in accordance with the current system or a persons mental model) and being revolutionary (everything in the system changes, not in line with a person’s mental model). In other words, when an innovation builds upon known systems, making it incremental, it is more likely to be accepted. To make sure a new technology does not estrange people, it is vital to know what their cognitive frame looks like [Lin and Silva, 2005]. When the technology is not in accordance with people’s routines or outlook on their professional identity, which is part of the mental model people have of their job and work domain, there is a larger probability they will reject it according to Elbanna and Linderoth [2014].

Link with LVNL In Chapter 2, a detailed description of the current ACC work domain and LVNL support systems is given. In this section, the focus will be on describing the mental model of ATCos regarding the way in which their job should be done, based on observations and unstructured interviews. It should be noted here that interviews were held with two different ATCos, as it is difficult to find people that are both motivated to help with external research and also have the time to do so; the representation given is therefore largely biased by the way these people view their job. Interviews were also held with Ferdinand Dijkstra from the Knowledge Development Centre during the course of this research, who knows many ATCos personally and has been performing research for LVNL for a long time.

To become an air traffic controller, one has to pass a strict selection and will have to follow a long education and trainings. In the context of the responsibility that comes with the job, it is easily seen why. Another factor that may be shaping in how ATCos (in general) view the work they do, is the organizational culture. ATCos take a lot of pride in their job, and value autonomy in their work. Autonomy can be found in many different aspects: the freedom ATCos have to plan their own shifts, the way in which they solve the problems that daily challenge them and the freedom to work on additional projects.

Culture and attitude toward innovation has two sides within LVNL [Personal communications with KDC, 2020–2021]: the one hand there is a group of people who believe that they do not need tools, as they are highly skilled and have a resistance toward technological innovations since in the end, the complexity of the work requires people to make the decisions for safety. On the other hand, there are people who believe that technological innovations can be used to their advantage, and that building support systems is actually a way in which they can either validate their own decisions, promoting safety, or steer towards higher accuracy in planning adherence, for example because a tool can free up workload and mental capacity while retaining safety. A tool can in that sense make an ATCo experience its work in a more fun and satisfactory manner: if a tool allows you to do a better job, that promotes the pride you take in delivering aircraft in an even more accurate manner.

The ATCos that have been interviewed fall in the latter category while discussions with Dijkstra give more substance to the first viewpoint. One of the two ATCos has actually taken the initiative to request and start a research project on holding support tools, while the other has volunteered to help and give feedback on the current project. This voluntariness gives an indication that they have a large willingness to innovate, learn and work with new technologies, as they took initiative to participate in an innovation project toward developing a new technology themselves. However, two people do not constitute a culture, which means that it cannot be concluded from the willingness to innovate of these two people that more people at LVNL have the same attitude. The truth must be somewhere in the middle (between strong resistance toward technological innovation and ATCos taking initiative for the innovation themselves). It is important to note here that an organizational culture can have a large influence on how a team handles an innovation (i.e., subjective norm as defined by Venkatesh and Davis [2000]), regardless of personal opinions, as illustrated in the case study by Vakola [2012], see Section 4.5.1. From the interviews it is concluded that there is quite some variation within the subject group regarding innovation.

Remarks that are often seen in previous studies done regarding support tools for LVNL is that the interface does not match with the LVNL interface Bakker et al. [2019], Ottenhoff et al. [2020], Dirkzwager et al. [2019]. The result in an extreme case would be that feedback only comes on already known shortcomings regarding the match with people's mental model, instead of feedback that can be used to improve the proposed tool. Another reason to put an emphasis on visually adhering to the ATCos mental model is that using their own visual language will trigger a different emotion than a strange visual language. The power to promote change is to be found in what is already known.

4.5. Favorable Circumstances for Innovation

In this section, some examples from literature regarding the circumstances in which a new technology was or was not accepted upon introduction, followed by a critique on how these relate to the problem at hand. One case study was found where a new technology was introduced within a medium-sized company in the public sector, which is relevant since LVNL is a medium-sized company that operates in the semi-public sector. In the case study, the term openness to change is used. This is defined by Miller et al. [1994] as the "willingness to support the change and the positive affect about the potential consequences of the change". The other concept, technology, should be interpreted as computer or digital technology, such as software or an application. Within this context, when reading through the case and when looking at the definition, it becomes clear that openness to change is related to the attitude a person has toward an innovation, which is why it is relevant for this research.

4.5.1. Case: Resistance to Change in the Public Sector

This case, as described by Vakola [2012] concerns a medium-sized company in the public sector, with an employee base that has an average age of 48 years, 35% higher educated, and "characterized by bureaucracy, predictability, stability and control". In the case study, the top management has decided to invest in a new technology, which is to be implemented by an external company. The emotions linked with new technologies within the company are that employees do not trust it and a strong sense of "that is not how we do things here". Resistance to change was identified as the main issue that blocked the program, split up into four categories: people were afraid their performance would be tracked (and turn out lower than that of colleagues), fear and stress about incompetence to work with the new technology, the union resisted the change, and there was a lack of trust in the management since many initiatives were left unimplemented in the past. There was a minority of employees who actually were open to the innovation and willing to (learn to) work with the new system. In the end, the management did push through to implement the change, but it was costly, time consuming, and key users would indicate various flaws and mistakes in the system and its implementation. In the long term, the system has not made a valuable contribution to the organization and was taken out of operation [Vakola, 2012].

Link to LVNL Since ATCos can only perform their job until they are 57 years, the average age is higher for the case; average education levels at LVNL are relatively high; and having a focus on safety and predictability, the characterization of the organization presents some resemblance. The emotion linked with technological change is also recognized by people who have been working with LVNL for longer; here, too, a group who is actually advocating for the innovations exists. If it is possible to take every key user on in the process of developing and implementing a technological innovation, the problems that are seen in the case may be prevented. Having people collaborate can lead to both a more efficient innovation as well as implementation process, where they can give input along the way. In the end, this leads to a better system for the users. Having ATCos involved in an innovation process could, therefore, have a positive impact on their attitude toward the innovation.

The factors emphasized above are the ones that are recognized by professionals who have worked with LVNL before. The first two factors, anxiety about performance tracking and resistance to change by the union of workers, have been present for longer. As in the past ten to five years, more innovation projects have started while the organization is sluggish in terms of innovation implementation and development. Reasons for this are regulations and safety issues that all require innovations to pass through long bureaucratic processes first. The result of this is that many projects have turned into floating or broken promises, but have not materialized in actual improvements. Therefore, in the last five years a sentiment of distrust regarding the realization of innovations has started to emerge at LVNL. Under ATCos, there is a sense of skepticism regarding the implementation of innovations as a result of this [Personal communications with KDC, 2020–2021].

4.5.2. Identifying Predictors of Openness to Change

During an extensive reorganization at the U.S. Department of Housing and Urban Development, Wanberg and Banas [2000] conducted research on the relation between the level up to which employees were open to change based on context-specific variables and individual-specific variables. It was found that personal resilience was a strong predictor for acceptance and openness to change, determined by three factors: self-esteem, perceived control, and optimism. These factors are personal and not influenced by the workplace directly or on a short term. However, the study also found that three context-specific variables would also impact the level of change acceptance, being: information received, participation in the process, and self-efficacy or perceived competence. On the other hand, low levels of change acceptance could be predicted by (low) job satisfaction, workplace irritations, and people's intention to quit [Wanberg and Banas, 2000].

Link to LVNL Even though in this context, the change is organizational and not technological, the way people cope with a change in their situation may still be representative. However, this study is conducted within a different context and therefore caution should be taken regarding its validity in the present context. From observations, people at LVNL seem to have high job satisfaction, take pride in the work they do and enjoy the autonomy they have. As for that, a lower change acceptance over the ACC workforce is probable to result from the moment their autonomy is put at risk, as this threatens people's job satisfaction. Factors that in this case are most likely to influence acceptance are the information presented about the change and the ability of people to contribute to the innovation. Since ATCos are used to working with complex technology, are high-educated, and have a maximum age of 57 (being relatively young), perceived competence to work with new technology is unlikely to be a driving factor for resistance to change [Wanberg and Banas, 2000].

4.5.3. Acceptance of Technology

For innovation to happen trough introducing a new technology, the computer system will first need to be accepted. To explain and improve user acceptance, Davis et al. [1989] have proposed the Technology Acceptance Model (TAM) in which they describe and predict people's intention to work with a computer system. The factor that mainly determines this is perceived usefulness of the system, and to a much lesser extent ease

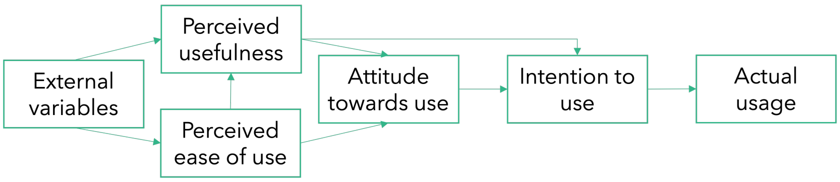


Figure 4.1: Technology Acceptance Model, adapted from Davis et al. [1989]

of use. Where its evaluation was initially done using a word processing tool, the concept is widely used and seen as a solid way to represent technology acceptance. The TAM layout is shown in Figure 4.1. One interesting factor that should be noted here is that the tool presented in the experiment is used on a voluntary basis, which explains the strong focus on intention of using as a measure for technology acceptance.

Research by Westin et al. [2015] discusses how the TAM can be used in the context of ATC decision making tools. First of all, they find that the TAM has been mainly applied to the acquisition and analysis of information, but not so much toward the actual decision-making process that follows. This is a critical factor for improving EAT adherence through the use of a support tool, as is the subject of the current research. What is more, Westin et al. explain how a higher conformance of a system to the human's problem-solving style can be used to overcome initial controller acceptance issues in expert user groups. However, they also argue that the highest level of conformance is only possible on an individual basis as each controller will have a unique problem-solving style.

Link to LVNL Potential resistance and potential acceptance in the case of ATCos can be linked to the TAM considering the way they view their job. The job comes with high responsibility, uncertainty and requires creative and non-standard solutions continuously. Ironies of automation, as introduced by Bainbridge [1983], are that a computer or automation system can deliver standard solutions while the system operates faulty upon an unexpected situation. It also becomes harder for the human controller to spot these errors. Considering these ironies and the TAM, a natural and logical response to a digital support system would be that the system can only get in the way of safe operations and is not useful: an explanation on why technologies are so often not accepted in the world of ATC. Currently, LVNL is implementing iLABs, which can be seen as a Living Lab where ATCos can first-hand experience new technologies. Since it is still under construction at the time of this research, nothing is yet to be said about it being a possible solution to this problem.

The precautions mentioned above are taken into account into the proposed design of the tool as explained in Chapter 3, making sure the technology in fact makes it easier for the human controller to operate in uncommon situations and by all means staying away from full automation, keeping a focus on controller autonomy and the ever critical human factor in ATC. Based on the above, the TAM is seen as a promising framework for explaining initial controller acceptance.

4.6. Research Focus

Researching the entire cultural situation and every specific of handling innovations and their surrounding research and implementation processes, even when narrowed down to the specific case of LVNL, is a project requiring tremendous resources. As to gain valuable, meaningful results within the scope of this research, it is essential to determine one area of focus in which to perform the research. It is currently unknown how the attitude people within LVNL have towards an innovation is influenced. It was found in this chapter that the social situation surrounding the problem is complex, and that there is no clear picture on what factors play a role regarding an ATCos attitude toward an innovation and how these factors influence said attitude. Therefore, this research will aim at identifying the factors that play a role in an area controller's intention to use the proposed display concept during a real-life holding situation, and how these factors are of influence. This is done specifically for the group of ACC within LVNL in the context of the proposed tool, which is the case study for this research. The theoretical framework used for this is outlined in the next chapter.

5 Theoretical Framework

In this chapter, the theoretical foundations of the subject in the context of communication are outlined. This is done by explaining the used theories, presenting the resulting theoretical framework and finally operationalizing the framework. The Technology Acceptance Model (TAM) will be used in combination with the concepts of autonomy and trust to explore the defining factors that determine attitude towards and intention to us an innovation. The reason for using the TAM in this research is the following. First, many researches have been conducted using the TAM, and it has been widely validated [Chuttur, 2009]. Second, the TAM has previously been used to describe acceptance of technology within the scope of human-system interaction under the presence of a decision support tool controlling air traffic (see Westin et al. [2015]). Finally, the TAM is seen as a suitable framework because it contains intermediate steps for technology acceptance, which allows to explore what are determining factors for technology acceptance in the present context. The reason why autonomy is important within the framework is that in unstructured interviews with ACC, indications were given that autonomy in problem-solving is an essential element for an ATCo in performing their job. Interviewees have indicated two reasons for this. The first is creativity or job satisfaction, i.e., being able to design a solution instead of only having to execute what a system dictates. The second is safety or solution reliability and robustness, i.e., ensuring a human weighs the risks and makes the final control decision rather than a computer system. The reason why trust is important also followed from these interviews. Given the critical nature of an ATCos job, the impact of an incorrect control decision or a system failure can be very large. It is therefore expected that being able to trust a technological support system is an essential feature for an ATCos willingness to use said system.

As this research is exploratory, promising results from this research should be tested in further research with larger subject groups to ensure their validity.

5.1. Method

The method for generating the theoretical framework is described in this section. After it was determined in Chapter 4 that the TAM would be a promising framework to explore the research objective, a literature study was performed on the TAM. This was done by researching the TAM; an overview of the searches that were relevant and generated literature that was used in this chapter can be found in Table 5.1. For a larger overview including searches that generated literature that was not used, the reader is referenced to D. In the context of interaction with support systems, autonomy and trust were determined as relevant factors that should also be present within the framework. The literature review performed while determining the communication challenge in Chapter 4 was used for the insights on trust, while an additional literature review on autonomy was performed to describe this in the framework. Search terms used were autonomy, learning, professional, motivation, innovation, technology acceptance, decision-making.

After defining the research framework, the method for operationalizing the variables was done in an iterative manner, where survey and semi-structured interview questions were drafted and presented to Communication Design for Interaction professors from TU Delft and to an experienced innovation researcher at LVNL [Personal communications with KDC, 2020–2021]. This was done to verify and validate the questions.

Table 5.1: Literature search related to TAM and theoretical framework

Search terms	Engine	Hits	Literature in chapter
Technology acceptance model external variables	TUD Library	31,614	Venkatesh and Davis [2000] Venkatesh and Davis [1996]
Technology acceptance model literature review	TUD Library	63,858	Chuttur [2009] Venkatesh and Bala [2008]
Technology acceptance model literature review	Google Scholar	1	Marangunić and Granić [2015]
Result demonstrability image social influence technology acceptance model definitions	Google Scholar	27,400	Moore and Benbassat [1991]
Tam definitions variables ease of use intention to use perceived usefulness Use references from Teo and Zhou [2014]	Google Scholar	33,330	Teo and Zhou [2014] Wu and Lederer [2009] Fishbein and Ajzen [1975]
Attitude toward use attitude definition affect	TUD Library	5,299	Fishbein and Ajzen [1977]
Autonomy trust support system acceptance	TUD Library	3,151	Dickinson [1995]
Technology acceptance autonomy trust support system	TUD Library	1,500	Eom et al. [1998] Stefanou et al. [2004]
Technology acceptance support system air traffic control autonomy trust	TUD Library	137	Blegen et al. [1993]
Technology acceptance support system air traffic control collaboration	TUD Library	1,187	Guiost et al. [2006]
Technology acceptance support system collaboration problem solving	TUD Library	7,150	Degani et al. [2017]
Trust time "building trust" "support system"	TUD Library	48	[Siemon et al., 2017]
Learning innovation new technology air traffic control	TUD Library	2,616	Teperi and Leppänen [2010]
Autonomy definition technology engagement	TUD Library	2,207	Deci and Ryan [1987] Wang and Peverly [1986]

5.2. Technology Acceptance Model

The TAM was once derived from the (psychology-based) theory of reasonable action and theory of planned behavior, and is mainly aimed at describing and predicting the user's behavior regarding the acceptance and use of the technology. The first introduction by Davis et al. [1989] proposes three factors that determine the user's motivation to use a system: perceived usefulness, perceived ease of use, and attitude towards use. In the original model, an immediate step is made toward actual system use, while in later versions, an intermediate step is taken at the user's intention to use [Venkatesh and Davis, 1996]. This is visualized in Figure 5.1. Over time, the TAM has been adapted and has evolved in many ways, with variations in the exact categories and links (see Chuttur [2009]). In 2000, Venkatesh and Davis proposed an extension on the model, called the TAM2, where a set of variables (such as job relevance, experience) was identified in the place where other models (for an overview, see Marangunić and Granić [2015]) often cite “external variables”. The categories in Figure 5.1 will be discussed in detail, including their operationalization in context of the present research. It should be noted here that actual usage cannot not be measured for the subject of the research and is therefore left out of the scope. The link between the TAM, the operationalization of the framework and the use of the tool is visualized in Figure 5.4.

5.2.1. External Variables

Due to the fact that the exact factors determining external variables within the TAM in the context of ATC have not been scientifically researched, it is not possible to determine the set of external variables based on litera-

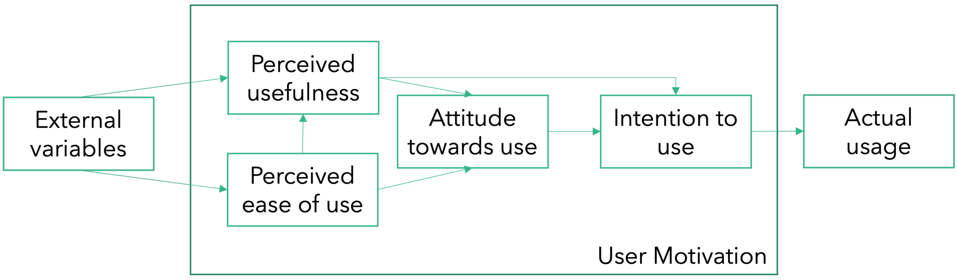


Figure 5.1: Technology Acceptance Model: User Motivation

ture. This reflects in the exploratory nature of the research. The set of external variables that is used to guide this research are the external variables presented in the TAM2. These external variables will be used when coding the interview results: result demonstrability, output quality, job relevance, image, subjective norm, experience, voluntariness and age [Venkatesh and Davis, 2000, Marangunić and Granić, 2015]. Definitions from literature are given below [Venkatesh and Davis, 2000, Venkatesh and Bala, 2008]. Since the research is exploratory and the set of external variables in the context of ATC is unknown, it should be explicitly mentioned that other external variables could also be of influence, or that some of the aforementioned external variables are not of influence.

Result demonstrability "The tangibility of the results of using the innovation" [Moore and Benbassat, 1991].

Output quality "How well the system performs the tasks that match their job relevance" [Davis et al., 1989]. In other words, quality of the result obtained using the tool and reaching its subsequent goal.

Job relevance "individual's perception regarding the degree to which the target system is applicable to his or her job. In other words [...] the importance within one's job of the set of tasks the system is capable of supporting" [Venkatesh and Davis, 2000].

Image (Social Influence) "The degree to which use of an innovation is perceived to enhance one's [...] status in one's social system." [Moore and Benbassat, 1991].

Subjective norm "A person's perception that most people who are important to him think he should or should not perform the behavior in question" [Fishbein and Ajzen, 1975].

Experience Amount of experience the participant has with the system [Venkatesh and Davis, 2000].

Voluntariness Degree to which a person participates in the experiment by their own incentive or triggered by external motivators. It has already been found by Wu and Lederer [2009] that the voluntariness of using the new technology has an impact on the links toward intention to use from perceived usefulness and perceived ease of use.

Age Participant age in years.

5.2.2. Perceived Ease of Use

The perceived ease of use "refers to the degree to which the prospective user expects the target system to be free of effort" [Davis et al., 1989]. In the context of this research, the prospective user is an experienced area controller, and therefor has extensive experience with ATC support systems and technologies. The target system is the full system, so the systems already present in the current environment extended with the proposed visual support system. Free of effort, in this case, is defined as the possibility to work with the full system after gaining a short explanation and a short (15 minutes) training session, versus e.g. requiring an in-depth course about the functioning of and/or hours of training with the full system.

5.2.3. Perceived Usefulness

Perceived usefulness refers to "the degree to which a person believes that using a particular system would enhance his or her job performance" and "the existence of a positive use-performance relationship" [Davis et al., 1989] which is derived from the definition of useful: "capable of being used advantageously" . In the context of this research, perceived usefulness will follow the definition by Davis et al. where "job performance" is defined as the level of EAT adherence and the "particular system" is the tool.

5.2.4. Attitude Towards Use

Attitude is defined by Teo and Zhou [2014] as "a person's degree of evaluative affect (like or dislike) toward a target behavior" which follows from "the affective evaluation towards a given task" [Fishbein and Ajzen, 1977]. In this case, the target behavior is using the tool to improve EAT adherence. In this research, attitude towards use is defined as the degree to which a person thinks or feels about using the fully developed version of the tool. This is slightly divergent from the definition of attitude: "a settled way of thinking or feeling about something", as the option that a participant changes or forms their attitude towards the (use of) the tool upon engaging with it is one of the possible expected experiment outcomes and therefore the word settled is removed.

5.2.5. Intention to Use

The intention to use is defined as "the subjective probability that an individual will perform a specified behavior" by Teo and Zhou [2014]. In this research, the intention to use is defined as the subjective probability (of an ATCo) to use the tool to define and validate control actions that have an impact on the turn-to-IAF command location of an aircraft. The subjective probability is defined as the degree of certainty to which a question about intended use of the tool and its sub-components is answered.

5.3. Interaction with Support Systems

A decision support system is, in this context, defined as a computer-based information system that can support an individual in the process of making decisions, and does so by presenting (integrated) information that is in some way related to the human decision maker's judgments through a human-computer interface [Eom et al., 1998]. This is relevant for the research context since the support tool concept presents integrated information to the controller that is aimed at supporting them decide when to give a turn-to-IAF command. Even though the use of decision support systems is increasingly widespread in ATM, the human controller remains the central decision-maker in the field [ICAO]. The paradox here is that the organizational structure and culture can create conflict in learning to work with these systems [Teperi and Leppänen, 2010]. This is partially supported by field research at LVNL, yet partially negated: each individual within the organization has a different willingness to interact with new support systems. Generally, younger people are more willing to engage with new technologies [Wanberg and Banas, 2000]. Research on cooperative (human-system interaction) support tools in ATC with a focus on interaction (both human-system and human-human, making it collaborative) indicates that essential factors are trust (in the system) and controller autonomy (to conceive a problem-resolving strategy). One factor that led to a more positive experience with a support system was identified to be the level to which the support system would actually enhance collaboration between controllers [Guiost et al., 2006]. This is important because it relates to one of the external factors within the TAM, namely subjective norm. Increased collaboration surrounding a tool means increased use by not only the individual, meaning the behavior (using the tool) is approved by more people in the target group.

5.3.1. Autonomy

Autonomy is defined by Deci and Ryan [1987] as "action that is chosen; action for which one is responsible", which is in line with the way Blegen et al. [1993] operationalize the concept: autonomy is the level of decision-making authority and accountability an individual should have regarding this task. Besides this operationalization, Blegen et al. [1993] have identified autonomy in a certain task to be positively related to job satisfaction. Other research looks at autonomy from the perspective of ownership [Stefanou et al., 2004]. Dickinson [1995] argue that in a learning context, higher autonomy leads to higher motivation. Wang and Peverly [1986] state that an autonomous learning process is characterized by the learner being able to be both active and independent. In this context, the relevant measurement is the learner's ability to design, have and adapt his or her own goals, set their own strategies and monitor their own learning process.

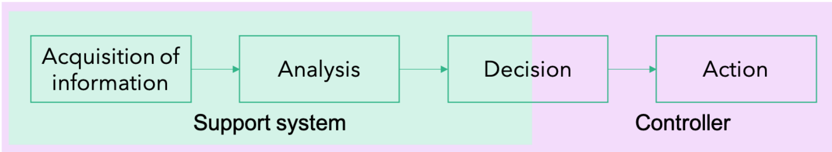


Figure 5.2: Decision process and proposed level of support. Feedback is possible when extending the figure with the impact of the control action, on which information can be acquired (but feedback is not necessarily present).

Autonomy and the new tool In Figure 5.2 the division of tasks between the support system and the controller is visualized when a control action needs to be made. The controller is responsible for every step in the process: acquisition of information, analysis (of this information), decision-making and performing the control action. The system offers support on acquisition of information, analysis of this information and partially on decision-making. It does this by presenting the controller with an integrated form of relevant information. In other words, the system gathers information, processes (analyzes) it and shows the controller what the impact of certain actions would be. Therefore, the controller now knows the predicted impact of certain control decisions and actions. From the set of presented decisions, the controller can choose one or decide to follow a different course of action (not select a strategy that has been suggested by the support system). Finally, the controller needs to autonomously perform the action of giving a control action; for this, the tool offers no support.

5.3.2. Trust

An important driver for people to engage with a support system is trust according to Guiost et al. [2006]. Trust is also identified as one of the attributes describing teamwork as a basis for human-machine interaction by Degani et al. [2017]. Trust can be seen as a two-sided prerequisite: for any larger system, not only is trust in the technological system vital, but also trust in any other person in the system; this is in line with human interaction with systems that is similar the that with other humans [Degani et al., 2017]. In other words: for an ATCo, it is essential that both the technological support system as well as one's colleagues can be trusted to be fail-safe: upon any error, failure or mishap, the system or colleague will communicate what happened. Before any system becomes operable within ATC, it undergoes extensive testing but often also requires some training before use, which is a possible moment for ATCos to build trust in the system as building trust takes time [Siemon et al., 2017].

5.3.3. Mental Model Research Aspects

The interaction with technological systems and decision support systems define a part of the manner in which a person defines the concept of a support system. Performance of current operating systems influences the view a person has on support systems within the organization (including systems under development) [Venkatesh and Davis, 2000]. Other aspects that are considered in the context of this research are the people within the organization, defining the social network, atmosphere [Lin and Silva, 2005] and organizational structure and experience people have with support systems and previous innovation projects.

5.4. Research Framework

Figure 5.3 is used to explain the theoretical framework and visualize the correlations between the theories, concepts and factors used. The circles should be first viewed, starting at the top left and going clock-wise. On the right, the links between the concepts related to the different theories are indicated.

To research the defining factors that determine the attitude towards a new technology within ACC, and how these factors shape attitude toward use and intention to use, the first concept that is relevant is system interaction (top left circle in Figure 5.3). From this, only a small subset of all concepts related to system interaction is relevant (dark purple triangle inside system interaction circle). First of all, it is narrowed down to human-(computer) system interaction. In this case, that concerns the interaction an ATCo has with technological support systems that are available at LVNL and the new technological support system that was researched. The concepts that are related to system interaction in this case are: performance of currently available computer systems, the human-machine interaction with the systems (in the past, currently, and interaction with the new system) and the autonomy people have in interacting with the system. Autonomy is part of the framework as a concept, and correlates with system interaction here.

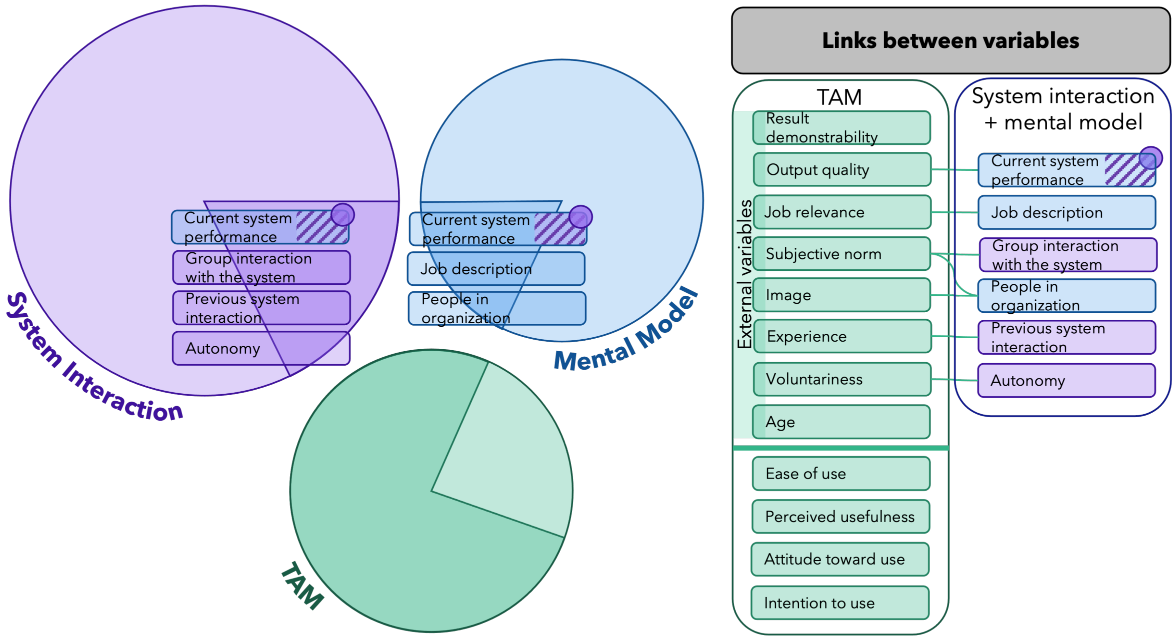


Figure 5.3: Theoretical framework: relations between concepts

Based on human-system interaction, a part of the mental model (top right circle in Figure 5.3) is formed (the mental definition of a human-(computer) system, i.e., what an ATCo thinks a human-computer system is, how it works, what it can do, what it should do). Not only the mental model based on human-system interaction is relevant here. The organizational context of the work environment has an influence on the cognitive frame. The frame with which an ATCo looks at the new technology can influence the acceptance or rejection of said technology. Narrowing down the scope, only those aspects of the mental model are considered that influence the external variables in the TAM (mental model aspects represented by dark blue triangle in mental model circle in Figure 5.3). These are: view on current system performance, job description and mental model of job (tasks, goals, responsibilities) and the people in the organization (colleagues, organizational structure, expectations of socially acceptable/appreciated behavior).

In the present research, the framework of the TAM is used but excluding actual use of technology, meaning that additional to the external variables mentioned, the following factors are considered: perceived ease of use, perceived usefulness, attitude toward use and intention to use. Since most concepts of the TAM are used, the dark green part of the circle in Figure 5.3 represents the presence of the TAM in the research. The relevant concepts are listed to the right of the circles. All factors in the TAM have been indicated in the figure for completeness, but the influence of the concepts in the TAM on each other have not been indicated in this figure. For these links, the reader is referred to Figures 5.1 and 5.4.

The following are the correlations between the external variables of the TAM and the concepts:

- Result demonstrability was not linked to another concept.
- Output quality, related to a person's view on current system performance (poor current system performance means output quality is improved more easily), which is both related to the interaction this person has had with current technological support system and with the mental model they have of present systems;
- Job relevance, related to how a person has mentally structured and defined their task description and priorities within their job;
- Subjective norm and image, related to the mental model a person has of the people in their work environment;
- Experience, related to previous technological support system interactions;
- Voluntariness, related to the autonomy a person has while interacting with the technological support system.
- Age was not linked to another concept.

Operationalizing these theories leads to the following. The “systems” are the technological support systems and innovations in these systems at LVNL that serve the purpose of supporting ACC in their operational work. Interaction with these systems is defined by the performance of the currently operating systems, the organizational context of and the people at LVNL and the way they interact with systems, and the level to which an ATCo maintains autonomy in making control decisions while using a support system. Partially from interaction with these systems, ATCos have formed a mental model of what their work domain looks like. The mental model considered here is the view an ATCos has on their work environment: tasks, objectives, goals, social setting, LVNL culture and policy. The context-specific meaning of each variable is outlined in Table 5.4.

Table 5.2: Context-specific meaning of concepts and indicators for coding

Theory	**Concept/Code**	**Explanation**
Mental model	Work domain	The mental picture an ATCo has of the tasks normally performed and support systems used for this; explaining the ATCos outlook on the work domain, EAT adherence
TAM: external variables	Result demonstrability	The level to which the impact on the EAT adherence is clear to the controller
	Output quality	The level of EAT adherence obtained with the tool
	Job relevance	The importance of improved EAT adherence from the perspective of the ATCo
	Image (social influence)	Whether or not an ATCo believes it is socially acceptable to use a support tool to perform their job in the entire organization of LVNL; in coding this also applies when participants think their status is influenced by the use of the tool
	Subjective norm	The idea that using a support tool is either approved or disapproved by the rest of the ACC group; in coding this applies when participants refer to what they think the rest of the group does
	Experience	The amount of experience the participant has as an ATCo in general, with holding stack management in specific, experience with using different strategies and tools for holding support, and general experience with system innovation processes within LVNL; it also refers to quotes about the familiarity of the simulation environment in general compared to actual LVNL systems
	Voluntariness	Whether there was any external factor (e.g., pressure from management, financial compensation) to participate in the study
	Age	Participant age
TAM: components	Perceived ease of use	Degree to which the ATCo believes working with the tool will be intuitive and free of (learning) effort
	Perceived usefulness	Degree to which an ATCo believes that using the particular system would enhance their job performance in terms of usefulness and satisfaction
	Attitude towards use	The emotion an ATCo feels toward the concept and using the proposed tool
	Intention to use	The estimate of the ATCo on their own subjective probability to use the tool when managing a holding stack
Interaction with systems	Autonomy	The degree to which the system allows the ATCo to take ownership in decision-making, so the degree to which the controller stays in charge of the active decision-taking
	Trust	The degree to which an ATCo believes the support system is reliant
Other factors		Will be labeled as “other factors”, and open coding will be done (factors will be categorized later)

5.5. Operationalization

In Table 5.4 the operationalization of all theoretical concepts is outlined and their specific meaning in the context of the research is explained. For each of these, it is also indicated whether it concerns the design

Table 5.3: Likert scale pointers operationalization table; all scales have five levels

Pointer	Min. value				Max. value
L1	> 2.5 mins	2 mins	1 min	30 s	10 s
L2	Absolutely not		...		Very much
L3	Very difficult		...		Natural
L4	**van der Laan scales**				
	Useful		...		Useless
	Pleasant		...		Unpleasant
	Bad		...		Good
	Nice		...		Annoying
	Effective		...		Superfluous
	Irritating		...		Likeable
	Assisting		...		Worthless
	Undesirable		...		Desirable
	Raising alertness		...		Sleep inducing
L5	1 s	5 s	10 s	30 s	60+ s

(D) of the concept, quantitative experiment results (E), survey results (S) or interview results (I). Figure 5.3 gives an overview of how the different concepts and theories relate to each other. Several external factors are linked to concepts related to system interaction, mental model theory and the mental model an ATCo has of its work environment as discussed above. The mental model, as discussed in Sections 4.4 and 5.3.3, involves the ATCos outlook on their work domain. This involves the way they do their work, but also their colleagues, the organizational structure and atmosphere, performance of current systems, trust in current system functioning, and expectations on innovation processes within LVNL. This basis partially overlaps with the external variables defined in the TAM (see Section 5.2.1).

To explore what are the defining factors of the attitude towards a new technology in the group of ACC toward technological innovation, their opinion and outlook on the situation is asked under the framework of the TAM during the course of the experiment. The questions that correspond to the different concepts are outlined in the operationalization table in Table 5.4. The indicators and operationalization types that have been used for evaluation of acceptance of the new tool are linked (in a general manner) to the TAM in Figure 5.1. It also indicates the place at which the different factors and the experiment, survey and interview results give insight into the technology acceptance in the framework of the TAM, within this research.

1. What is your view on the purpose and need of tooling?
2. How would you explain the benefits and disadvantages of a higher EAT adherence?
3. How do you see the link between the presence of a holding support system and the minimum EAT adherence window size?
4. And if looking at the case of the tool you just tested, specifically?
5. Would you want to use the tool you have just seen? Why?
6. Did your affect on this topic change during the course of this experiment?
7. What suggestions and improvements do you envision for a holding support tool?
8. What other aspects do you think are important for a holding support tool?
9. Would you want to use a tool that has all features? Or are there any specific features you would like to use?
10. Do you think there are any aspects to an improvement or innovation process that influence your intention toward using a new tool?

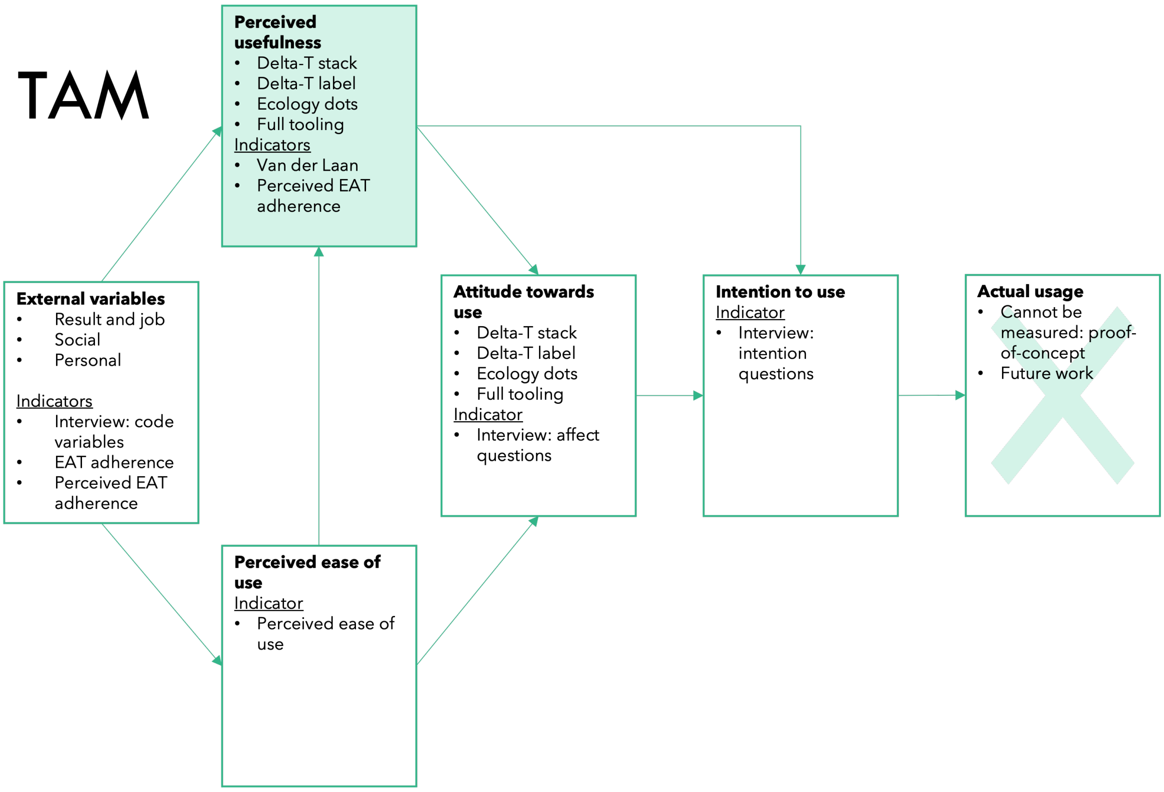


Figure 5.4: Indicators for different aspects of TAM

Table 5.4: Operationalization table

Concept		Operationalization
Mental model: Work domain	D	Setting of experiment and tool layout resembles current systems as close as possible
TAM: external variables		
Result demonstrability	E	Actual EAT adherence results from scenarios with and without tool
	S	What is the level of EAT adherence you have obtained in scenario X? (L1)
Output quality	E	Actual EAT adherence results from scenarios with and without tool
Job relevance	S	Do you think there should be a holding support system (L2)
Image (social influence)	I	Q5 (* only if answer gears towards image/social influence)
Subjective norm	I	Q3, Q5 (* only if answer includes statements about use by rest of ACC)
Experience	S	Number of years of experience as an ATCo
	S	Positions within ATC
	S	Experience with other innovation projects
Voluntariness		Way of inviting participants, see Appendix A for the full experiment invitation
Age	S	Age (open question)
TAM: components		
Perceived ease of use	S	Using the tool/system was ...? (L3) (Question asked after training, scenario without tool, scenario with tool)
Perceived usefulness	S	What did you think about the system without tool/full tool/delta-T/stack list update/ECOL dots? (L4)
Attitude towards use	I	Q1 – Q6
Intention to use	I	Q7 – Q9
Interaction with systems		
Autonomy	D	System designed to show margins and boundaries of problem based on previous unstructured interviews in the process
	S	What kind of expectations do you have from a holding support tool?
	I	Q8, Q10 (* Only if codes are mentioned)
Trust	S	What do you think the level of accuracy of the prediction by the tool was? (L5)
	I	Q4, Q6, Q7

6 Evaluation

In this chapter, the method, results and findings regarding technology acceptance for ACC at LVNL are presented, based on the case study of testing the designed holding support tool concept.

6.1. Method

In this research, the main question that is being explored is what factors influence an ATCos attitude towards a new technology, and how these factors are of influence. After the problem was defined based on interviews with ACC and KDC [Personal communications with Area Controllers, 2020, Personal communications with KDC, 2020–2021], a tool was developed and a theoretical framework was constructed based on literature research. The TAM combined with trust and autonomy are used as a framework. The operationalized framework is used to assess the intention of ATCos to use a holding support tool with the aim of increasing EAT adherence, which is further explained in this chapter. An experiment was performed where participants had to perform a control task, both with and without the proposed tool. The results on performance were used to evaluate the quality of the technological solution (technical problem). To answer the main question of this research, not only the performance of an ATCo on EAT adherence under the presence of the tool was evaluated. At multiple moments in time, before, during and after working with the tool, participants were asked to fill out survey questions and mention their thoughts. After this a semi-structured interview was held. The results gathered during this experiment were collected and analyzed to explore how the willingness to innovate is determined and influenced within this group. For a visualization of the research process Figure 1.2 can be referenced.

6.1.1. Problem Definition

Before the assessment of the tool in an experimental setup, unstructured interviews were first held with two professional area controllers who gave input to what they believed was the problem and who explained what was important to them. Multiple interviews were held, and the controllers have really been taken along from the beginning of the research. During the process of determining the research problem and designing the innovation, the controllers were also asked for input on a regular basis (1-2x per month), either through having a meeting or through email contact. Even though this has not been researched, it became clear when searching for participants that these two ATCos helped in forwarding the experiment invitation and told their colleagues about the experiment. An interesting thing that should be noted here is that in similar researches, the researchers have not reported this exact approach and have also had many problems with finding participants, which is an indication that in the case of LVNL, there could be a relation between making the projected end-users, that are in-group at your target participant group, collaborate and give input to a project early on and the willingness of people in the target participant group to perform an experiment on the innovation.

6.1.2. Experiment: Participants, Instructions and Procedure

The study was performed in a mixed setup (two groups, per group within-subject setup), where all participants were given a control task which they were to perform under two different conditions: with and without the presence of the tool. The groups were distinguished by the order of the measurement runs with and without tool. There were also two scenarios such that the participants were not presented with the exact same

Table 6.1: Overview of experiment procedure

Task	Time
Survey	5 min
Briefing, explanation	20 min
Training	10 min
Survey	5 min
Group A: no tool Group B: tool	20 min
Survey	5 min
Group A: tool Group B: no tool	20 min
Survey	5 min
Semi-structured interview	20 min

Figure 6.1: Age and experienced distribution of participants

scenario twice. The scenarios were comparable in conditions and traffic density, meaning they had a similar level of difficulty and workload.

The control task that was to be performed during the experiment was the alignment of the time the IAF was crossed with the planned EAT through giving turn-in commands to aircraft that are in their final holding loop, with the explicit goal of getting an EAT adherence of $\pm 30s$ while aiming at an error as close to zero as possible.

Before the measurement runs, each participant was briefed about the aim of the experiment, told to focus on minimizing the EAT adherence error in each scenario and that they should speak say their thoughts out loud during the experiment and while answering the survey questions. Then they were given an explanation of the tool, and did a training run with the display. The training time is relatively short since the baseline display closely resembles the real LVNL interfaces that the participants work with on a daily basis. The measurement runs were such that five participants worked with tool in the first measurement run and five participants worked without tool in the first measurement run. During these runs the participants were asked to think out loud; after each measurement run the participants filled out survey questions related to factors in the TAM, autonomy and trust. An overview of the experiment procedure is given in Table 6.1.

In total 10 participants took part in the study. All participants were professional area controllers from LVNL, of whom eight are fully licensed professionals and two are in the final stage of their education, meaning that they currently only work under supervision. The distribution of age and experience (grouped) is shown in Figure 6.1. It can be seen that half of the participants fall within the youngest age group (25-29 years); seven out of the ten participants have less than ten years experience. At 57, retirement is mandatory which is the reason 50+ is the last age group.

6.1.3. Survey

The full survey can be found in Appendix C. The survey is used to measure result demonstrability of the tool, job relevance, experience of the participant, age, perceived ease of use, perceived usefulness, and gain insights in previous expectations of the participant (autonomy) and perceived level of accuracy of the prediction of the tool (trust in output quality). The survey consists of a couple of open questions on experience, expectations and reasoning for a holding support system. It mainly has questions that each involve a 5-point Likert scale (see Table 5.3 for the scales used) in which the participants can indicate their opinion on different aspects of the tool, perceived and expected EAT adherence for tool features, workload, ease of use and perceived usefulness and satisfaction. Questions were presented both after the scenario with the tool as well as after the scenario without the tool.

In the original TAM, Davis et al. propose various scales to assess ease of use and usefulness, see Chuttur [2009]. However, it is seen that these scales vary largely over time in the various applications and evolution of the TAM (see Chuttur [2009], Marangunić and Granić [2015]) and are highly dependent on the exact technology that is to be accepted. Different scales have been researched, after which it has been concluded that van der Laan acceptance scales (see Laan et al. [1997]) would make a suitable choice for measuring perceived usefulness in this research, as the nine aspects that are used in rating perceived usefulness and satisfaction align well with the experiment setup and testing of the tool. The scales have been used in their original form as proposed by Laan et al. [1997], using the Dutch translation [de Waard]. In the processing of the results, the scales have been moved around such that all negative scores are to the left, however, it should be noted that the participants did fill out the scales in their original order and form.

6.1.4. Semi-Structured Interview Setup

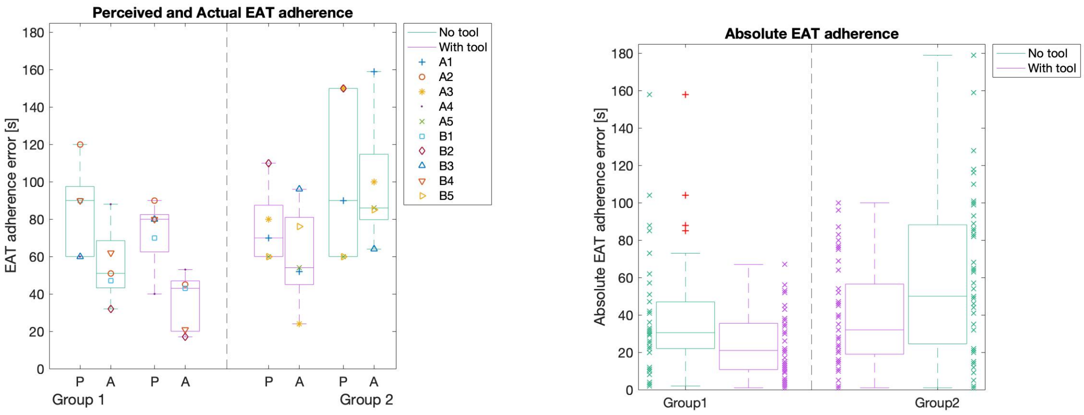
The semi-structured interview is setup as follows. First, the focus is on the motivation for tooling and participants are asked about how their stance on the relevance of a tool like the one being researched is in order to gain insights in their affect towards using a tool for improved EAT adherence. Then, questions are shifted towards intention and suggestions. The questions are presented below. Since the setup is in a semi-structured interview style, these questions are guiding, not leading, and have been mainly used to ensure that all information was gathered during the interview.

1. What is your view on the purpose and need of tooling?
2. How would you explain the benefits and disadvantages of a higher EAT adherence?
3. How do you see the link between the presence of a holding support system and the minimum EAT adherence window size?
4. And if looking at the case of the tool you just tested, specifically?
5. Would you want to use the tool you have just seen? Why?
6. Did your affect on this topic change during the course of this experiment?
7. What suggestions and improvements do you envision for a holding support tool?
8. What other aspects do you think are important for a holding support tool?
9. Would you want to use a tool that has all features? Or are there any specific features you would like to use?
10. Do you think there are any aspects to an improvement or innovation process that influence your intention toward using a new tool?

After performing all interviews, they were transcribed and coded using the concepts/codes presented in Table 5.4. Interesting quotes were collected under “other factors” and labeled with notes. A summary of the quotes related to each code are presented below in the same order as in the operationalization chart, along with interesting quotes where relevant. The full interview results can be found in Appendix B.

6.2. Results

The results are discussed in this section. First, the external variables are discussed based on the survey, interviews and EAT adherence scores. Then, the outcome of the survey questions on the perceived ease of use, perceived usefulness and satisfaction of the tool are presented. This is followed by quotes from the interview that can be related to participants’ attitude toward use and intention to use. This section is followed by a discussion on the results.



(a) Result demonstrability: level of actual VS perceived EAT adherence. The participants have been split per group here, where A1–A5 are P1–P5 and B1–B5 are P6–P10.

(b) Output quality: obtained levels of EAT adherence

Figure 6.2: Results on actually obtained and perceived EAT adherence

6.2.1. External Variables

Result demonstrability It can be seen from the boxplot in Figure 6.2a that the EAT adherence error that was obtained by the participants was actually much lower (=better) than the level of EAT adherence error the participants had perceived they managed to obtain. In other words, the participants assess their level of EAT adherence worse than it actually is. This is also reflected by the average perceived output prediction quality at 28.5s, meaning that the participants expect that the prediction could be maximum 28.5s off from the actual optimal point. No direct feedback was given on performance during the experiment; however, it was possible to verify at what moment an aircraft actually crosses the IAF.

Out of all participants, only P6 did not indicate anything related to result demonstrability, with 18 quotes in total. The quotes can be summarized with the following three points: (1) the participants think it is very important that they can rely on the system to make the correct prediction, and they feel the need to be ensured of that [P1, P2, P3, P7, P10], (2) participants indicated that they did perform double checks when the tool was present [P2, P8, P9, P10] and (3) that it is important to be aware of the shortcomings of the system and that the system is able to show where these are [P2, P4, P5].

Participant P9 said, regarding their overall opinion and how the course of the experiment demonstrated the results of the tool: “No, I was sure that it is convenient and useful before. And so it turned out [during the experiment]. Emptying out the holding stack felt much more calm and structured with the tool than without.” On the topic of being able to rely on the system, many participants started their sentences with something similar to “If this works well, ...” [P3].

Output quality In Figure 6.2b the EAT adherence that was actually obtained can be found, where the absolute EAT adherence scores are are plotted in boxplots. It can be seen that the scores improve when participants use the tool, and therefore the quality of the output when using the tool improves. The average quality of the solution without the tool was 44.55s error, and with the tool 29.91s error, which is an improvement of 49%. Regarding quality of output, no interview questions were asked but P5 indicated that “when you want to convince people to use the tool, it [the tool output] just has to be right”. Participants P2–P6 indicated similar things about output quality, which can be summarized as that it is important that the system needs to prove that the EAT actually improves; there were 9 quotes in total.

Job relevance All participants except for P7 indicated things about job relevance, with 21 quotes in total. These quotes (all participants except P7) can be summarized by participants outlining the relevance for their job and possibilities in terms of level of EAT adherence (aim at zero error) and the possibility to fly standard arrival routes (improving noise pollution and flight efficiency) as a result of improved adherence. Several participants [P3, P4, P5, P8, P10] indicated that more possibilities for validation using predictions is something they regard as positive. P10 did stress that holding is not something that is done often at LVNL, while P1 indicated that they expected to use the tool maximum a couple of times per year because of the frequency of holding stack presence at Schiphol. In general, however, the group did indicate that they thought both this tool as well as the goal (improve EAT adherence) would be relevant for their job. Quotes to sustain this are:

> "In my view, this is not a necessity but it is a sick [very good] support device" [P2]

All participants indicated that they believed the stack list did not support them in EAT adherence while managing a holding stack. The following quote gives an insight in the thoughts of this participant on the topic:

> "I did not use the stack list at all because it does not add value" [P1]

Image (social influence) Only five comments were made [P2, P4, P5, P8] that were in some way relevant for image, but each of these quotes can also be linked to another code. P2 indicated that they thought it was important to show you could comply exactly with what was agreed, such that in the case of a 2-minute error allowance the perfect score is 1 minute and 59 seconds error. P8 also said that the agreement that has been made with the entire group is important for the EAT adherence error score people aim for. P5 explained that within the group of ACC, there is "a shifting perspective on technological innovations" but that in this specific case, the problem is also that people aim to comply with the error bound instead of aiming for 0 seconds error.

Subjective norm In total, there were 22 quotes about subjective norm, by all participants but P1 and P9. These are summarized by the idea that many people within ACC (the colleagues of the participants) are very well able to aim at a certain error margin, e.g., 120s, and that because everyone within ACC does so, people keep aiming for this margin instead of at ±0s error. P2 explained that "during the night, there is the night transition and at that moment it is not allowed to deviate from planning either", implying that if it is possible at that moment there should be no reason for higher adherence to planning during daytime to be impossible. Regarding the norm of exceeding the error margin, P2 said that if someone flies blue times [EAT prediction and time over IAF becomes blue the error margin is exceeded], the other ATCos will wonder or ask why that happened. In other words, there is a form of social control within the group.

Participants [P3, P4] both said that they thought some of their colleagues would show some resistance to new tooling, e.g., "people indicating they can manage without a tool" [P4] while they themselves did have a positive attitude toward improving EAT adherence and this innovation. P5 also indicated perceiving a general resistance within the group. These suggestions are not in accordance with what the participants of the experiment indicated regarding their stance on improving EAT adherence and system innovation.

Furthermore, several participants [P2, P5, P6, P8] said things about how the opinion of their colleagues mattered to them and to the way ACC deals with new tooling. P6 was quite literal in explaining this:

> That is my opinion, but I do also wonder what others think about this [tool]

As a final note on subjective norm within the ACC group, the learning process when becoming an ATCo is shaped by having a coach, who will instruct and coach new people on how they should manage the traffic and explain their own strategies. Coaching is part of the learning process. No research has been done on this topic but the interviews with [P2,P6,P7,P9] indicate that actually aiming for a +120s error instead of keeping this within the ±120s error margin is maintained through the learning process.

Experience Since the experiment is a proof-of-concept experiment and none of the participants has worked with the tool before, there is no difference in experience between the participants. The years of experience in ATC is shown in Figure 6.1; two of the participants are currently at the end of their education and therefore have not yet operated without supervision, which is the reason there are two participants with zero years of experience.

In total, there were 16 quotes on experience by all participants except for P3. Part of these regarded the fact that the system in which the test was performed was different from the systems they normally use. Getting used to working with the tool was linked to their performance by the participants, where some of them [P4, P8, P9] indicated that they expected that after getting used to the tool, they would have improved results on EAT adherence a next time. These people indicated that upon the first introduction of the tool, they spent some time processing what they actually saw on the screen and how to use that information. P5 indicated that the changed focus (on EAT adherence over separation) was also something that felt unnatural, and that getting used to it could have an impact on the way they would manage the traffic. Overall,

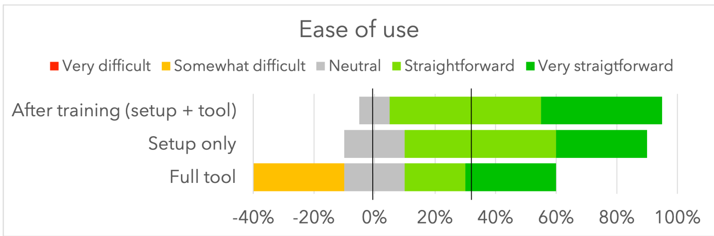


Figure 6.3: Perceived ease of use, n=10

Voluntariness The participants were invited to participate in the experiment via email. Two emails were sent out; one of the participants sent a message in the ACC whatsapp group to notify people they were invited to participate in the experiment. Each participant voluntary participated in the experiment; eight of them replied to the invitation completely autonomously and two of the participants [P2, P7] were encouraged by their coach to partake in the experiment.

In total, there were 11 quotes regarding voluntariness by participants [P2, P5, P6, P8, P9]. Part of these regarded the voluntariness of participating in this experiment or innovation projects in general. P8 talked about the "involvement of operational staff at development projects" while P9 indicated the following:

> "What was remarkable is that yesterday we were talking about it [the experiment]. Half of the people said they did not get the email, or made comments like "I am never asked for anything anymore", so there are still people who for some reason do not realize they can participate in these things."

The other quotes regard the voluntariness of using (parts of) the tool, and participants indicated that they would like to be able to turn the features of the tool on and of when desired. For example, P2 indicated "when holding for another reason, like visibility conditions, it is important that those [the ECOL] dots can be turned off".

Age The age distribution of the participants is shown in Figure 6.1. It can be seen that 50% of the participants are under 30, but that there were also participants from the older age groups.

Only participant [P2] indicated something about age:

> "I think we have the advantage that we are relatively inexperienced. I think the older generation has more resistance [to technological/system innovations like this one]"

6.2.2. Perceived Ease of Use

In Figure 6.3 the perceived ease of use as indicated by the participants can be found. Participants were asked to rate the ease of use of the interface after the first introduction during the training, after they had performed the scenario without the tool (as to measure the perceived ease of use of the simulation setup) and after using the tool. It can be seen that overall, participants did think using the interface was straightforward. During the first introduction, half of the participants indicated they thought it was straightforward, and another four that it was very straightforward. In the scenario without tool, these numbers were, respectively, five and three. When the participants used the full tool, three of them indicated that the use of the tool was somewhat difficult. Since the ease of use was also questioned for just the interface, it can be seen that some participants did find working with the tool somewhat difficult (and that this cannot be attributed for by the different interface than they normally work with).

In total, 9 quotes were given on ease of use by participants [P1, P3, P5, P8, P10]. These indicated that the experiment setup was similar to the current work environment, which made it easy to use for them. For example, [P5] indicated "It aligns with what we are doing now, you do not need to work in any different manner, it just gives better insights in what you are already doing" where [P10] said "the simulation system looks good". Regarding implementation and ease of use, [P5] added about the delta-T that it could be "implemented tomorrow and everyone would use it as intended".

6.2.3. Perceived Usefulness

The results of the survey regarding usefulness and satisfaction are discussed in this section. Usefulness and satisfaction serve as a measure for perceived usefulness, substantiated with interview data. The scores for

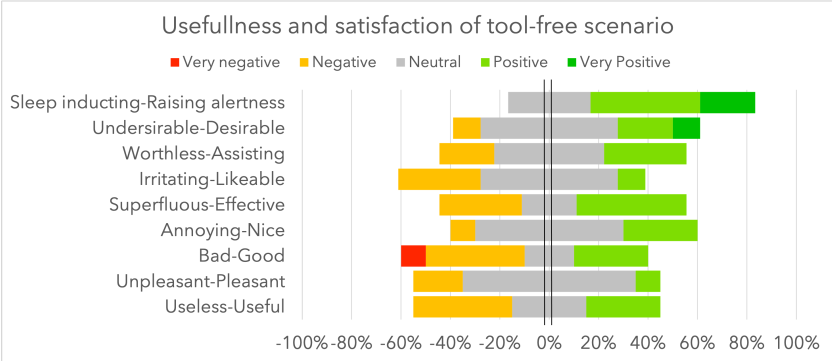


Figure 6.4: Usefulness and satisfaction without tool

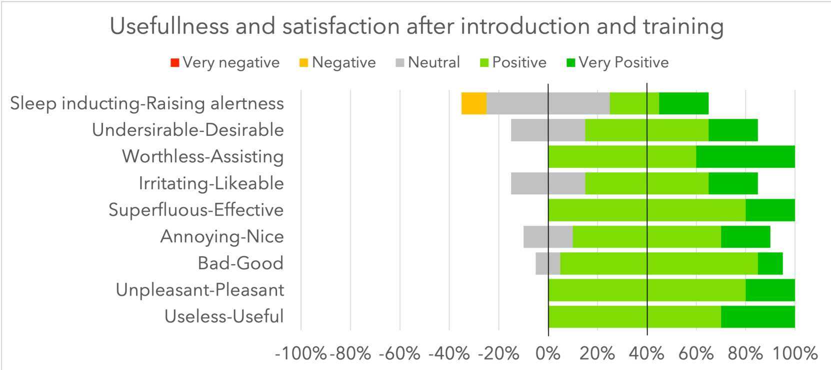


Figure 6.5: Usefulness and satisfaction after introduction and training

usefulness and satisfaction are determined as follows. A maximum positive score yields +2 points, neutral 0 points and a maximum negative score yields -2 points, while the in between scores yield +1 and -1 points. For usefulness, elements 1, 3, 5, 7 and 9 contribute to the score. The sum of these scores is then divided by 5 (elements). The satisfaction score is composed of the sum of elements 2, 4, 6 and 8, divided by 4. Both scores are normalized to fit in a 1-10 scale, meaning the score is multiplied by (9/40) and added to 5.5. The middle line representing the center of gravity of the overall survey results is determined by the average of the location of the middle of each bar.

In Figure 6.4 the results of the survey on usefulness and satisfaction without tool can be found. It can be seen that many participants scored this scenario neutral, and extreme scores (maximum either positive or negative) have barely been given. The normalized score for usefulness is 5.77, and the normalized score for satisfaction is 5.61. The middle line of the overall survey results and zero-line are very close to each other, with the middle line only slightly to the right of the zero line. The overall score for raising alertness is seen to be much higher than the rest of the overall scores (position of the bar is skewed further to the right). This can be substantiated by the interview data, e.g., participant [P1] mentioned “without having a tool, I know that I must pay attention and therefore the absence of the tool raises alertness for me”.

In Figure 6.5 the results of the survey on usefulness and satisfaction after introduction of the tool and the training round can be found. It can be seen that zero very negative scores and only one negative score were given. The majority of the participants scored the overall tool positive at this moment. The normalized score for usefulness is 7.93, and the normalized score for satisfaction is 7.75. The middle line of the overall survey results is positioned relatively far to the right of the zero-line.

In Figure 6.6 the results of the survey on usefulness and satisfaction of delta-T in the stack list after the measurement run can be found. It can be seen that many very negative scores were given, especially in terms of usefulness; not a single very positive score was given. This is also reflected in the score for usefulness, being 4.87. The normalized score for satisfaction is 5.84. The middle line of the overall survey results and zero-line are very close to each other, with the middle line only slightly to the right of the zero line. The bar indicating superfluousness is furthest to the left (negative side), which is in accordance with interview results such as e.g.,

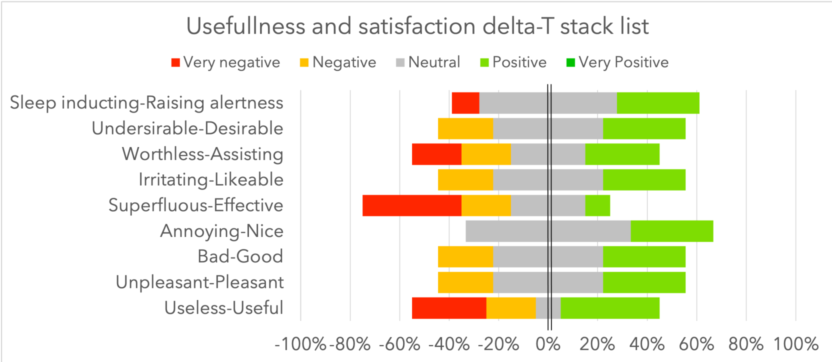


Figure 6.6: Usefulness and satisfaction of delta-T in stack list

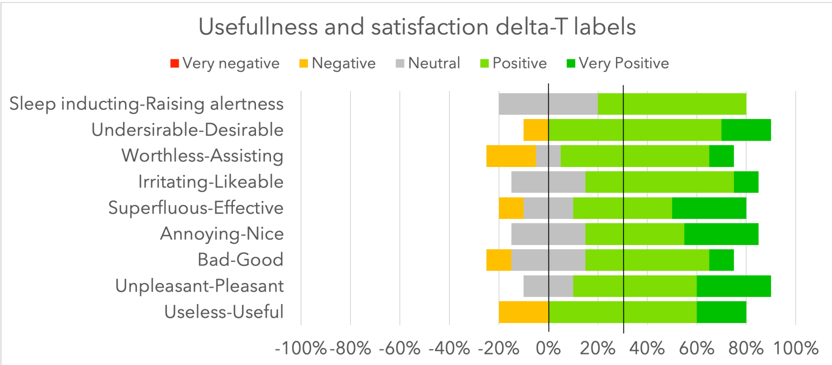


Figure 6.7: Usefulness and satisfaction of delta-T in labels

> “I did not use the stack list at all because it does not add value” [P7]

> “[after performing the scenario with tool] I haven’t looked at the stack list and did not use those delta-T values” [P6]

This participant indicated both perceived ease of use in terms of how fast they thought they learned to work with the tool, as well as perceived usefulness.

> “I was pleasantly surprised, as I could lean on the tool to use it what it was meant for very quickly. I also noticed that I left the stack list since it did not provide any added value in this phase.” [P10]

In Figure 6.7 the results of the survey on usefulness and satisfaction of delta-T in the labels after the measurement run can be found. It can be seen that zero very negative scores were given, and the delta-T in the labels is scored slightly better in the satisfaction categories with respect to the usefulness categories. The normalized score for usefulness is 7.08, and the normalized score for satisfaction is 7.69. The middle line of the overall survey results and zero-line are located apart from each other, with the weight of the scoring positioned to the right of the zero-line.

In Figure 6.8 the results of the survey on usefulness and satisfaction of the ecology dots after the measurement run can be found. It can be seen that many very positive scores were awarded to the ecology dots. Especially in the category of raising awareness, the ecology dots scored high. A quote from the interviews that can be linked to this phenomenon is “I’ve changed my strategy [...] and used the ecology dots as a measure of when to turn in” [P10]. The normalized score for usefulness is 7.57, and the normalized score for satisfaction is 7.58. The middle line of the overall survey results is positioned the furthers to the right of the zero-line of all the results.

Overall, there were 35 quotes about perceived usefulness, by all participants. These can be summarized as that each participant thought the rationale behind the tool was good and they saw the use of it. All participants did mention something related to further development of the tool being needed before it could be used to full potential and implemented within their systems, but they did deem the concept useful. Participants linked the usefulness to improved EAT adherence [P1, P4, P6, P9], gaining time (increased workflow

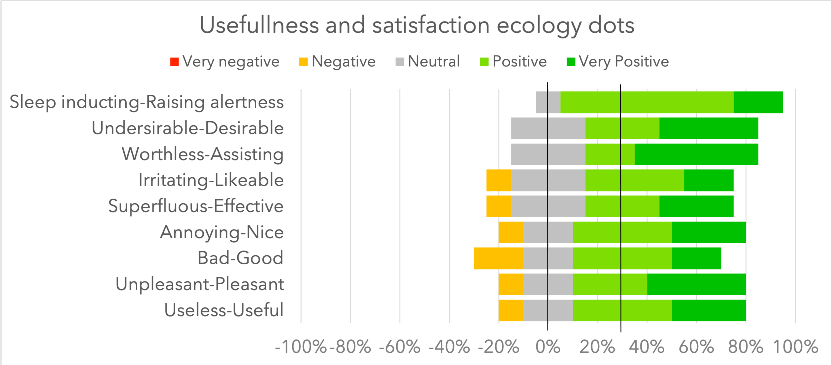


Figure 6.8: Usefulness and satisfaction of ecology dots

efficiency) [P2, P4, P5, P6, P9, P10] and increased predictability [P1, P4, P5]. Participant [P5] even indicated that they thought the concept would be useful beyond the context of a holding pattern, but also when they use vectoring for delaying aircraft.

6.2.4. Attitude Towards Use

In total, there were 37 quotes about attitude towards use by all participants. The participants all indicated a positive affect towards the use of the tool. Several participants indicated a preference toward the delta-T [P3, P6] or the ECOL dots [P1, P4, P5, P9].

Some participants linked their attitude toward use to other factors that are present within the TAM. The following participant [P1] links attitude towards use, perceived usefulness, ease of use and output quality.

> "If you want to convince people to use this, to have a positive feeling about using your tool, it [the prediction] just has to be right. It needs to be very user-friendly"

Another participant [P8] linked experience and result demonstrability to people's attitude toward use.

> "For every change it is necessary to stress that it will cost time and effort, we will be asking something from you, or you'll have to learn something new or unlearn something old, but in the end, this is what it will bring you. When people understand that, when you are really able to take them along and convince them, this program can be successful and in general will be successful."

About the current setup of doing a proof-of-concept experiment and really taking on the opinions of ACC from very early on in the process, [P5] said:

> "Anyway, when you want people to accept your innovation, take people along [in the process]. Many people can make a valuable contribution and in this way, you use that to the full potential"

Finally, there were also some participants [P1, P2] who did indicate a positive attitude toward use but explained that during this proof-of-concept they also verified whether the system prediction was correct. They did use the tool in the first place, but did not fully rely on it.

6.2.5. Intention to Use

In total, there were 20 quotes about intention to use. All participants indicated a positive intention to use some aspects of the tool. Out of ten participants, nine indicated that they would use the decluttering feature, seven indicated they would use the full tool (both delta-T in label and ECOL dots) if available, two indicated they would just use the ECOL dots and one indicated an intention to use just the delta-T in the label.

> "If this would be implemented, I would use it." (P4)

The following quote shows both an intention to use as well as a perceived usefulness.

> "Definitely would want to use it, I think the feature where you can make the labels less visible is very useful: a top feature that I would really want to have in the hold. [...] The delta-T in the label is not very useful for me, which is because I prefer working with the vertical view, so personally it is okay if it is there but I don't need it." [P1]

This participant indicated an intention to use, combined with a perceived ease of use and perceived usefulness.

> "You could implement that tomorrow and I would use it. It matches what we do now and you don't have to learn anything new from it, so everyone would use it in the right way from the start; it just gives a better insight in what we are doing." [P5]

6.3. Interpretation of Results

This section discusses the results and explains the possible implications of the gathered data.

External variables The external variables that seem to play the largest role within the subject group are result demonstrability, output quality, job relevance and subjective norm.

The **result demonstrability** seems to be relevant in the sense that the participants indicate they have performed double checks during the current setup and are not ready to trust the system completely. In the current setup, people did indicate that they believed they did not yet receive perfect scores as the tool is still under development, but accepted that as it concerned a proof-of-concept experiment. Participant P1: "I believe that the results of your experiment do not do right to the potential of your tool". The results imply that the ATCos would want to experience a system first, have it prove the demonstrability of results obtained as well as its reliability, in order for the group to improve their stance toward using the innovation. **Output quality** was indicated by several participants as a crucial factor, also combined with being able to fully trust the prediction the system makes.

Image is a factor that seems to have a small impact as within the group, there seems to be little desire to stand out or have a different social status. On the other hand, the responses from the participants imply that **subjective norm** has a large impact. Participants saying things like "everyone does this or that" and "I'm wondering what others would think of it indicate that within ACC, the opinion of the group matters much for what is actually done. Several participants indicated they thought their colleagues would show some resistance to new tooling, while this is not in line with the results obtained within the participant group. Since the participant group made up only 10% of the total ACC group, and these are the people that voluntarily took place in the experiment, a possible explanation for this phenomenon could be that the subgroup who participated in the experiment has a more positive attitude toward technological innovation in general. However, the participant group did represent the ACC group well in terms of age and ACC experience. Therefore, another explanation could be that ATCos have an image of the stance of their colleagues toward innovation which is more negative than their stance is in reality. This also seems to be the case when interviewing people that have worked with ATCos: the resistance toward innovation is always mentioned, which is not in accordance with what the participants indicated. The participant group was to small to draw any conclusions from this that are representative for the entire group, but since subjective norm seems to partially determine the way ATCos execute their job, it is recommended to do a research on how people within the entire subject group view technological innovation.

Since there were no differences in **experience** between the participants, the effect of that on a positive outlook on the present innovation was not tested. From the interview results, it does seem as if gaining some experience with an innovation increases trust in the system and with that, the attitude towards using the system.

The **voluntariness** of participating in the experiment can potentially have caused that the people who participated had a more positive attitude toward innovation in general than the entire ATCo group. As explained above under subjective norm, this would require further research. In terms of voluntariness in using the (parts of) the tool, it seems as if being able to turn components of the tool on- and off when desired made the participants more at ease with the concept. This voluntariness seems to create a notion where the ATCos improve their attitude toward the system, as it lets them keep their autonomy and they have no need to fear the tool interfering or causing clutter in their screens when it is redundant.

As a final external factor, **age** was predicted to influence the stance on innovation in a negative way [Personal communications with Area Controllers, 2020, Personal communications with KDC, 2020–2021, Personal communications with NLR, 2021]. However, no link was found between age and the stance people had within this experiment on the innovation or their attitude and intention to use the tool. Again, this could be attributed to the size of the participant group and the possibility that people participating have a more positive stance toward innovation in general.

Influence of external variables on attitude toward use From the way participants linked external factors to the other components of the TAM, it seems as if not only perceived usefulness and perceived ease of use are influenced by the external variables as is suggested within the TAM, but also the attitude toward use. The affect a person has toward using a certain tool or system, and more general the introduction of all system innovations at LVNL seemed to be largely impacted by these factors from the interviews. This could be explained through the pride ATCos take in their job, which seems to be the main motivator for decreasing EAT adherence error, e.g., “I am capable of doing that” [P7].

Timing of involvement From the interview results it was found that multiple participants valued that they were taken along in the development process of the tool. Contrary to previous expectations, the fact that certain parts of the tool were still under development during the proof-of-concept test in the case study actually had a positive effect on how people indicated they appreciated being part of the test. One of the participants indicated that “the fact that it is not finished yet makes me feel much more comfortable with giving feedback on the concept” [P10]. An often-heard complaint was in line with the participant who indicated that “people are afraid to talk to OPS [operations; air traffic controllers]” [P5] which seemingly induced a vicious circle: “they always want to present us with something that is already finished, but then they get frustrated when we give them feedback on something in the core of their product” [P9]. In other words, the lack of feedback early on in a development process has on multiple occasions caused developers to produce unwanted products. In the interviews, ATCos suggested that giving this feedback to developers so late in the process causes the developers to fear negative feedback from operations, as it resulted in them having to re-develop their products or having to stop the development process after finding out it was not based on the right design requirements. Participants suggested that this situation has led to an even lower frequency of asking input from operations in development processes, making it impossible to change the direction of the project early on in the process, causing frustration within the organization. Since timing of taking people along in the development process of a tool was not part of this research, but findings are promising, it is recommended to do further research on this topic.

During the experiment, participants experience a scenario with and without the tool. Through this, it is possible for them to experience the added benefit of using the tool for improved EAT adherence by seeing the difference between the two scenarios.

Recommendations are to perform a more thorough research on the common communication channels and to explore the communication possibilities within the organization, to research the link between timing of involvement (timing of involving operational staff in a system innovation project) and attitude toward use.

Perceived usefulness, ease of use, attitude and intention Based on the results, the participant group believes the delta-T, ECOL dots and decluttering feature are useful for holding stack management and EAT adherence. The group does not perceive the updated stack list as useful for these tasks. The participant group also showed an overall outlook on ease of use as being straightforward. In accordance with the TAM, where these positively influence attitude toward use and, both indirectly as well as indirectly (in the case of usefulness), intention to use the participants showed a positive attitude toward use and intention to use based on the results. Therefore, it seems as if the concept of the tool will be positively accepted by ACC, especially when considering previous comments on subjective norm and the notion that already 10% of the group has a positive attitude toward and intention to use the tool.

7
Conclusion

This study has researched what are defining factors on the attitude toward a new technology within the group of ACC at LVNL and how these factors shape an ATCo's attitude toward use and intention to use the technology. In this conclusion, first the answers to the sub-questions of the research will be given, followed by a conclusion on the main research question.

7.1. Information Required for EAT Adhrence

The first research question was: "what information would support an area controller in ensuring an aircraft can adhere to a desired EAT upon passing the IAF?" The information required is a prediction of the time it takes to reach the IAF from different locations, taking into account aircraft characteristics and wind, presented in an integrated manner, which is in accordance with the layout and style of present LVNL systems.

7.2. Presentation of Support Information

The second research question was: "how can the boundaries and margins of the control problem be best represented?" It was found that the ATCo should be presented with two things. First, a prediction of the EAT adherence error upon giving an immediate turn-to-IAF command in the form of a delta-T in the aircraft label. Second, and a prediction of the turn-to-IAF locations at which an EAT adherence error of +120s, +110s, ..., 0s, 10s, ...-120s will be achieved, in the form of colored dots (ECOL dots) on the vertical view and the top view radar screen.

7.3. Context of Social (Communication) Problem

The third research question was: "how can the social situation at LVNL be described in relation to aspects that are of interest to the research (innovation, EAT adherence, collaboration between groups, perception of job responsibilities and goals)?"

The social situation on innovation did not let itself be described in a straightforward way, as indications were found for two opposite things. On the one hand, that (some) ATCos are willing to innovate and actually take initiative in innovation processes, and on the other hand, that (some) ATCos have a strong resistance toward technological system innovation. On EAT adherence, it has been found that ATCos aim for a +2:00 minute deviation from EAT (instead of 0s) which is the current error margin they are allowed to operate on. Regarding collaboration between groups, it was found that the relation between ACC and APP that is characterized by skepticism on the skills of the other party. Finally, it was found that ATCos take pride in the way they execute their job and are willing to work hard to achieve the goals they believe match their job description. In doing this, ATCos have indicated to value their autonomy and the idea that the effort they put in actually adds value for the full ATC process.

From three case studies that showed similarities to the context of LVNL, three things were found. First, ensuring people can contribute and influence the innovation from early stages of the innovation process is a promising factor that seems to influence a person's attitude toward using the innovation in a positive way. Second, the lack of implementation of innovations has caused skepticism under ATCos. Third, the TAM is a suitable framework to further explore how area controllers at LVNL's attitude toward innovations manifests itself.

7.4. Literature and Operationalization

The fourth research question was: "how can literature support exploring the problem and how should definitions from literature be operationalized in the present research?" The answer is by defining concepts with definitions from literature and then linking this to the context of LVNL and what was found in interviews with ACC. Literature was used to define concepts that together form the theoretical framework of the research. This framework contains the TAM, including external variables, plus autonomy and trust. The following external variables were found in literature: result demonstrability, output quality, job relevance, image, subjective norm, experience, voluntariness, age. Output quality, job description, subjective norm and image were found to be related to the mental model of an ATCo. Subjective norm, experience and voluntariness were found to be related to the interaction with technological support systems.

7.5. Exploration of Factors Related to Attitude Toward Innovation

The fifth research question was: "what factors have a relevant influence on an ATCo's attitude towards the proposed system innovation? (The goal is to explore relevant and dominant factors, not to generate an exhaustive list of all factors that influence an ATCo's attitude toward the innovation)" The relevant and most dominant factors for the participant group were found to be result demonstrability, output quality, job relevance and subjective norm and the timing of involvement (in the development process of the innovation).

7.6. Final Conclusion

The main research question was: "what are important factors that determine the attitude towards a new technology within the group of ACC at LVNL and how do these factors determine an ATCo's attitude toward the technology and intention to use?" Based on the answers to the sub-questions, this can be answered. It was found that the TAM is a suitable theory to describe this, where the perceived usefulness is a defining concept. This was found to be influenced in the most dominant way by result demonstrability, output quality, job relevance, subjective norm and timing of involvement.

These factors not only influenced the perceived usefulness, but it was found that the participants also linked these factors directly to their attitude towards using the tool. The way the participant's attitude toward use and intention to use the tool was shaped was by (1) how well they perceived the tool to perform on these factors and (2) the communication surrounding known shortcomings on these factors.

The exact way these dominant factors influenced attitude toward the technology and the intention to use the technology is the following. The interviews with the participants indicated that a higher result demonstrability and output quality would lead to a higher perceived usefulness, which in turn would lead to a more positive attitude toward the technology (from the TAM). From the interviews, it became clear that job relevance was important in the sense that the ATCos thought it was important to see a purpose for improved EAT adherence and that they thought it was important the tool added value to their job goals. Subjective norm seemed to play a large role within the organization and the subject group, which was also found to be of influence on the participants personal objective in the level of EAT adherence they aim to obtain in their day-to-day work. Finally, timing of involvement was found to be of positive influence on the attitude toward the innovation, as participants indicated they appreciated being part of an innovation process rather than being presented with the final solution. It was found that the fact that the concept was visibly not perfected yet (even though it was functioning, it was clear it was still under development and showed some minor issues in e.g., the stability of the computer program) had a positive influence on the participants' attitude toward the innovation.

8
Discussion

This chapter is meant as a critical reflection on the research. It discusses the way results were obtained (method) and the resulting reliability of the results and research outcomes. This is followed by zooming out to a broader context, outlining the real-world impact and implications of the research.

8.1. Reflection on Method

The overall method for this research was the following. The background of the problem was defined based on online research and interviews with air traffic controllers (two) and a professional who is very familiar with the topic and LVNL, since there was not much literature available on the topic. Then, a new tool was designed, where the design of the innovation was based on requirements that followed from these interviews. The research question was evaluated by doing a case study with ten air traffic controllers. The entire group of ACC consists of approximately 100 people, such that approximately 10% of the entire group of interest has participated in the research.

Reflecting on this method, there is one first obvious shortcoming. From the entire group who is of interest for the topic, only 10% participated in the study. This means that it is not possible to draw significant conclusions for the entire group, as the percentage is not big enough to be completely representative and because it is known that there are many people within the group of ACC who do not have a positive attitude toward innovation in general. Because of this, the method of the research (case study on a part of the group of ACC) could introduce a bias toward a relatively more positive attitude toward innovation as the participants in the study could have had a more positive attitude toward all innovation in LVNL in general.

On the other hand, the alternatives for the chosen method can be rejected based on a similar logic. For example, when a survey would be held on the entire group of ACC on their attitude toward innovation, the ideas people have on innovation will be very pronounced (since doing a survey requires much less time and effort from participants, it is more likely to perform a survey with the entire ACC group than it is to do a similar experiment with the entire ACC group). This is in contrast with doing a case study where people give feedback on a new tool that they experience. In the latter case (by just doing surveys, but e.g., with a larger subject group) the test would probably more strongly represent what people think about themselves than it would test their actual attitude toward a new technology.

Willingness to engage with a new technology, or more formal in terms of the research objective, factors that determine a person's or ATCo's attitude toward a new technology, can be a relatively vague concept in itself. Therefore, strictly defining relevant factors and concepts to be researched gives some body to the conducted research. Even though it was not possible to ensure a research group larger than 10% of the total group of ACC, it is known that previous researches had much less participants. Summarizing, the method of combining literature and doing a hands-on study with participants from the target group certainly has shortcomings (not representative for the entire group, possibility of bias, time commitment required for research); it also has benefits (test what people do over chance to accidentally test what people think of themselves, allow people to engage with and become enthused about a technological concept before it is operable).

Because the view on the social situation at LVNL was composed based on interviews with just three people, it is subjective rather than scientifically solid. The view on the situation has been generalized and used in the research. This should be considered when interpreting the results that were obtained. It is possible that the outlook obtained on the social situation was biased. It is important to realize that this outlook did influence the setup of the experiment (survey questions and interview questions). The interviewees are all knowledgeable about the social situation at LVNL since they are part of this (they all currently work at LVNL), which does contribute to the validity of the view that was composed.

8.2. Reliability of Research

As already mentioned in the previous section, reflecting on the method, the participant group consisted of approximately 10% of the entire group that was of interest (ACC within LVNL). For the reliability of the research, this means that the outcomes are not representative for the full group.

Reliability of found dominant factors The attitude toward innovation of the participant group may have been more positive than that of the entire subject group. In relation to the reliability of the research, however, it is not expected that the dominant factors (result demonstrability, output quality, job relevance, subjective norm) influencing attitude toward the new technology will change when having a bigger subject group. The way some these factors influence the attitude toward use could, however, change in this case. This is discussed below.

Both result demonstrability and output quality are the result of the engagement with the new tool, and therefore do not depend on a person's initial attitude toward innovation. It is expected that these factors will continue to weigh strongly in all of ACC and that their effect on a person's attitude toward the new technology is similar (positive) for the entire group, because it depends on the engagement with the new tool and because of indications that everyone in the group of ACC thinks these factors are important [Personal communications with Area Controllers, 2020]. The setup of the experiment was aimed at showing result demonstrability and output quality of the new tool by having participants perform a scenario with and a scenario without the tool, i.e., the experiment was aimed at letting participants experience the benefits of using the tool for improving EAT adherence. Regardless of this setup, the finding that these factors are important and that a high result demonstrability and output quality have a positive effect on the attitude toward the new tool is seen as reliable.

The job relevance was also found to be an important factor influencing attitude toward use. During the interviews, participants were asked on their view on the importance of improving EAT adherence. From interviews it was found that not everyone in the group of ACC thinks improved EAT adherence is important or necessary [Personal communications with KDC, 2020–2021, Personal communications with Area Controllers, 2020]. It is expected that for these people, this factor will continue to be dominant but now negatively effect the attitude toward the tool.

One finding from the research stands out in this context: subjective norm seemed to play a large role within the subject group. This is interesting in relation to the fact that not everyone from ACC participated in the study because the subjective norm is also created by these people who did not participate. In terms of reliability of the research, there are indications that subjective norm is of large influence for everyone in the group of ACC. Since the interview questions did not put a strong emphasis on image or subjective norm, the finding that subjective norm did come forward as an important factor is seen as reliable as participants were not nudged or stimulated to give answers related to subjective norm. It is suggested to investigate the influence of subjective norm for the entire group in a future research to validate this.

In the current setup, each subject participated in the experiment voluntarily. This would change when doing a research within the entire group of interest (ACC at LVNL, approximately 100 people). In this case, it is possible that voluntariness (and lack of voluntariness in participation and using the tool) could have a stronger influence on the attitude toward the new technology. Therefore, the finding that voluntariness was not a dominant factor is not seen as reliable for the entire group of ACC. It is suggested to investigate the influence of voluntariness in a future research.

The set of factors that was researched, the setup of the research and the exact survey and interview questions are expected to be of influence on the dominant factors that were found. In terms of reliability, doing an experiment where people engage with a new technology is seen to be more reliable than doing a survey because in the latter case, results may be confounded by the way people view themselves rather than what their actual attitude toward a new technology is and how this attitude is determined. The survey and research questions were designed such that they touched upon the factors of interest, but without steering people toward certain answers. It is still possible that the context of the research has geared people toward given certain answers e.g. about the importance of improved EAT adherence (job relevance) as the participants knew that was the purpose of the new tool that was being researched.

8.3. Suggestions for Future Research for LVNL

The outcomes of the research suggest that ATCos from ACC have more positive affect towards using new tooling and a higher intention to use when the innovation and its introduction process adhere to the following conditions: (1) operations (ACC) is involved from early on in the process, (2) result demonstrability, output quality and job relevance are high while (3) people believe that their colleagues also accept the innovation (positively reinforcing subjective norm).

Condition (1) should be investigated in a future research. The conundrum in this case is that ATCos do indicate they want to focus on the content of their actual job instead of continuously being involved in research processes, yet they simultaneously indicate that they appreciate being involved early on in a research process. A potential solution for this problem could be to think about communication structures that do reach operations, without taking significant portions of their time, and setting up a structure that allows for easy feedback.

It seems as if (2) result demonstrability, output quality and job relevance are main drivers for perceived usefulness while also being of influence on attitude toward use within this group. Therefore, it is recommended to LVNL within an innovation process to continuously ensure a clear communication about how a tool or system innovation performs on these aspects. This also means that, when taking on people early in the process, and asking them for feedback at that moment, it is essential to be open about the benefits as well as shortcomings in these areas.

Finally, it is recommended to research the actual stance of people within the entire ACC group towards system innovations, and the reasons people have for their opinion. Since subjective norm seems to be an important factor within ACC while the ATCos may not always have a correct view of the opinion of their colleagues, better information and communication about this can accelerate the acceptance of an innovation in the case the actual attitude of people toward innovation is more positive than their colleagues believe it to be.

8.4. Broader Context, Application and Implications for LVNL

The findings of this research are important because lack of positive attitude towards new technologies is a known problem in air traffic control as well as in other domains that are known to be either conservative, bureaucratic or highly safety-oriented. Identifying not only the exact factors that play a role in determining the final affect and intention towards use of a technology, but understanding the relationship between timing and development of affect and intention can clarify the view people have on decision support systems within their organization in general.

The broader objective or long-term goal that is related to this research is to make sure ATCos have a more positive attitude toward the use of new technologies in their work. This research contributes to this by identifying several dominant factors and generating insight in how these factors shape an ATCo's attitude toward a technology. Indications on how several factors could be changed for positively influencing attitude toward new technology are the following. When introducing a new technology, the communication about the added benefits (job relevance) should be clear. Not only the benefits of the technology, but also the shortcomings should be discussed in an open manner. Since subjective norm was found to be important within the group while people were not always aware of the actual attitude of their colleagues toward technological innovation. By first researching what people in ACC think about the use of a new tool (or e.g., improving EAT adherence), and then communicating this to the group, subjective norm could be used as a more positive influence on ATCos attitude toward the technology. Finally, as people have indicated that timely involvement of operations is important, communication about development processes and the level of involvement of operations during the process is recommended.

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A

Experiment Invitation

The experiment invitation e-mail text is presented in the frame below, and the invitation in Figure A.1.

Beste ACC's,

Bij deze wil ik jullie graag uitnodigen mee te doen aan een experiment om de vertical view/stack te verbeteren voor tijdens het holden - dus op het moment dat er een dedicated stack controller is.

Wie vraagt dit eigenlijk aan jullie? Leuk dat je de tijd neemt om tot zo ver te lezen! Ik ben Stephanie Wiechers, 26 jaar, en studeer op dit moment communicatie en lucht- en ruimtevaart in Delft. Oorspronkelijk kom ik uit Breda, maar woon nu al een tijdje in Rotterdam, en vind het leuk om in mijn vrije tijd te tennissen en te pottenbakken. Sinds oktober ben ik bezig mijn master afstudeeronderzoek te doen dat gaat over holding stacks en dan specifiek de invloed van het indraaimoment op de EAT. Hierbij heb ik al veel samengewerkt met Jonah en Jorien, en ben ook al eens mee gaan kijken in de sim om te zien hoe het er in het "echt" aan toe gaat. Maar goed, dé manier om er achter te komen wat jullie belangrijk vinden is natuurlijk door het jullie in het echt te vragen. Vandaar deze oproep.

Het verdere idee is dat over een paar jaar een aantal nieuwe hulpmiddelen in de vertical view beschikbaar zijn + eventueel in de radarschermen om ondersteuning te bieden bij het indraaien. Met zo'n tool wordt het voor jullie makkelijker in te schatten wanneer je kan indraaien, en ook overzichtelijker - dat is in ieder geval de bedoeling. Aangezien de ontwikkeling nu nog in een vrij vroeg stadium is, is dit hét moment om dingen aan te passen en precies te maken zoals jullie ze graag zouden zien! Het enige nadeel is wel dat de uitvoering dus niet meteen morgen in de systemen gaat zitten.

In het kort Op basis van wat ik allemaal heb gezien en gehoord in de afgelopen 8 maanden, heb ik een eerste idee voor een tool in elkaar gezet. We zullen aan de slag gaan met een gesimuleerd holding scenario in een iets versimpelde interface, waarbij jullie zelf kunnen ervaren of het prettig werkt, wat nuttig is, wat juist niet, of dat er onderdelen zijn die jullie graag in de systemen zouden terugzien of dat het juist helemaal anders moet.

Na het draaien van het holding scenario is er ook nog genoeg tijd ingecalculeerd waar ik graag van jullie wil horen hoe je het hebt ervaren. Dit is dan ook meteen een oproep om eventueel van te voren na te denken over wat er nu nog minder goed werkt in de praktijk met holden en op welke punten jullie graag verbetering zouden willen zien.

Wanneer Tussen XXX t/m XXX. In het totaal (scenario + feedback) gaat het ongeveer 2 uur duren, omdat ik jullie er niet te veel mee wil belasten en van zo veel mogelijk feedback wil krijgen!

Qua tijden is het super flexibel: bijvoorbeeld voor/na een shift als je toch op LVNL bent. Als je thuis aan de slag bent en het liever vanaf daar wilt doen dan ga ik er alles aan doen om dat te regelen. Dus laat me vooral weten wat voor jou goed uitkomt en dan gaan we dat plannen. Als je het nog niet helemaal weet maar wel graag mee doet kunnen we ook samen naar een moment zoeken.

Extra extra Last but not least: voor wie het leuk vindt is er een klassement. Wie het scherpst op de EAT kan sturen met de tool wint. Meedoen is geheel vrijwillig, maar ik kan wel verklappen dat de winnaar een taart krijgt!

Ik hoop van jullie te horen!

Groetjes, Stephanie

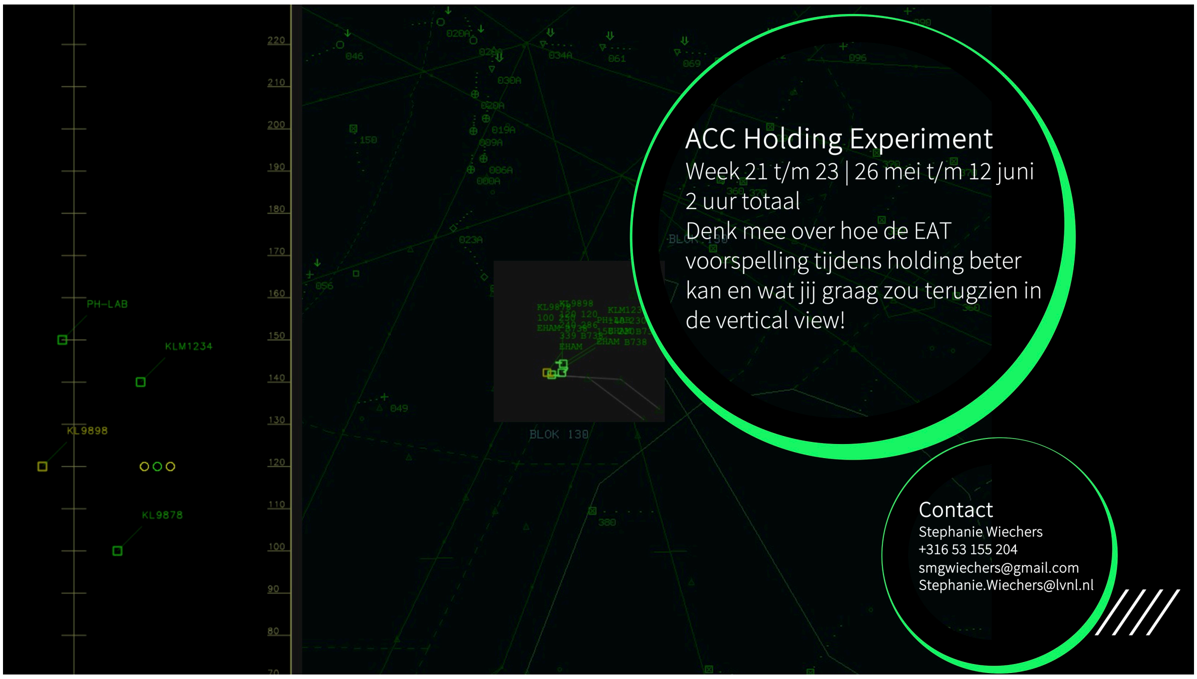

Figure A.1: Experiment invitation

B

Survey and Interview Questions

Survey and Interview Questions

Design and Evaluation of a Visual Support Tool and Exploring the Emotional Relation Between Air Traffic Controller and Interface Innovation

By Stephanie Wiechers

Introductie

Dit document vormt de basis van de subjectieve vragen die betrekking hebben op het experiment wat we gaan uitvoeren, holding support (zowel in het algemeen als specifiek over het concept), en is daarnaast bedoeld om op in het kader van een wetenschappelijk onderzoek informatie te verzamelen.

Vertrouwelijkheid

Alle gegevens die je hier invult zullen vertrouwelijk worden gebruikt. De enige mensen die er toegang tot hebben ben ik plus, als het nodig is, mijn directe afstudeerbegeleiders. In alle gevallen zal ik ervoor zorgen dat dit geanonimiseerd wordt verwerkt. Alles wat je invult wordt vertrouwelijk behandeld en op een anonieme manier in mijn afstudeerverslag verwerkt (denk aan "P1"). Verder zal ik eventuele quotes altijd eerst aan je voorleggen voor ik ze verwerk. Op de volgende pagina word je gevraagd een "informed consent [Engels]" in te vullen, waarmee ik toestemming vraag je gegevens te verwerken.

Opzet

Er zal steeds als je moet wachten tot na een bepaald onderdeel een lege pagina zijn met "omslaan na …. [onderdeel X]". Ik zal dit ook aangeven tijdens het experiment.

Timing

Er zijn best veel survey vragen. Deze lijken voor een groot deel vrij veel op elkaar. Je hoeft hier niet super lang over na te denken; alleen als de vraag niet duidelijk is dan is het handig om me om verheldering te vragen! Een aantal van de vragen zijn op nét een andere manier gesteld om zo altijd een helder en duidelijk beeld van jullie mening te krijgen. Om zo veel mogelijk tijd over te houden voor feedback en een gesprek aan het einde wil ik dus vragen om niet al te veel na te denken bij het invullen van de survey vragen maar gewoon je eerste gedachte op te schrijven.

Informed consent

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated __/08/2021, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a simulation experiment combined with survey questions and an audio-recorded semi-structured interview, both of which will be destroyed after completing the research.	☐	☐
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: potential mental discomfort through reflective insights.	☐	☐
Use of the information in the study		
I understand that information I provide will be used to draft up a report.	☐	☐
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted anonymously in research outputs.	☐	☐
I agree to joint copyright of the written information during the workshop to the researcher.	☐	☐
Future use and reuse of the information		
I give permission for the anonymized audio transcripts and anonymized interview data that I provide to be archived as long as the research lasts.	☐	☐
I give permission for the anonymized survey data and interview transcripts to be archived such that they can be used for future holding support researches.	☐	☐

Signatures

_______________________	_______________________	_________
Name of participant	Signature	Date

I have presented the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__________________________	____________________	_________
Researcher name	Signature	Date

Algemene vragen

Naam ____

Leeftijd ____

Geslacht ______________________________ Links/rechtshandig ___________________

Email ____

Telefoon ____

Aantal jaren ervaring als verkeersleider ______________________________________

Posities gehad binnen luchtverkeersleiding ____________________________________

____

____

____

Ervaring met eerdere innovatie-onderzoeken ____________________________________

____

____

____

Holding support

Vind je dat er een holding support systeem moet komen?

Zeker niet ☐☐☐☐☐ Heel graag

Waarom? ____

____

____

Wat voor verwachtingen zou je van zo'n systeem hebben? _________________________

____

____

____

Hoe scherp denk je dat EAT adherence in holding nu is? Hij valt 95% van de tijd binnen…

o	o	o	o	o
>2.5 mins	2 mins	1 min	30 s	10 s

Toelichting? Vind je hier iets van? ____

____

____

Uitleg experiment verloop

Training scenario

Gebruiksgemak & werklast

A1. Op basis van de uitleg en training lijkt het gebruiken van de tool me …

Heel moeilijk						Vanzelfsprekend

A2. Op basis van de uitleg en training verwacht ik dat de werklast **met tool** ten opzichte van de werklast zonder tool als volgt verandert:

Neemt sterk af						Neemt sterk toe

Effectiviteit

A3. Deze tool lijkt me:

Nuttig						Nutteloos
Aangenaam						Onaangenaam
Slecht						Goed
Prettig						Vervelend
Effectief						Overbodig
Irritant						Aantrekkelijk
Behulpzaam						Waardeloos
Ongewenst						Gewenst
Maakt me alert						Slaapverwekkend

EAT adherence

Bij de volgende vragen gaat het er om dat hij 95% van de tijd binnen… valt

A4. Welke EAT adherence denk je dat je gaat halen in de simulatie **zonder** de tool?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

A5. Welke EAT adherence denk je dat je gaat halen in de simulatie met het gebruik van de tool?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

A6. Welke EAT adherence denk je dat je zou halen als **alleen de delta-T in de stack list** zou updaten?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

A7. Welke EAT adherence denk je dat je zou halen met **alleen de delta-T in de labels?**

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

A8. Welke EAT adherence denk je dat je zou halen met **alleen de ecology dots?**

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

Scenario 1

Gebruiksgemak & werklast

B1. Ik vond het werken met de interface in scenario 1…

Heel moeilijk						Vanzelfsprekend

B2. Ik vond de werklast van scenario 1…

Heel erg zwaar						Heel erg licht

B3. Was het realistisch?

Effectiviteit

B4. De mogelijkheden die ik in scenario 1 had om een overzicht van de verkeerssituatie te krijgen en de EAT adherence zo dicht mogelijk naar 0 te krijgen waren…

Nuttig						Nutteloos
Aangenaam						Onaangenaam
Slecht						Goed
Prettig						Vervelend
Effectief						Overbodig
Irritant						Aantrekkelijk
Behulpzaam						Waardeloos
Ongewenst						Gewenst
Maakt me alert						Slaapverwekkend

EAT adherence

B5. Welke EAT adherence denk je dat je hebt gehaald in scenario 1?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

Scenario 2

Gebruiksgemak & werklast

C1. Ik vond het werken met de interface in scenario 2…

Heel moeilijk						Vanzelfsprekend

C2. Ik vond de werklast van scenario 2…

Heel erg zwaar						Heel erg licht
Veel lichter dan S1						Veel zwaarder dan S1

C3. Was het realistisch?

Effectiviteit

C4. De **delta-T** update in de **stack list** was … voor het overzicht van de verkeerssituatie en EAT adherence

Nuttig						Nutteloos
Aangenaam						Onaangenaam
Slecht						Goed
Prettig						Vervelend
Effectief						Overbodig
Irritant						Aantrekkelijk
Behulpzaam						Waardeloos
Ongewenst						Gewenst
Maakt me alert						Slaapverwekkend

C5. De **delta-T** in de **labels** was … voor het overzicht van de verkeerssituatie en EAT adherence

Nuttig						Nutteloos
Aangenaam						Onaangenaam
Slecht						Goed
Prettig						Vervelend
Effectief						Overbodig
Irritant						Aantrekkelijk
Behulpzaam						Waardeloos
Ongewenst						Gewenst
Maakt me alert						Slaapverwekkend

C6.De **ecology dots** waren … voor het overzicht van de verkeerssituatie en EAT adherence

Nuttig						Nutteloos
Aangenaam						Onaangenaam
Slecht						Goed
Prettig						Vervelend
Effectief						Overbodig
Irritant						Aantrekkelijk
Behulpzaam						Waardeloos
Ongewenst						Gewenst
Maakt me alert						Slaapverwekkend

EAT adherence

C7. Welke EAT adherence denk je dat je hebt gehaald in scenario 2?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

C8. Welke EAT adherence denk je dat je zou halen als **alleen de delta-T in de stack list** zou updaten?

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

C9. Welke EAT adherence denk je dat je zou halen met **alleen de delta-T in de labels?**

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

C10. Welke EAT adherence denk je dat je zou halen met **alleen de ecology dots?**

o	o	o	o	o
>2.5 mins	2 mins	1.5 min	1 min	30 s

Nauwkeurigheid voorspelling

C11. De voorspelling gemaakt door de tool valt 95% van de tijd binnen een marge van …

o	o	o	o	o
1s	5s	10s	30 s	60s +

Interview | Feedback

Vragen

Opzet

1. Motivatie tooling
2. Suggesties, verbeterpunten

Vragen

1. Hoe zie jij nut/noodzaak van een tool voor holding support?
2. Wat voor voor- en nadelen zitten er aan hogere EAT adherence?
3. Hoe zie jij de link tussen het wel/niet hebben van een holding support systeem en de EAT adherence die minimaal gehaald kan worden?
4. En in het specifieke geval van deze tool?
5. Zou je de tool die je net hebt gezien willen gebruiken? Wat wel/niet?
6. Is je gevoel daarover veranderd of bijgesteld tijdens de loop van het experiment?

Suggesties

1. Wat voor suggesties of verbeterpunten zie jij voor een holding support tool?
2. Wat voor onderdelen vind je nog meer belangrijk?
3. Zou je een tool die al die features heeft willen gebruiken? En hoe veel?
4. Denk je dat er nog andere dingen zijn in een verbeter/innovatieproces die jouw motivatie om zo'n tool te gebruiken kunnen veranderen? Bv betrekken ACC, communicatie, implementatie….

C
Full Interview Transcripts

The coded quotes can be found in Table C.2. The codes that were not pre-defined (open coding) and have been labeled under "other factors" as a general finding can be foudn in Table C.1. An overview of the frequency of quotes per participant can be found in Figure C.2. The total frequency by which each code occurred can be found in Figure C.1.

Table C.1: Additional codes from open coding the interviews

Code	Explanation
Involvement	Involvement of ATCos / operations at any time in the innovation development process
Recommendation	Something that is important for LVNL and can be used in the future
Expectations	Things that have happened in the past, e.g., lack of implementation, causes skepticism among ATCos which influences their attitude toward innovation

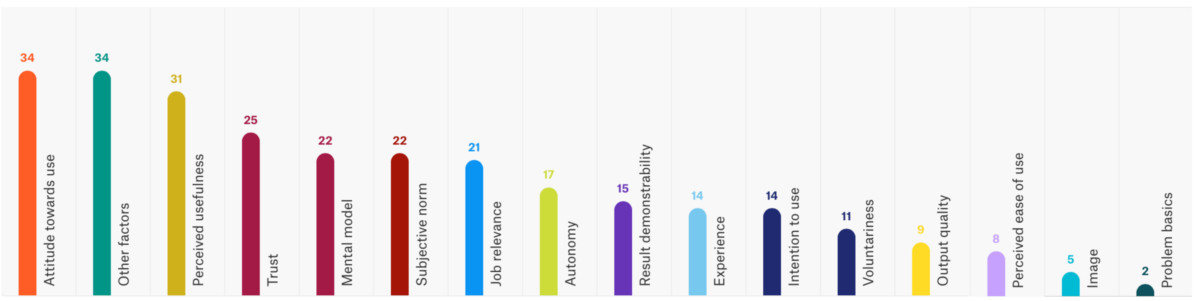

Figure C.1: Frequency of different codes in interviews

Table C.2: Coded quotes per participant [1]

Participant	Quotation	Codes	Comment
P5.docx	[Tijdens loop v experiment gevoel bijgesteld] Je gaat er op bouwen. Ik wil uitgebreider zien. Je begint met kist 1, handig, daar moet ik indraaien, kist 2. Ik heb in dat opzicht minder in mijn hoofd een soort plan om dat ik het idee heb dat die tool me daar bij gaat helpen	Attitude towards use, Trust	
P10.docx	Afhankelijk van het gedeelte van de vlucht ben ik overgestapt van de ene op de andere tool.	AE | Strategy	
P10.docx	Afhankelijk van het gedeelte van de vlucht ben ik overgestapt van de ene op de andere tool. Dus delta-t om te bepalen waar zit ik, hoe ver moet ik nog, en dan delta-t in samenwerking met de eco dots om te bedeken, waar zit ik en kan ik nu ongeveer gaan draaien.	AE | Strategy	
P4.docx	Al helemaal als je een dataset er in gooit met van hee dit is wat deze kisten gemiddeld genomen doen. Kijk als er te veel variantie is moet je er niet van uit gaan.	Trust, Other factors	Future improvements
P5.docx	Alle veranderingen die we krijgken zijn vaak dingen die we niet zelf willen, maar ons worden opgelegd. En dat hoort er ook bij, je kan niet altijd maar alles krijgen wat je zelf wilt, maar het zou mooi zijn als het een compbinatie is van dingen die moeten gebeuren en dingen die ook voor ons bruikbaar zijn	Voluntariness, Job relevance	
P4.docx	Als de EAT adherence pm 15 sec ofzo is kan je in de TMA gewoon heel voorspelbare patronen vliegen, zoals vaste naderingsroutes. Dus dat is voor APP voorspelbaarder en voor de omgeving kan je dan vaste glijpaden volgen, eerder dan alleen op de ILS, maar dan moet je het wel in alle sectoren doen en het systeem zo inrichten dat het voor iedereen haalbaar is.	Other factors	Purpose of tool in bigger picture
P3.docx	Als dit goed werkt is het een goede toeveoging, daar ben ik van overtuigd.	Trust, Perceived usefulness, Attitude towards use, Result demonstrability	
P4.docx	Als het begin mis gaat zit je er wel de hele tijd mee	Mental model, Experience	Mental model because separation is still kept
P5.docx	Als het er niet is, ga je er ook niet op bouwen	Autonomy	
P3.docx	als het kan is de 0 altijd het beste.	Job relevance	
P2.docx	Als hij blauw is dan zit iedereen te kijken van hoe zit dat eigenlijk.	Subjective norm	
P4.docx	Als je daar die afteller in ziet, het zou kunnen helpen, ik vond de rust dat je het op je radarscherm ziet, van als hij daar is en dan moet je wat doen, dat vond ik wel lekker.	Perceived usefulness, Attitude towards use	
P3.docx	Als je echt een goede tool hebt, en ziet van nu moet ik indraaien om op nul uit te komen, is het eenvoudig om op nul uit te komen	Trust, Perceived ease of use, Result demonstrability	

Table C.3: Coded quotes per participant [2]

Participant	Quotation	Codes	Comment
P3.docx	Als je echt met de tool wilt werken, dan werkt de huidige tool niet zo goed, als je echt op de nul wil uitkomen in de hold	Other factors, Mental model	
P3.docx	Als je een werekende delta-t hebt dan zou het usper goed zijn. Zo van nu moet ik indraaien, dat is ideaal.	Result demonstrability, Trust, Perceived usefulness, Attitude towards use	
P5.docx	Als je mensen wil overtuigen om het te gebruiken moet het gewoon kloppen	Trust, Output quality, Intention to use, Result demonstrability	
P5.docx	Als je mensen wil overtuigen om het te gebruiken moet het gewoon kloppen. Het moet heel gebruiksvriendelijk zijn	Perceived ease of use	
P5.docx	Als je mensen wil overtuigen om het te gebruiken moet het gewoon kloppen. Het moet heel gebruiksvriendelijk zijn. Er moeten geen fouten in zitten dat je iets instuurt en er dan toch 2 minuten verschil in zit. Er mag een bepaalde foutmarge in zitten want die zit er ook in als ik het doe maar in de basis moet het gewoon altijd goed werken. Dat is belangrijk	Output quality, Perceived usefulness, Intention to use, Attitude towards use, Result demonstrability	
P4.docx	Als je zo'n tool hebt zou je meer op de geplande tijden kunnen doorsturen en daarin meer rust kunnen ervaren	Perceived usefulness, AE | Workload	
P4.docx	Als jeh et niet met de tool eens bent kan je altijd afwijken	Autonomy	
P10.docx	Als mens leer je daar omheen werken, bijna het manipuleren van het systeem om te zorgen dat je alsnog binnen de lijntjes kan krijten	Other factors, Autonomy	
P5.docx	Als we hier op gaan bouwen, moet het gewoon werke	Trust	
P9.docx	Beetje jammer dat we het niet geimplementeerd hebben op AAA, dat we het beneden niet geimplementeerd hebben, want ik denk dat we daar veel betere en realistischer resultaten op kan halen	Mental model, Other factors, Experience	Realism
P10.docx	Begin moment vormen mening is geloof ik voor ik de tool heb gezien. Ik heb in het stukje wat je voor we de test hebben gedraaid opgeschreven dat ik hoopte op een bepaalde manier van integratie, dat dat fijn is, want piloten weten ook wat ze aan het doen zijn. Dat zie je in de tool niet, maar dat is misschien ook wel ten goede van de tool. Het maakt gebruik van de middelen die we hier hebben, het maakt geen gebuik van derde partijen. Ik was eigenlijk wel prettig verrast, ik was heel snel kon ik er op leunen om de tool te gebruiken waar voor hij bedoeld was, en merkte ik dat ik de stack lijst liet voor wat hij is omdat hij in deze fase vn het verkeer niet van toegevoegde waarde was.	Mental model, Job relevance, Attitude towards use, Perceived usefulness	
P2.docx	Betrouwbaarheid is het belangrijkste en dat je mensen betrekt om die betrouwbaarheid voor elkaar te krijgen.	Trust, Autonomy	

Table C.4: Coded quotes per participant [3]

Participant	Quotation	Codes / Comment
P8.docx	Bij iedere verandering moet even worden duidelijk gemaakt, het kost je tijd en moeite, er wordt wat van je gevraagd, of iets nieuws te leren of iets ouds af te leren, maar uiteindelijk gaat het je dit opleveren. Als dit tussen de oren zit van de mensen, en die overtuiging er maar is, dan kan zon traject succesvol zijn, en is het over het algemeen ook succesvol.	Attitude towards use, Experience, Perceived ease of use
P6.docx	Bij S2 had ik als je dan een kist aanklikt dat hij dan gehighlight wordt. Ik vond het persoonlijk wat minder fijn	Attitude towards use
P6.docx	Conclusie was dat je zonder de tool eigenlijk best veel tijd kwijt bent aan wat is de EAT enhuidige tijd en indraaien. Zeker als een hold best vol hangt en je ook bezig bent met zakken en labels, en dat dan een tool wel gewenst is.	Perceived usefulness, Attitude towards use
P5.docx	Daar heeft corona niet bij geholpen. Het feit dat jij nu hier zit en dat we het er over kunnen hebben op een regelmatige basis. Dus jij bent iets aan het maken, oh hoe zal ik dit doen, en dat je het gelijk kan neerleggen, dat maakt het zo veel eter dan soort van oh ik heb drie maanden iets gedaan, kijk er even naar, dan heb je heel veel tijd besteed aan iets en dan zegt iemand toch van ik vind het veel handiger als je het zo doet. Dat is ook heel kut voor jou. Ik denk dat zoiets als dit daar heel erg bij helpt, dat je op regelmatige basis met hele kleine vragen, bijvoorbeeld moet dit geel of blauw zijn, iets heel simpels eigenlijk, maar wat wel veel verschil kan maken voor hoe mensen iets beleven, dat dat heel waardevol is. En nu ben ik hier, maar als er meer mensen bij betrokken worden van ops, die kennen het dan al, hebben al een steentje er aan bijgedragen en worden van vervolgens ook een soort pleitdrager van die ontwikkeling omdat ze het gevoel hebben dat ze er zelf iets aan hebben bijgedragen. Stel dat je nu zou zeggen, tien mensen hebben dat experiment gedaan, over 2-3 jaar willen we dit concept gaan uitwerken, dan heb je al een groep mensen die betrokken zijn geweest en een idee hebben wat afwegingen zijn geweest om iets wel of niet te doen. Dat maakt het veel makkelijker om iets in de praktijk te doen. Wat er nu gebeurd is dat het een soort van cold turkey iets wordt geroepen of gedaan,d it is wat we gaan doen, dan voelen mensen zich gepasseeerd, al dan niet terecht, maar goed je wilt dat mensen die ontwikkeling accepteren, heel veel mensen kunnen ook een waardebolle bijdrage leveren en daar maak je op deze manier wel het beste gebruik van denk ik. De laatste twee weken toen je hier hebt gezeten, ging je toch sneller vragen, merkte je al dat de drempel weg was. Dus ik hoop dat dit meer de standaard wordt dan wat jij in het eerste gedeelte hebt gehad. Nuttig voor afstudeerders in de toekomst. Wat je ziet, en wat heel jammer is, is dat afgelopen jaren 3-4 mensen per jaar zijn afgestudeerd. En letterlijk, van al die dingen, mensen weten niet eens dat het bestaat. Dan zit je 6 maanden te ploeteren op iets wat misschien heel interessant is, misschien niet, maar mensen weten niet eens dat het bestaat en we doen er niks mee. En als er iets mee wordt gedaan is het altijd iemand op een kantoor van kijk wat interessant en dan komt het weer in een laatje.	Other factors. Comment: What is relevant for future development processes: regularly ask OPS questions, be on the floor, engage people, explain what drivers were and why they were chosen (in contact with OPS)
P2.docx	Daarom keek ik ook veel minder naar die dots en veel meer naar die tijd in het label	Perceived usefulness
P3.docx	Dat hij altijd goed werkt	Trust, Perceived usefulness, Output quality

Table C.5: Coded quotes per participant [4]

Participant	Quotation	Codes	Comment
P4.docx	Dat hij dan aangeeft van, die moet je op de heading locken.	Trust	
P6.docx	Dat is mijn mening ik ben ook benieuwd wat de anderen er van vinden, want het geeft wel een rustiger beeld. Ik vond het leuk en best wel veelbelovend.	Subjective norm, Attitude towards use, AE | Workload	
P2.docx	Dat je volledig kan vertrouwen op het systeem.	Trust	
P5.docx	Dat kan je doorontwikkelen, maar ik zou dat echt zien als iets wat je doet nadat je zoiets al hebt. Dus we gebruiken zon systeem en dan gaan we weer een stap verder zetten. Ik ben bang dat als je te veel in een keer doet, je het onmogelijk voor jezelf maakt om zoiets te gaan doen. Maar ik kan me voorstellen dat je het uiteindelijk gaat doen.	Other factors	Doorontwikkeling systeem
P8.docx	Dat moet je dan wel echt leren kennen	Experience	
P4.docx	Dat si ook waar ik in het begin niet goed ging, bij de kisten waarbij ik dat niet had gedaan. Maar als je dan op een gegeven moment lockt op koers 70, koers 70, en dan op die kleurtjes kijken. Als je dan zo draait, en je moet nog drie minuten en het is twee minuten vliegen, dan is koersje 70 net een beetje heftig, want als hij dan rechtsom een orbitje gaat maken dan ben je weer net te laat. Dus dat is misschien de limitatie aan wat je nu doet, maar dat kan je voorkomen door ze al eerder op hun outbound te locken.	AE | Strategy	
P4.docx	De computer kan beter rekenen dan jijzelf.	Mental model	
P9.docx	De delta-t in het label daar heb ik niet super veel aan dat heeft er meer me e te maken dat je meer met vv werkt maar in het label hier zelf denk ik kan wel hoeft niet	Intention to use, Perceived usefulness	
P5.docx	De delta-t in label en list kan je wat iedereen betreft denk ik morgen er in zetten	Attitude towards use, Intention to use, Subjective norm	
P10.docx	De toepassing van de tool was goed	Other factors	realism
P6.docx	De tool: ik vond het leuk om te zien, zeker delta-t	Attitude towards use	
P3.docx	Deze tool hier, de ecology tool, voor mij als de delta-t goed werkt, zo van als ik nu draai dan komt het goed, dat is voor mij het belangrijkste.	AE | Strategy	
P5.docx	Die delta-t zou je morgen in kan voeren, en bij wijze van spreken overmorgen die dots in een bepaalde vorm.	Attitude towards use, Intention to use	
P5.docx	Die dots, ik vond die heel handig, op de achtergrond weet hij het allemaal al. Laat ht dan zien. Laat ons dat gebruiken in onze besluitvorming	Perceived usefulness, Attitude towards use	
P9.docx	Die economy dots vind ik super mooi om te zien	Attitude towards use	
P4.docx	Dus daarbij zou zon tool zeker kunnen helpen	Perceived usefulness	
P4.docx	Dus dat is misschien de limitatie aan wat je nu doet, maar dat kan je voorkomen door ze al eerder op hun outbound te locken.	AE | Strategy	
P4.docx	Dus het is ook een soort mindset, de tool heeft namelijk toch wel gelijk	Subjective norm, Autonomy, Mental model	
P2.docx	Dus ik focus gewoon op ze netjes in een rijtje aanleveren	Autonomy	

Table C.6: Coded quotes per participant [5]

Participant	Quotation	Codes	Comment
P2.docx	Dus ik was wel constant aan het checken van klopt het allemaal	Trust	
P5.docx	Dus tussen haakjes is het heel simpel, maar het zou voor ons een enorm innovatieve stap zijn omdat het mij veel beter ondersteunt in het nemen van een beslissing dan iets wat ik nu heb.	Other factors, Perceived usefulness, Result demonstrability	
P9.docx	Economy dots en highlighten, dat zijn tweee dingen die ik graag zou willen zien	Intention to use, Attitude towards use	
P5.docx	Een vorm van support duwt mensen ook in dezelfde werkwijze dus je maakt als de support goed werkt het mensen makkelijker en mogelijk om accurater af te handelen	Voluntariness, Perceived usefulness	
P2.docx	En als we om een andere reden holden, bijvoorbeeld op zicht, is het wel belangrijk dat je die puntjes uit kan zetten.	Voluntariness, Autonomy	
P5.docx	En daarom denk ik dat iets als wat jij hebt gemaakt plus eventuele doorontwikkeling heel bruikbaar is en direct een soort van winst oplevert.	Attitude towards use, Job relevance, Perceived usefulness	
P4.docx	En dan komen ze vaak te laat, en soms wel drie minuten te laat	Other factors, Problem basics	
P3.docx	En dat hij de wind meeneemt, en je het holding pattern in je algoritme zet, zo van zo lang duurt een holding pattern en zo duurt de bocht	Output quality	
P2.docx	En dat je er mee gewerkt hebt en dat het zich heeft bewezen, dat het heel goed werkt.	Experience, Result demonstrability, Trust, Output quality	
P5.docx	En heel bruikbaar omdat we nu niet extreem vaak holden	Job relevance, Perceived usefulness	
P6.docx	En het is wel grappig om in vergelijking met S2 te zien dat we echt heel weinig hebben nu	Other factors, Perceived usefulness	Let people EXPERIENCE tool and learn that it is better because of this
P2.docx	En iedereen op zaal kan heel goed op plus 2 min mikken maar dus ik denk ook dat in plaats van 2 minuten 50 seconden ook kan.	Subjective norm	
P2.docx	En ik denk iedereen als je dit vraagt aan andere verkeersleiders dat 80% het er mee eens is-schijnbaar niet want anders waren we allang terug gegaan	Subjective norm	
P2.docx	en ik heb allemaal tijden van kisten die 1 of 2 minuten van elkaar zitten dan kijk ik eigenlijk niet meer naar tijd en ga ik gewoon een rijtje maken	Autonomy	
P10.docx	En in de praktijk zie je ook dat bij mensen er verschillende omlsagpunten zijn van wanneer ze niet meer gaan vectoren maar gaan holding. Mensen vinden ook dat ze een beetje controle verliezen. Want als je op dat moment doormag ben je de bocht kwijt. Aan de andere kant, als je aan het vectoren bent geldt hetzelfde, dan moet je ook terugdraaien. Het ligt er dus ook aan wat je gewend bent.	Autonomy, Mental model, Other factors	Strategies

Table C.7: Coded quotes per participant [6]

Participant	Quotation	Codes	Comment
P5.docx	En of je het nou precies zo doet, maar in ieder geval het concept dat je op je track een bandbreetje laat zien waarin je kan draaien. En als ik dan beslis om op een ander moment te draaien, prima, maar dan weet ik in ieder geval wat voor effect het gaat hebben op mijn verkeer. Dat vind ik iets positiefs, het dicteert mij niet wat ik moet doen, het maakt alleen maar inzichtelijk wat er gebeurd als ik nu iets doe.	Autonomy	
P4.docx	En op die manier kan je ook met zon tool, als je mensen daarin meeneemt, en laat zien van dit kan het al, dat je die weerstand meeneemt. Zoals nu. Zon experiment is al heel goed, laat mensen het maar testen voordat het op zaal komt.	Other factors	SUPER IMPORTANT FOR FUTURE INNOVATION :)
P2.docx	Er is altijd een grens, 0 gaat niet lukken, maar een 2 minuten range zorgt er eigenlijk voor dat wij altijd 2 minuten te vroeg zijn en het liefst 1 min 59 want dan hebben we precies voldaan aan de afspraak.	Subjective norm, Image	
P4.docx	Er zijn tekortkomingen, die erkennen we, maar het is wel beter voor dit en dit en dit,	Job relevance, Output quality, Result demonstrability	
P5.docx	Het begint iets minder te worden maar zeker vroeger was afstand de enige graadmeter voor overdracht	Mental model	
P8.docx	Het fijne is ook dat je met die delta-t kan zien wat je speed instructie gaat doen	Result demonstrability	
P2.docx	het idee er achter begrijp ik en ik denk dat het best wel oke is	Perceived usefulness	
P2.docx	het idee is heel goed	Perceived usefulness	
P8.docx	Het is dus alleen maar nuttig, beter op de EAT vliegen, als je er daarna iets mee doet. Precies	Job relevance	
P2.docx	Het is geen must in mijn ogen maar wel een ziek hulpmiddel	Job relevance	
P3.docx	Het is vrij lastig als de tijden verspringen	AE | Performance	
P3.docx	Het maakt bij ons eigenlijk niet uit wat je brengt, 50% gaat toch altijd klagen, wat je ook brengt, dus daar moet je altijd doorheen als je iets nieuws wilt invoeren.	Subjective norm, Mental model	
P5.docx	Het moet niet uitvallen, maar als het uitvalt is het jammer. Niet onveilig. Wel jammer voor de sequence, maar als je ziet hoe we nu een sequence bouwen vanuit een holding is dat ook geen ideale situatie. Je moet het wel vergelijken met hoe het nu in de praktijk is. Het is een soort support tool die niet nodig is voor de veiligheid maar voor efficiente verkeersafhandeling	Trust	
P3.docx	Het moet wel echt goed werken, anders creeert het alleen maar verwarring.	Output quality, Trust, Perceived usefulness, Result demonstrability	
P5.docx	Het past bij wat we nu doen	Mental model, Perceived ease of use	
P5.docx	Het past bij wat we nu doen, je hoeft er niks anders voro te werken, het geeft alleene een beter inzicht in wat je al doet	Perceived ease of use, Autonomy	

Table C.8: Coded quotes per participant [7]

Participant	Quotation	Codes/Comment
P10.docx	Het systeem van de simulatie van wat we hebben ziet er goed uit. Snel genoeg om mee te kunnen helpen	Perceived ease of use, Experience
P10.docx	Het vetrouwen in het systeem is super belangirijk; dit zou een mooie tussenoplossing/tussenstap zijn. Dan heb je precies getest wat het moet doen, en je het op een parallel ding laat lopen, zodat je het kan testen in het echt	Trust, Result demonstrability
P6.docx	Het viel op dat delta-t in het label anders was dan die in de stack list. Ik vond hem in het label heel fijn en had ook dat ik er veel naar keek. En die ecology dots vond ik wel fijn	Attitude towards use
P6.docx	Hij houdt al rekening met huidige speed en wind toch? Ja. Nee denk dat dit wel het belangrijkste is.	Job relevance, Output quality
P9.docx	Iedereen gaat zeggen dat dit een super handig tool voor ons is en dat we daar eerder dan over 5 of 8 jaar iets mee willen.	Other factors / Implementation time
P9.docx	Ik bedoel wij doen dit ook om ons werk een beetje beter door te kunnen voeren en volgens mij moet dan het management of hetnou fedrinand is of iemand van onze unit managers of wie dan ook naar de mensen toe die hier aan deelnemen van hee zie je nut hier van hebben we tijd om dit voer een paar jaar te doen en dan kan je je prioritizering een beetje aanpassen. Ik denk dat elke verkeersleider het er mee eens is. Nu is het, je neemt deel hier aan en dan hoor je er 567 jaar niks van. En dat is niet de bedoeling, vooral als het ons werk makkelijker en efficienter maakt. Ik denk ook dat je hier.	Other factors / implementation time
P10.docx	Ik ben goed in opmerkingen maar niet in de oplossingen. Dat is ook de reden dat ik niet aan de kantoor- of systeemkant veel meeloop	Other factors
betrokkenheid		
P2.docx	Ik controleerde ook als ik dat lijntje zag en dan checkte ik met de tijd, en dan zag ik van oh dat klopt wel ongeveer	Result demonstrability, Output quality
P2.docx	Ik denk als je er van uit kan gaan dat de dots klop[en dat het dan wel beter werkt.	Result demonstrability, Trust
P2.docx	Ik denk dat betrokkenheid heel belangrijk is binnen welk innovatieproject dan ook.	Other factors
P9.docx	Ik denk dat de combi eco dots en vv een prettigere en rustigere holding maakt.	Attitude towards use
P5.docx	Ik denk dat die dots zoals jij ze gemaakt hebt ook zou kunnen toepassen in onze normale situatie met vectoren.	Other factors, Perceived usefulness, Intention to use, Attitude towards use
P6.docx	Ik denk dat er vanuit ons ook wel meer aan gedaan kan worden om het nut te zien, zo van als we dit zouden testen met zijn30en dan zouden we veel meer uithalen dan als we maar met 5 deon en dat kan verbeterd worden vanuit LVNL ook	Subjective norm
P5.docx	Ik denk dat het doel hiervan is je tijd halen. Dus niet extra separatie waarborg geven. Dat kan wel, maar dat is dan een uitbreiding van je doelen, en dat is dan weer een verschil. Het liefst zou ik oo heel veel in een keer willen doen. Maar de ervaring leert dat het uberhaupt al niet lukt om een ding te doen. Dus laten we daar mee beginnen en dan daarna kijken of het lukt om nog meer te doen	Job relevance
P4.docx	Ik denk dat het een kwestie is van mensen in het proces meenemen. Waar komt dit vandaan	Other factors, Autonomy, Mental model

Table C.9: Coded quotes per participant [8]

Participant	Quotation	Codes/Comment
P4.docx	Ik denk dat het genoeg ruimte geeft.	Autonomy
P2.docx	Ik denk dat het heel moelijk wordt omdat die fixed routes als je een inbound peak hebt.	Result demonstrability
P4.docx	ik denk dat het wel handig is	Perceived usefulness
P4.docx	Ik denk dat ik het als een ondersteuning zie die je kan helpen, en dat ik dat nog steeds zo zie	Attitude towards use, Intention to use
P6.docx	Ik denk dat verkeersleiders ook denken van ik vind het wel leuk zon experiment maar hoe groot is nou de kans dat er iets mee wordt gedaan terwijl ik denk dat hoe meer we dat doen hoe groter de kans dat er iets mee gedaan wordt. En dat denk ik ook wel ik snap ook dat het niet volgend jaar al in het systeem zit, dat duurt misschien nog wel jaren [5jr] dat is echt erg eingelijk, ik kan me ook wel voorstellen dat mensen dan denken hm geen zin in dat gaat toch niet op krote termijn gebeuren maar aan de andere kant dan blijft alles zoals het nu is dus ikd enk dat mensen daar wel meer enthousiast voor gemaakt zouden kunnen worden.	Other factors, Trust / People dont think anything will happen
P8.docx	Ik denk dat we het tegenwoordig redelijk goed hebben ingeregeld bij LVNL. De betrokkenheid van operationeel personeel bij ontwikkelaars, of dat nou op het gebied van innovatie is, of van procedures, of hoe houden we mensen vakbekwaam. Overal zijn teams met inhoudsdeskundigen bezig die daar over nadenken en gekoppeld daaraan zijn operationele verkeersleiders met bepaalde interesse in dat gebied. Daar voel je van daar is over nagedacht en in zon groep is dat goed bekeken.	Voluntariness, Subjective norm, Mental model
P2.docx	Ik denk dat wij het voordeel hebben dat we nog heel weinig ervaring hebben. Ik denk dat de oudere generatie meer weerstand heeft.	Experience, Age
P4.docx	Ik denk dus dat zon tool wel nuttig zou kunnen zijn	Perceived usefulness
P8.docx	Ik denk wel met zon tool, rekening houdend met hoe conservatief een verkeersleider is, want dat zijn we, het is al lastige genoeg wat we doen, laat die kaders hetzelfde. Want je merkt dat als je de zekerheid van die kaders kwijtraakt, dan moet je die opnieuw eigen maken, en dan kun je weer de vrijheid om in dat hele complexe geheel weer kan doen wat je wilt.	Experience, Autonomy
P6.docx	Ik had ook in die apprgroep gegooid envan hebben jullie je al opgegeven en dan zeggen mensen van oh dat ga ik nu wel doen maar ook niet iedereen. JXXXX had het ook al gestuurd.	Voluntariness
P6.docx	Ik had wel best een beeld bij die ecology dots maar van de delta-t eigenlijk niet en dat vond ik wel verassend en leuk	Attitude towards use
P2.docx	Ik heb nog nooit eerder van het idee gehoord	Experience
P9.docx	Ik vind het een heel nuttig tool	Perceived usefulness
P8.docx	Ik vind het wel een sport om binnen die ene minuut te komen. Maar het is wel iets wat samen op moet gaan. Dus ja ik vind het mooi om dicht bij die EAT te komen, maar als je ziet dat daarna dat geen nut heeft gehad, ja dan ga je het ook niet doen.	Other factors, Mental model / Pride in job + it needs to be used/something needs to be done with it
P4.docx	Ik vond die ecology dots het fijnst	Attitude towards use
P4.docx	Ik vond die ecology dots het fijnst. Omdat die het mooi visueel weergaven.	Attitude towards use
P10.docx	Ik vond het leuk wat je hebt opgezet en wat er staat. Vooral met de beperkte middelen die je hebt, is het heel leuk om te zien.	Attitude towards use
P5.docx	Ik vond het leuk.	Voluntariness
P2.docx	Ik zit dan altijd te meten, verkeersleiders kijken altijd nog steeds naar de afstand en niet naar de tijd.	Subjective norm, Job relevance
P2.docx	Ik zou er niet 100% op kunnen vertrouwen. Want dan draai je met de eerste te vroeg en dan zit je straks te krap achter je voorganger.	Result demonstrability, Trust

Table C.10: Coded quotes per participant [9]

Participant	Quotation	Codes/Comment
P10.docx	Ik zou haast zeggen, de durf hebben om bepaalde dingen in te zetten, zoals we net al bespraken, zodat het non-intrusive is. Dat het niks stuk kan maken, maar gewoon mee kan draaien, en dat als het uitvalt we gewoon weer op de oude manier gaan werken. Ik vind dit eigenlijk al een hele simpele, ik zou zeggen implementeer dat. Desnoods doe je een pagina op cecis, daar kan niks stuk. Daar refereer je aan. Cecis is ons informatiesysteem, dat zit naast ons radarscherm, met een soort teletext waar we heel veel referentiemateriaal hebben. Zo'n systeem is los van wat er op het radarscherm gebeurd. Dus ik zou zeggen, doe het op een ander scherm zodat het non-intrusive is en niks kan breken in het systeem	Other factors / speed of implementation
P4.docx	Ik zou het wel gebruiken.	Intention to use
P9.docx	Ik zou het wel handig vinden als mensen die hier aan mee doen door unit management nog gevraagd worden van joh vind je dat nodig zouden we dat snel willen implementeren of hebben we tijd om dat te doen, om misschien ook de prioriteit stelling van dit soort onderzoek te done	Other factors, Trust / Trust in implementation
P2.docx	In de nacht hebben we nachttransistie en dan mag je ook niet afwijken er van.	Subjective norm
P5.docx	J ekan je afvragen, is het kritisch, semi-kritisch, of nice to have. Als je het heel lang hebt en het wordt een soort gewoonte gaat het misschien ooit richting het kritische.	Trust
P6.docx	Ja ik denk wel eh ik vind het wel lastig eignelijk zijn er best weinig mensen van een hele grote groep die eignelijk meedoen aan zon experiment terwijl als ik het met mensen er over heb zijn ze wel enthousiast	Subjective norm
P8.docx	Je hoort nu ook al op zaal, waarom gaan we onszelf niet opleggen dat we pm 60s gaan doen, dus pm 1 min. En dat kan best. Ik vind het zelf ook een sport om daar te komen	Other factors, Voluntariness, Subjective norm, Image / Pride/honor in the job they do
P5.docx	Je kan die morgen er in zetten, iedereen zou het gebruiken zoals het bedoeld is.	Perceived ease of use
P6.docx	Je merkt sowieso dat omdat het nog een beetje een ander systeem je in vergelijking met AAA je net wat drukker bent met labels goed zetten en met klikken dan normaal. De werklast is dus wel iets hoger.	AE | Workload
P9.docx	je ziet wel bij die vergelijking dat je er heel veel winst uit kan halen.	Attitude towards use, Perceived usefulness / Learning effect different scenarios
P6.docx	k denk als het gewoon ook weetje er zit nu een beperking in omdat het een systeem is waar ik nog niet mee gewend ben. Als ik het nog een keer zou doen zou het al 10x beter gaan. Ik denk een minuut of 30 sec.	Experience
P4.docx	k denk dat als mensen zeggen, ik red het ook wel zo, dat klopt wel maar dat is zonde want je gooit iets weg wat je ondersteunt.	Image, Subjective norm, Intention to use, Attitude towards use
P2.docx	k zou er niet 100% op kunnen vertrouwen	Result demonstrability

Table C.11: Coded quotes per participant [10]

Participant	Quotation	Codes/Comment
P5.docx	Maar afgelopen vijf jaar hebben we niks op systeemgebied kunnen doen en komende vijf jaar gaan we ook niks op systeemgebied doen. En mensen worden daar cynisch van, zo van ik kan wel wat voorstellen maar het gaat toch niet gebeuren. En idat is ook zo. Ik weet dat dit gegarandeerd de komende 5 jaar niet gaat gebeuren, ook die delta-t niet. Terwijl dat super simpel is, het is waarschijnlijk gewoon een regeltje toevoegen. En dat is super zonde, het is iets kleins dat een heel groot verschil kan maken. Maar dat is helaas de situatie waar we in zitten. Een sad note [zo aan het einde].	Other factors / Lack of implementation causes negative attitude
P4.docx	Maar als je dan op een gegeven moment lockt op koers 70, koers 70, en dan op die kleurtjes kijken. Als je dan zo draait, en je moet nog drie minuten en het is twee minuten vliegen, dan is koersje 70 net een beetje heftig, want als hij dan rechtsom een orbitje gaat maken dan ben je weer net te laat.	Experience, AE | Strategy
P4.docx	maar dan moet je het wel in alle sectoren doen en het systeem zo inrichten dat het voor iedereen haalbaar is.	Perceived usefulness, Image, Mental model
P5.docx	Maar die bochten zijn heel lastig in te schatten, het is anders als wanneer je een rechte lijn vliegt en dan moet bepalen wanneer je moet indraaien. We hebben geen indicatie van tijd. Het is echt manual labour. We doen het niet extreem vaak dus we zijn er niet extreem bekwaam in. Als je de hele dag aan het holden bent merk je dat je in de loop van de dag in een soort flow komt. Het probleem is dat het super zonde is dat wanneer we te laat doorkomen, dat je landsingscapaciteit laat schieten	Other factors / Need for tooling
P3.docx	maar het is belangirjk dat je verkeersleiders meenemeent vanaf het begin	Other factors, Subjective norm
P2.docx	Maar je blijft inderdaad dubbel checken	Trust
P10.docx	Mits het systeem wat daar achter komt, wat in de TMA zit, daar een goede ondersteuning voor is.	Other factors, Job relevance / dat je het niet voor niks doet/reden om eat te verbeteren
P6.docx	Naar 0 zou sowieos beter zijn en daar wordt ook wel over gesproken dat we daar naar streven	Job relevance
P9.docx	Nadeel is dat we het nu in een wat complexere siutatie moeten doen in plaats van dat we het beneden doen, daardoor krijg je denk ik ook een beetje foute resultaten als ik dat zo mag zeggen.	Mental model
P8.docx	Natuurlijk wijkt dit dan nog af van wat we beneden op zaal hebben staan, maar het lijkt toch het meest op wat we hebben dus ik voel me hier prettig bij	Mental model
P9.docx	Nee eigenlijk niet, ik vind het mooi verwerkt en zie het nut er van	Perceived usefulness
P4.docx	nee eigenlijk niet. Ik dacht eerst, de flexibiliteit raak je kwijt, maar je hebt opzich wel de ruimte.	Autonomy
P9.docx	Nee, ik was zeker dat het hanidg is en nut heeft. En dat bleek ook. Het is veel rustiger de hold leeg draaien met het tool dan zonder tool	Result demonstrability, Perceived usefulness
P2.docx	Niemand kijkt van oh ik laat hem gewoon door gaan.	Subjective norm
P4.docx	Nou ik denk het niet. Nee. Ik denk dat ik het als een ondersteuning zie die je kan helpen, en dat ik dat nog steeds zo zie. En zon indraaimoment kan best wel helpen	Attitude towards use
P9.docx	nu also controller wordt het voor jezelf ook prettiger.	Attitude towards use
P5.docx	Nu is het met het timmermansoog een beetje links beetje rechts. Dat is niet helemaal meer van deze tijd. En ik denk dat je dat timmermansoog kan ondersteunen door een tool neer te zetten	Other factors, Job relevance
P5.docx	Nu kan het niet omdat we al drie ajar wachten op ons nieuwe systeem wat al drie jaar uitgelopen is. Het is overheid en ICT. Semi-overheid en ICT.	Other factors / Lack of implementation/slow implementation causes people to be cynic
P8.docx	Oke, wat zie ik nou? En wat betekent dat voor mij? Moet ik daar wat mee? En zo ja, wat dan? Of wacht, kan ik het ook omdraaien	Experience

Table C.12: Coded quotes per participant [11]

Participant	Quotation	Codes/Comment
P5.docx	Om het positief af te sluiten. Je hebt onderzoek gedaan en je hebt al 10 verkeersleiders er bij betrokken, wat al oneindig veel meer is dan sommige afstudeerders. Dus daarmee ben je al heel veel dichterbij daadwerkelijk iets zijn dan al je voorgangers.	Voluntariness, Attitude towards use, Other factors / People DID actually participate in my experiment
P2.docx	ondanks dat het niet helemaal werkt zoals het systeem wat we zelf hebben	Mental model
P2.docx	Ook al had ik de tool, ik keek nog steeds stiekem naar de tijd en ging indraaien op eigen gevoe	Attitude towards use, Trust
P4.docx	rust	AE | Workload
P10.docx	Separatie is interessant punt, je hebt namelijk niet jezelf er mee en je weet niet wat de persoon naar wie jij het overzet wilt	Mental model, Other factors / This one is really interesting as it shows somethign about the mindset and this person just realizing that there IS a special mindset here
P4.docx	Stack list heb ik eigenlijk heel weinig gebruik van gemaakt. Het voegt niet heel veel toe, ik was gewoon naar het verkeer aan het kijken en om dan ook nog naar die lijst zit te kijken	Intention to use
P5.docx	Terwijl je gewend was: oh ik heb 7 mijl, indraaien	Experience, Mental model
P4.docx	Uiteindelijk moet je zelf inschatten wat handig is.	Autonomy
P2.docx	Vanuit een hold leeg vliegen wordt er wel een stuk efficienter van en misschien met standard arrival routes en wat dat betreft wordt de tool heel nuttig.	Job relevance, Perceived usefulness
P3.docx	Verder dat hij duidelijk is en goed te zien	Perceived ease of use
P9.docx	Vertical view, economy dots, highlighten zorgt er voor dat je veel rustiger een hold kan draaien	Attitude towards use
P5.docx	Voordelen: precies op je plannin, als iedereen zich aan de EAT houdt heb je op papier een perfecte situatie in de TMA. Nadeel is dat waneer je dit doet blijkt dat de planning helemaal niet zo accuraat is als we willen. In holding situaties zie je wel eens 4 minuten afwijking van de EAT. Als alle stacks dit doen, heeft het een negatief ecfect op verkeer in de TMA. Grove afwijkingen zijn sowieso niet gewenst maar precieze EAT adherence is naar de toekomst toe gewenst omdat we dan vaste naderingsroutes willen gaan vliegen en dan heb je in de TMA gewoon niet meer de ruimte om 4 of 2 minuten op te vangen	Job relevance
P9.docx	Want dan dit is natuurlijk je gaat hier naartoe en het is een heel ander tool.	Experience
P9.docx	Want toevallig in het begin hier bij die survey bij wat verwacht je heb ik precies dat op geschreven dat ik een tool wil die je verteld wanneer je moet indraaien zodat je precies daar op ARTIP kan zijn.	Other factors / Expectations
P2.docx	Want tussen 1 en 2 lukt het me wel dus dan zou tussen 0 en 1 ook niet moeilijk zijn en ik denk dat heel veel mensen dat hebben.	Subjective norm
P5.docx	Wat een probleem is dat de gemiddelde verkeersleider niet weet dat dit speelt	Voluntariness
P5.docx	Wat er nu gebeurd is dat het een soort van cold turkey iets wordt geroepen of gedaan,d it is wat we gaan doen, dan voelen mensen zich gepasseeerd, al dan niet terecht, maar goed je wilt dat mensen die ontwikkeling accepteren, heel veel mensen kunnen ook een waardebolle bijdrage leveren en daar maak je op deze manier wel het beste gebruik van denk ik.	Image, Subjective norm, Intention to use, Attitude towards use
P4.docx	Wat ik zou toevoegen is dat hij de bochten meeneemt, en dat hij een warning kan geven	Perceived usefulness, Trust
P5.docx	Wat je vaak ziet met dit soort future concepts is dat het veel te veel is en in een keer het hele verkeer probeert te regelen	Mental model, Trust, Autonomy, Result demonstrability

Table C.13: Coded quotes per participant [12]

Participant	Quotation	Codes/Comment
P4.docx	Wat je ziet is, mensen wachten even en draaien nog niet, en dan heb je zon zware delta die heel rustig de bocht door gaat en dan zie je dat er gaten ontstaan.	Problem basics
P9.docx	Wat opviel, gisteren hadden we het op zaal er over, toen zeiden mensen van email niet gezien of ik word niet meer gevraagd, dus zijn nog steeds mensen die voor de een of andere reden niet mee krijgen dat je hier aan mee mag doen. Mischien email altijd goed maar we hebben zon mededelingen boek op zaal en briefings enzo die je moet doen gewoon daar een extra iets van joh wie wil er meedoen aan zon onderzoek dus daar zouden meer mensen dat kunnen zien. Dat is meestal zon a4 pagina over mensen die met pensioen gaan en mensen die geslaagd zijn voor hun opleiding enzo, daar zou je ook iest bij kunnen doen en ik denk dat je daar meer mensen mee bereikt dan met een email uiteindelijk	Other factors, Voluntariness / FUTURE RECOMMENDATION
P10.docx	We holden niet vaak hier. Dus in die zin, als de tool er slechts is om het indraaien te helpen, dan gaat dat niet vaak gebruikt worden.	Job relevance
P2.docx	We kijken dan altijd mee maar ik weet niet of mensen dan lettelrijk kijken naar de tijden die er dan zijn	Subjective norm
P10.docx	We willen graag pleasen en zorgen dat we beter aan de EATs kunnen voldoen.	Subjective norm, Job relevance, Perceived usefulness
P8.docx	Wordt het belangrijker om dichter bij die tijd te komen, dan is het wel rete makkelijk als je een extra tool hebt	Job relevance
P5.docx	Zeker met die delta-t dingen, iedereen zou dit wel willen.	Attitude towards use, Subjective norm
P5.docx	Zeker met die delta-t dingen, iedereen zou dit wel willen. Als je vraagt, willen jullie dit op zaal morgen, dan zegt iedereen ja. Als iedere verkeersleider nou elke keer als die mijn baas tegenkomt vraagt, wanneer komt die delta-t nou in de holding. Als ze niet weten dat dingen er zijn, gaan ze het ook niet zeggen. En daarom blijven we heel erg vast in wat we hebben.	Voluntariness, Other factors, Mental model, Intention to use / Innovation processes can be speeded up by ensuring OPS is in the loop and actually ASKS for an innovation. (Technology pull VS push?)
P9.docx	Zeker willen gebruiken, ik vind die lichter maken van labels die je kiest echt super handig dat vind ik echt een top ding dat zou ik graag in de hold willen hebben	Intention to use
P3.docx	Zo veel voorspelling die je kan creeren in luchtvaartsystemen, dat is gewoon beter	Job relevance
P5.docx	Zonder support, juist omdat een hold zo onzeker is, pilot reaction heeft een enorme invloed, dat het onmogelijk is om consequent een EAT adherence van een minuut of 45 sec kunnen halen puur op je eigen kunnen	Job relevance

	P10.docx	P2.docx	P3.docx	P4.docx	P5.docx	P6.docx	P8.docx	P9.docx
Attitude towards use	2	1	2	6	10	6	1	6
Autonomy	2	4	0	6	4	0	1	0
Experience	1	3	0	2	1	1	4	2
Image	0	1	0	2	1	0	1	0
Intention to use	0	0	0	4	7	0	0	3
Job relevance	4	3	2	1	7	2	2	0
Mental model	3	1	2	5	5	0	3	2
Other factors	7	1	2	5	10	2	2	6
Output quality	0	2	3	1	2	1	0	0
Perceived ease of use	1	0	2	0	4	0	1	0
Perceived usefulness	2	4	4	7	7	2	0	5
Problem basics	0	0	0	2	0	0	0	0
Realism	0	0	0	0	0	0	0	0
Result demonstrability	1	6	4	1	4	0	1	1
Subjective norm	1	9	2	2	3	3	2	0
Trust	1	8	5	3	6	1	0	1
Voluntariness	0	1	0	0	6	1	2	1

Figure C.2: Code frequency per participant

D
Literature Search for Communication Research

Table D.1: Literature search on communication research [1]

Search terms	Engine	Hits	Literature in chapter
Ironies of automation	TUD Library	3	Bainbridge [1983]
Mental model collaboration	TUD Library	258	-
Mental model innovation	TUD Library	27,235	-
Mental model teams	TUD Library	20,825	Uitdewilligen et al. [2013]
References/related articles Uitdewilligen et al. [2013]			Mohammed et al. [2010]
Perceived usefulness perceived ease of use and user acceptance of information technology	Google Scholar	7,103	TAM references pop up, no additional literature found
User acceptance social situation	TUD Library	18,151	-
Technology acceptance cognitive frame	Google Scholar	403,000	Lin and Silva [2005]
Mental model technology acceptance	TUD Library	13,398	Elbanna and Linderoth [2014]
Technology acceptance model external factors	TUD Library	40,943	Venkatesh and Davis [2000]
Innovation case study	Google Scholar	750,000	-
Organization openness change innovation	Google Scholar	505,000	Vakola [2012]
technology			Miller et al. [1994]
Organization work environment resistance	Google Scholar	304000	Vakola [2012]
change technology innovation			Wanberg and Banas [2000]
Technology acceptance intention to use	TUD Library	24753	Davis et al. [1989]
Sent by AE supervisor after discussion on TAM and ATC	-	1	Westin et al. [2015]
Articles on previous research at LVNL obtained via AE supervisor	-	3	Bakker et al. [2019], Ottenhoff et al. [2020], Dirkzwager et al. [2019]
Constructivist collaborative discovery learning	TUD Library	637	-

Table D.2: Literature search on communication research [2]

Search terms	Engine	Hits	Literature in chapter
Constructivist learning	TUD Library	14,815	-
Learning human interaction	TUD Library	129,000	-
Innovation change emotion trust	TUD Library	1,577	-
Technology acceptance model external variables	TUD Library	31,614	Venkatesh and Davis [2000] Venkatesh and Davis [1996]
Technology acceptance model literature review	TUD Library	63,858	Chuttur [2009] Venkatesh and Bala [2008]
Technology acceptance model literature review	Google Scholar	1	Marangunić and Granić [2015]
Technology acceptance model external variables definitions	Google Scholar	603,000	-
Result demonstrability image social influence technology acceptance model definitions	Google Scholar	27,400	Moore and Benbassat [1991]
Tam definitions variables ease of use intention to use perceived usefulness	Google Scholar	33,330	Teo and Zhou [2014]
			Wu and Lederer [2009]
Use references from Teo and Zhou [2014]			Fishbein and Ajzen [1975]
Attitude toward use attitude definition affect	TUD Library	5,299	Fishbein and Ajzen [1977]
Autonomy trust support system acceptance	TUD Library	3,151	Dickinson [1995]
Technology acceptance autonomy trust support system	TUD Library	1,500	Eom et al. [1998]
			Stefanou et al. [2004]
Technology acceptance support system air traffic control	TUD Library	7,845	-
Technology acceptance support system air traffic control autonomy trust	TUD Library	137	Blegen et al. [1993]
Technology acceptance support system air traffic control collaboration	TUD Library	1,187	Guiost et al. [2006]
Technology acceptance support system collaboration	TUD Library	20,241	
Technology acceptance support system collaboration problem solving	TUD Library	7,150	Degani et al. [2017]
Technology acceptance support system collaboration holding	TUD Library	8,041	
Hyper object	TUD Library	17,917	-
Trust time "building trust"	TUD Library	2,356	-
Trust time "building trust" "support system"	TUD Library	48	[Siemon et al., 2017]
Learning innovation new technology air traffic control	TUD Library	2,616	Teperi and Leppänen [2010]
Autonomy definition technology engagement	TUD Library	2,207	Deci and Ryan [1987]
			Wang and Peverly [1986]