Schiphol

Investigating the adoption of decision support systems in a multi-stakeholder system

A case study in flow control at Schiphol Airport

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“Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted.”

-Albert Einstein

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Preface

Dear reader,

This document marks the final result of my graduation project and the completion of my studies at TU Delft, an exciting milestone for me!

I have truly enjoyed working on this project, immersing myself in the world of Schiphol Airport and connecting with the people behind its operations. Exploring and advocating the role of human factors in the design of new technologies has been inspiring and has reinforced my passion for this field.

Throughout this journey, several people have supported and encouraged me, whom I would like to thank.

First and foremost, I would like to thank my family and friends for being there every step of the way. My parents, whose motivation, patience, and unwavering belief in me made all the difference. My sisters, who kept things in perspective with their down-to-earth comments. And my friends, thank you for the distractions, fun, and advice. Your support and company has been invaluable during my entire time spend in Delft!

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And, I would also like to express my gratitude to Carien, my mentor at Schiphol, for making this project such a valuable and enjoyable experience. Our conversations were inspirational, even if they sometimes wandered off in all directions. Your insights and support played a key role in shaping my understanding of the project.

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And lastly, I want to thank the PC PAX and Floor managers and designers that have participated in this project for their time invested, sharp comments, honesty, and their enthusiasm and humor. Which has made this project fun and rewarding to me.

Enjoy reading!

Sophie Cleton
March 2025

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Abstract

Despite recent advances in using Decision Support Systems (DSS) for automating or enhancing processes within organizations, their adoption remains low in work contexts. While much research has explored DSS adoption by individual workers, there has been limited focus on the broader multi-stakeholder systems in which they operate. To study this further, this research investigates the adoption of a DSS within a multi-stakeholder environment by using a case study on passenger flow control situated at an international airport.

After the literature research, a context research was performed, consisting of observations, unstructured interviews, and a semi-structured interview study with 11 participants. During this research, several challenges faced by the flow controllers were identified, alongside tensions present between flow controllers, flow guiders, and flow moderators.

By discussing the effects that introducing a DSS might have on these existing challenges and tensions, potential opportunities and adoption barriers were formulated for the adoption of the DSS. The potential adoption barriers were identified on two levels: the integration of the DSS into the multi-stakeholder system and the interaction between the flow controller and the DSS. Regarding the integration into the multi-stakeholder system, the introduction of the DSS might deteriorate interactions between flow controllers, flow moderators, and flow guiders, limiting the exchange of important information and alignment regarding the decision-making process, which is currently valued. Regarding the interaction between decision-makers and the DSS, decision-makers might struggle to integrate subjective insights with DSS recommendations, as subjective information is not considered by the system.

To address these adoption issues, ideation was conducted using storyboarding. Based on the insights gathered, design guidelines were formulated.

The design guidelines highlight that DSS adoption in multi-stakeholder systems is influenced by the dynamics between stakeholders. And proposed to consider this in the design of DSS, by seeking closer involvement and collaboration with the flow moderators and flow guiders during the decision-making process. Also, considering how flow controllers can be supported in combining subjective and contextual insights with recommendations of the DSS is proposed. The guidelines were validated with the intended user group through testing their actionability and understandability (n=6).

Ultimately, this research contributes to the human-computer interaction (HCI) community by formulating design guidelines that address the complexities of DSS adoption within multi-stakeholder systems. It also provides practical insights for organizations, such as Schiphol, by offering a structured approach to integrating DSS into operational workflows while maintaining stakeholder engagement and collaboration.

Keywords: Decision support systems, adoption, aviation, artificial intelligence, barriers, design guidelines

Abbreviations

DSS - decision support system

AI - artificial intelligence

RSG - Royal Schiphol Group

HCI - human computer interaction

ADM - augmented decision-making

AF - arrival filters

PC PAX - process control passengers

FLM - floor managers

PA - passenger assistants

OPS - operations department

kMar - Marechaussee

OKP - operationeel knelpunt (Marechaussee)

Wilbur - in-house build decision support system for employees at Schiphol working at the day of operation

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Introduction

In the introduction, the aim, relevance and approach of this research project are explained. The project investigates the adoption of decision support systems in a multi-stakeholder system, using the case study of passenger flow control at Schiphol Airport. In this context a decision support system is being developed to augment workers in their decision-making, the aim is to developed guidelines to assist the designers of this system in designing for adoption by users.

- 1.1 Motivation for the project
- 1.2 Goal of the project
- 1.3 Approach used

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1.1 Motivation for the project

In recent years, many organizations saw the opportunity to automate or augment part of the work currently performed by their employees [4], with the current hype around Artificial Intelligence (AI) this has gained even more attention [20]. Organizations see (partial) automation as a potential to increase productivity and relieve employees from repetitive tasks.

One example of a task being automated or enhanced by AI is decision-making. In many organizations, decision-making is a crucial task that is often associated with high complexity and large potential effects, and therefore also large potential benefits of automation are seen [20]. Examples of decision-making automation or augmentation can be found in different sectors. For example, in healthcare, where decisions about which treatment to provide patients require the analysis of large amounts of case-specific information [13], or in aviation when pilots have to quickly decide which alternative airport to divert towards in case of an emergency [81]. Automating or augmenting decision-making is usually done by implementing decision support systems (DSS). Morrison et al. [45] define DSS as computerized information systems that support humans in making decisions by collecting, presenting, and integrating useful information from an array of sources and modalities. This way, the human user is led to one or more plausible courses of action, for example in the form of recommendation, which should reduce the complexity of the task the workers perform. Next to simplifying the task, computerized tools can be used to make sure decisions are made in a more uniform and formal way, instead of the more subjective and informal way that human workers usually apply [36].

Although the benefits of using DSS for different stakeholders in organizations are widely acknowledged, the usage of DSS in practice is still low. Different studies have shown that workers can still be unlikely to adopt algorithms even if the algorithm has the best possible performance [2, 19]. This suggests that adoption is not directly related to performance, while organizations often invest most resources in optimizing performance in the development process. Many studies within the human-computer interaction (HCI) community advocate for the importance of considering human factors instead of merely the quality of the output in the design of DSS to improve the adoption by the users [55].

To make sure DSS can be used to its full potential, the aim was to investigate the implementation and more specifically the adoption phase of DSS within organizations. Adoption is defined by Rogers [54] as the decision made by the envisioned user to make full use of an innovation as the best course of action. Different studies have identified factors influencing the adoption of workers. For instance, the perception of workers towards the DSS [77], its alignment with their current workflow and practices [80], and external influences [34]. But besides these internal factors related to adoption, external factors also have an influence on the decision of workers whether to adopt new technologies. For instance, whether coworkers and stakeholders support the usage of the DSS [50, 52], but also existing tensions or conflicting priorities between stakeholders could influence adoption [17, 43].

In this research, an integral perspective to investigate the adoption of DSS was used, as decision-making in an organization is often dependent on not only the decision makers themselves, but situated in a multi-stakeholder system. In multi-stakeholder systems, for example, input for decision-making is dependent on others or output has to be executed by other parties than the decision makers [74]. This creates a more entangled picture for adoption, as these stakeholders also have an influence on the adoption of DSS by the users.

For example, due to the introduction of a DSS, the current dependencies and interactions between stakeholders will likely change, which might cause adoption issues if this is not appropriately addressed and designed for [17, 22]. At airports [26, 83] or in healthcare [22, 25], decision-making usually occurs in multi-stakeholder systems, where different stakeholders operate alongside and subsequent to each other and all parties experience effects from important decisions made by one of the stakeholders.

For investigating adoption from this perspective, a case study regarding an automation project within Schiphol Airport was used. This project entails the augmentation of an operational decision-making process performed by workers, by implementing a decision support system that uses AI technology; we refer to this system as ADM (augmented decision-making).

1.2 Goal of the project

As previously mentioned, a case study will be used to investigate the adoption of DSS in a multi-stakeholder system. For this case study, we aim to investigate what factors in the design and integration of ADM influence its adoption in the multi-stakeholder system currently present at Schiphol Airport for flow balancing. The research question that we aimed to answer is:

What should be considered in the design of Decision Support Systems in multi-stakeholder systems to enhance the adoption by users and within the multi-stakeholder system?

As a result, guidelines have been formulated for the people that design, develop, and implement this DSS at Schiphol Airport. The guidelines are made to accompany the needs of the different stakeholders that are involved in the decision-making process and the users of the DSS. The aim has been to formulate design guidelines in this research, as design guidelines can serve as intermediate knowledge bridging between real-world contexts and theoretical knowledge, utilizing generative formulations [39]. Therefore, it is suited to serve as a translation between theory and practice and be of value to both Schiphol and the HCI research community. During the project, it was found that interactions in the multi-stakeholder system mainly occur on two levels, as visualized in Figure 1 and that these two levels have influence on each other as well.

Therefore, the guidelines are also separated into these two different levels:

1. Guidelines for interaction design with the user of the DSS.
2. Guidelines for the integration of the DSS into the multi-stakeholder system.

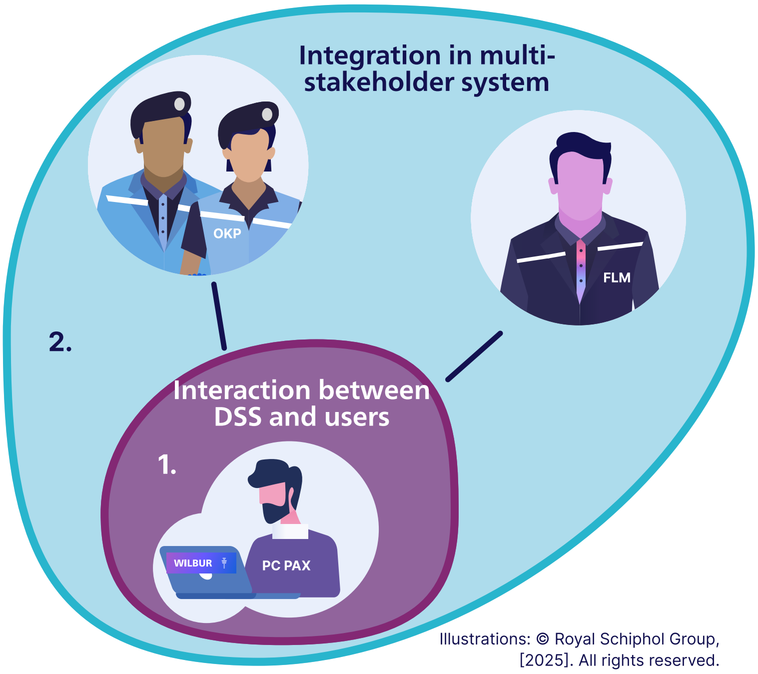

Fig. 1. Two different levels of guidelines defined in this project

1.3 Contribution

By taking a multi-stakeholder perspective to studying the adoption of DSS, the aim is to contribute to the research in DSS as is currently understudied in the Human-Computer Interaction (HCI) community. A few papers, have investigated DSS in multi-stakeholder systems and the effects of this introduction on the interactions between stakeholders. But there are no concrete and actionable guidelines formulated yet.

Therefore this research project aims to contribute to and demonstrate the value of the growing effort to investigate DSS in complex real-world applications, with aviation as a domain that is currently understudied in the Human-Computer Interaction (HCI) community [82]. Next to the designers working on the case studied, also designers of DSS in other sectors, could benefit from the guidelines formulated in this research.

1.4 Approach used

To achieve the previously stated goals, various research methods have been executed as explained below. These different elements and how they are connected are visualized in Figure 2.

1.3.1 Introduction and literature
After highlighting the relevance and contribution of this project, in section 2, the executed literature research is explained. The aim of this section is to understand what factors influence the adoption of decision support systems and what effect multi-stakeholder relations and interactions have on this adoption.

1.3.2 Context research
In section 3, the necessary background information about the context of the case study is explained. It contains information to understand the case study, the decision-making process, the relevant stakeholders, and how they interact with each other currently. Subsequently, a dive into the context of the case study is made, in section 4, where the current context is explained. Which consists of three main parts and two different types of research (observations and semi-structured interviews). The decision-making process is explained as well as the current challenges as experienced by the decision makers. And the multi-stakeholder system is explained, consisting of the different stakeholders and the tensions that currently exist between them.

1.3.3 Discussing potential adoption barriers
After the research phase, insights from the context research are discussed by investigating how the introduction of the DSS (ADM) would affect the current context. By comparing this with adoption barriers, as identified in the literature, a number of potential adoption barriers for the DSS in the multi-stakeholder system are described in section 5. Also, several opportunities of introducing ADM in the context were identified.

1.3.4 Ideation of interactions
In this phase, we aimed to ideate for ways to overcome the adoption barriers as formulated in the previous section. This is done through storyboarding with input from several sources; this is explained in section 6.

1.3.5 Validating and delivering guidelines
In the last part of the report, the guidelines are validated with interaction designers from Schiphol; this can be read in section 8. We aimed to test actionability, understandability, and added value of the guidelines as perceived by intended users. In section 7, the final guidelines are presented. And in section 9 the results are discussed and the contribution of the project to Schiphol Airport and academia is explained.

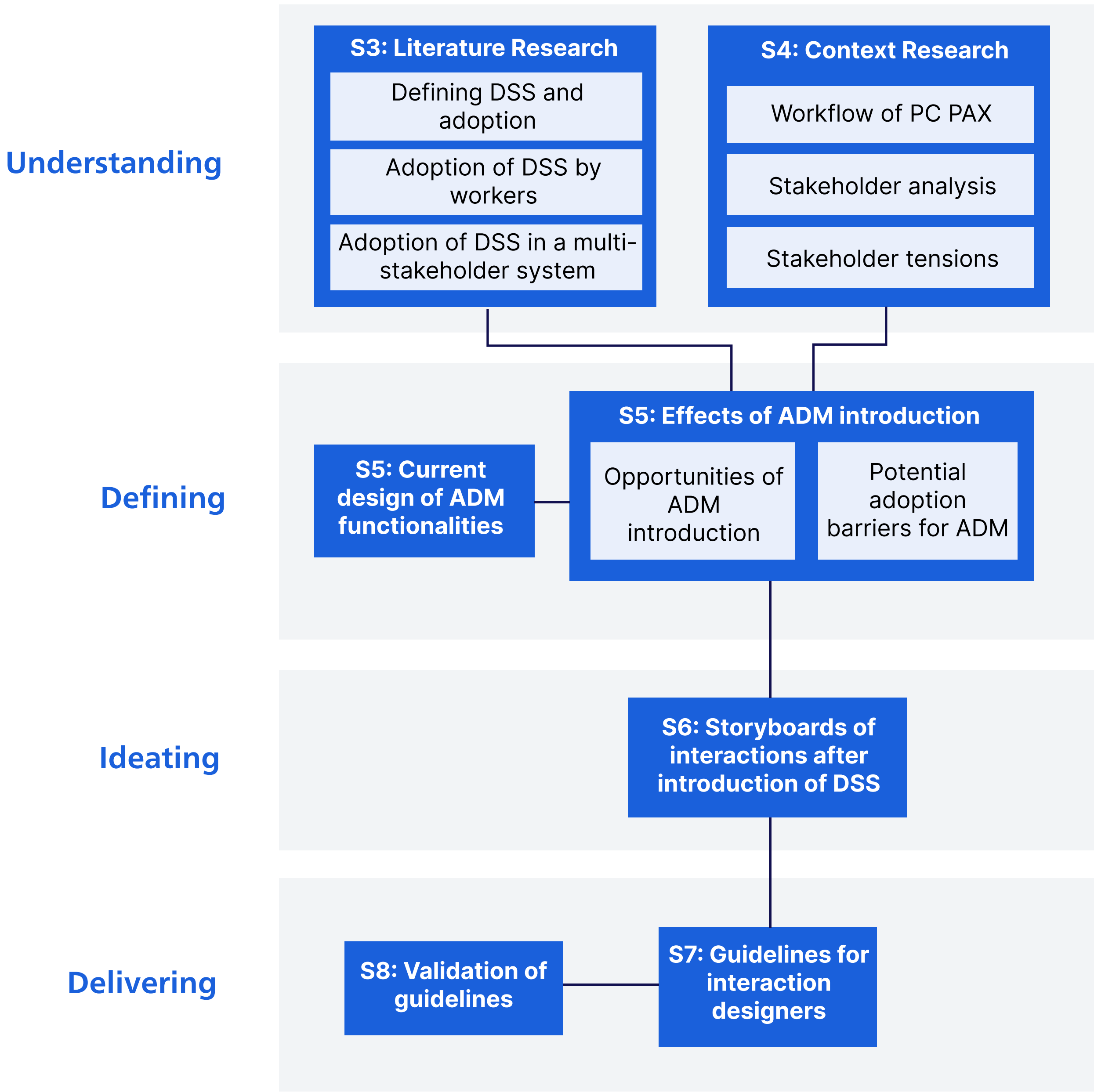

Fig. 2. Approach of project

Literature Research

adoption of decision support systems

In this chapter the existing knowledge about the topic investigated in this research is explained. While much research has explored the adoption of Decision Support Systems (DSS) by individual workers, there is limited focus on adoption in multi-stakeholder systems. This chapter starts with defining DSS and their applications in the workplace across different sectors. Afterwards, the factors influencing adoption by individual users and factors influencing adoption in a multi-stakeholder system and related to their integration in these systems are explored.

2.1 Methodology

2.2 Understanding decision support systems

2.3 Investigating adoption of DSS in the workplace

2

2.1 Methodology for literature research

This literature study consists of two main parts; the first one is the adoption of DSS by workers, and the second part is in multi-stakeholder systems. For the first part, a scoping review has been conducted; the second one was performed in a semi-structured way.

This chapter aims to answer the following research questions:

1. *What are DSS, and what are their applications across different industries?*
2. *What factors are important for the adoption of a DSS by workers?*
3. *What factors are important for the adoption of a DSS in a multi-stakeholder system?*

3.1.1 Scoping review

The scoping review is used to map the current knowledge on the adoption of DSS by workers. More specifically, the review is used to identify key factors related to the investigated concept; therefore, a scoping review was the most suited method for answering the research question [46]. For the search, the Association for Computing Machinery (ACM) Digital Library was used for identifying literature papers. The following search query has been used:

[All: adopt] AND [[All: "decision support system"] OR [All: "decision support tool"] OR [All: "decision support technology"]] AND [All: facilitators enablers] AND [All: barriers challenges] AND [All: workers]*

In Figure 3 the selection of papers made can be seen. In Appendix B.1, the complete scoping review can be found, including a more detailed description of the methodology followed.

3.1.2 Semi-structured literature research

For the second part of the literature research, with the focus on adoption and DSS in multi-stakeholder systems, a semi-structured approach was used. The publications used in this second part were found using the ACM database, Springer, ScienceDirect, and Google Scholar. The following keywords were used during the search: “decision support”, “operator”, “stakeholders”, “multi-stakeholder system”, “adopt*”, and “interaction”. Initially, sequential sampling has been used, involving multiple rounds of article selection until adding more articles ceased to provide new insights. Subsequently, snowball sampling was utilized, using insightful articles relevant to the research.

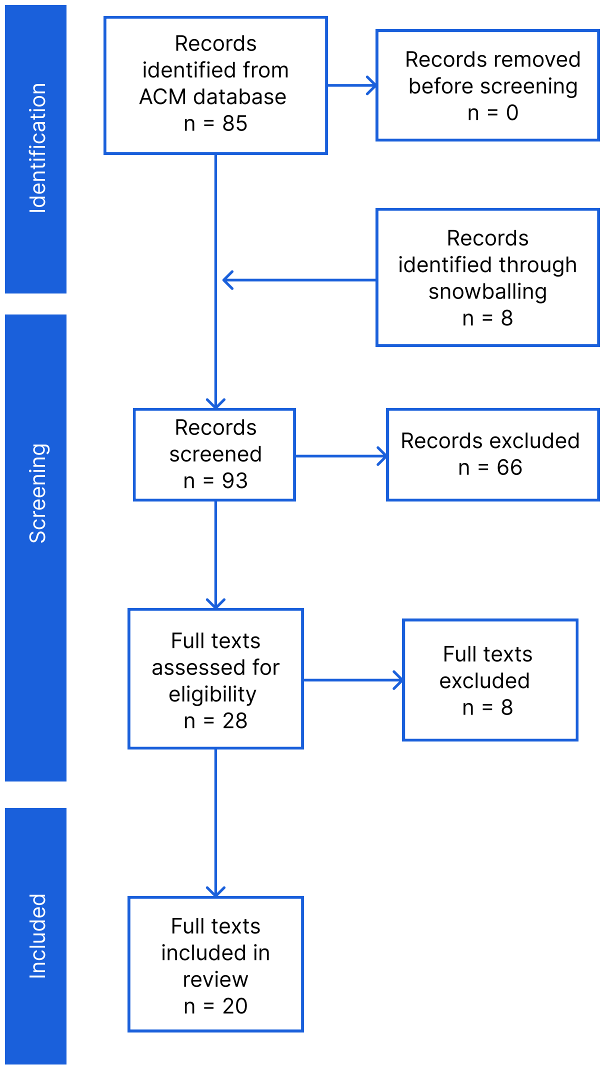

Fig. 3. Flow of records through different phases of the data collection process of the scoping review

2.2 Understanding decision support systems

2.2.1 Defining Decision Support Systems

Decision Support Systems are computational tools designed to assist human decision-makers in tasks such as information acquisition, analysis, decision-making, and action. DSS often aim to reduce errors and improve decision quality by supporting the early stages of decision-making (information acquisition and analysis) [47].

In recent years, advances in artificial intelligence have expanded the potential of DSS. These systems now offer capabilities such as explainable AI, enhanced visualization, and real-time decision insights. However, despite these advancements, successful workplace implementation remains a challenge [7, 42]. Information Commissioner's Office (ICO) [29] has distinguished two main forms of decision support; the first one is full automation where AI systems analyze information and take decisions themselves. The second one is also called augmented decision-making or human-in-the-loop; in this version, humans remain in control over the decision-making and are merely supported by the AI system that analyzes information and provides useful insights to the human user. In literature, the second version, of augmented decision-making is most often found. As collaboration of humans and AI enables them to complement each other, which can be beneficial in complex decision-making processes. Compared to human intelligence, AI is especially capable of quickly providing access to real-time information and analyzing this, while humans have the capability of making intuitive decisions, dealing with uncertainty, negotiating and building consensus [31]. Jarrahi [31] also advocate for exploring the complementarity of human and AI and therefore also imply that augmentation should be the intention instead of automation regarding decision-making.

2.2.2 Applications of DSS across different industries

Applications of DSS are widespread, including healthcare, where they assist in diagnostic decisions [13], or for automating student grading and at airports for strategic planning of runway capacity [64] or employee scheduling for check-in desk occupation [12] Yet, researchers highlight the low adoption rates of DSS, linking this to insufficient user trust and poorly integrated system designs. This sets the stage for a deeper exploration of adoption factors in the next section.

The studies that we have seen so far have mainly been in the health care domain with only a few exceptions. But besides the healthcare environment, where different stakeholders collaborate closely, airports are also multi- stakeholder systems. Zografos and Madas [83] mention the complexity of decision-making at airports, where, due to the high number of stakeholders and their conflicting objectives, this creates complex situations for implementing new technologies. In their paper, they aim at creating a tool for providing an integrated view of the total airport process, which is also the aim of Schiphol. But this research is merely focused on the development of the functionalities of the DSS and does not consider the human factors related to the usage.

Also, Gomez-Beldarrain et al. [26] point at the barriers that arise when airports try to implement automation technologies related to the lack of consensus between stakeholders and not involving them closely in these projects.

2.3 Investigating adoption of DSS in the workplace

3.3.1 Defining adoption of new technologies in the workplace

Adoption is defined by Rogers [54] as the decision made by the envisioned user to make full use of an innovation as the best course of action. Adoption can be seen as one step further than implementation, ensuring that the system is not only deployed but also embedded within the organization [53]. Improving adoption is key if organizations want to make sure the full extent of benefits is exploited for DSS [20].

Adoption of decision support systems in general is still lacking in many fields. Many causes can be assigned for this, like non-intuitive interfacing, users lacking programming skills, and high complexity in the systems in place [16]. Most researchers do agree that DSS and AI in general are most likely to be accepted by humans as an augmentation tool rather than as an automation tool to replace them [20, 31]. But what this should look like and how the collaboration between humans and the DSS should look like is still unknown to a large extent.

The paper by Ali Fenwick et al. [1] proposes that often development teams of DSS do not have insight into the human factors that are often key in the adoption of technology by workers. Development and design teams of DSS tend to focus on improving the quality of output of the DSS. For this reason, more research should be done on these human factors. As human factors are influencing the adoption to a large part. By listing the barriers and facilitators to adoption experienced by workers, designers and developers of DSS are provided more knowledge to include these human factors into the DSS. The aim is to, thereby, improve the adoption of these systems within organizations.

For accessing the adoption of DSS and other technologies, several different frameworks can be found in the literature. The most common ones are the Technology, Organization, Environment (TOE) framework [3], the (extended) Unified Theory of Acceptance and Use of Technology (UTAUT) [44], and Diffusion of Innovations [54]. All frameworks have another, slightly different perspective on the adoption process of users and the influential factors that determine whether these users will actually adopt or reject a new technology into their work. Sitorus et al. [62] and Sitorus et al. [61] have summarized the most commonly used frameworks into one where the focus is put on the interactions that exist between the individual user, the technology and task, and the environment in which they exist, see Figure 4. As the technology and task interaction is already investigated thoroughly by the development team of ADM, in this project we focus on the individual and technology interaction, referred to as user and DSS interaction, and the individual and its environment interaction, referred to as stakeholder interactions.

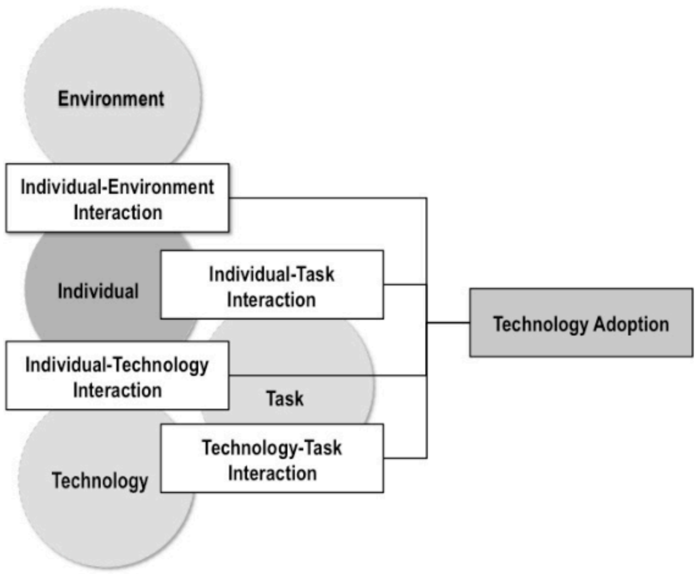

Fig. 4. Framework of technology adoption: Interaction perspective by Sitorus et al. [49]

Design methods and Actor involvement in DSS	Workers' Attitudes Towards DSS	Social and Technical Organizational Support
Consideration of needs, expectations and concerns of workers and other stakeholders [15, 28, 60, 73]	Performance expectancy of workers [7 , 28, 33, 50, 60, 65, 71, 73, 75, 81]	Clarity regarding liability and accountability among workers [14, 28, 50, 75]
Adjustment of DSS to knowledge, work-flow and practices of workers [7, 30, 60, 63, 71, 73, 75]	Effort expectancy of workers [30, 33, 75, 81]	Organizational support for usage of DSS [7, 14, 50, 52]
Appropriate and adaptive to the context specific situation [40, 73, 75, 81]	Trust in the technology and output of DSS [50, 52, 71, 73]	Availability of resources for the implementation and usage of DSS [7, 14, 15, 65, 75]
Role of DSS is supportive, decision-making happens in collaboration between DSS and worker [45, 59, 63, 73, 75]	Resistance to change among workers [45]	
Involvement of stakeholders in the design of DSS [15, 28, 30, 52, 59, 60, 73]	Perceived loss of professional autonomy [45]	
	Understanding of outcomes and functioning of DSS [7, 45, 52, 59, 65, 71]	

Table 1. Categories of factors influencing adoption of DSS by workers

Furthermore, different studies highlight the importance of viewing DSS not merely as a technical tool but as a sociotechnical system, where technology and social interactions are deeply interwoven [22]. Changes in decision-making processes (technology) inherently influence power structures (social relationships) and operational workflows (organization).

For example, a DSS that automates decision-making may shift authority from human experts to algorithmic outputs, raising concerns about accountability. Similarly, a system that centralizes data access can alter collaboration dynamics, leading to resistance among stakeholders who feel excluded from decision-making [58]. Recognizing these socio technical dimensions is essential to addressing non-technical adoption barriers.

3.3.2 Factors influencing adoption by individual workers

First, the factors related to the user and DSS interaction related to the adoption are investigated. The existing knowledge about this has been researched by performing a scoping review, that can be seen in Appendix B.1. From its findings, it becomes evident that the successful adoption of DSS is contingent upon a cohesive strategy that integrates design considerations, user engagement, and organizational support.

The interaction between users and the DSS, facilitated through a design that accounts for their specific challenges and workflows, sets the foundation for building a positive user attitude. This, in turn, is reinforced by trust in the technology, which is shaped not only during the design phase but also through continuous interaction and feedback during its use. The results of the scoping review, Table 1, also suggest that achieving a high level of trust and alignment between DSS and user expectations is critical for overcoming resistance and fostering acceptance. Furthermore, providing adequate training, resources, and expert endorsement acts as a catalyst that propels the transition from initial resistance to sustained adoption. As the focus of this project is related to the design of DSS, the insights relevant for this research are extracted from the left column of Table 1.

Factor 1: Consideration of needs, expectations and concerns of workers and other stakeholders in the design of a DSS.

Factor 2: Adjustment of DSS to knowledge, workflow and practices of workers.

Factor 3: DSS should be appropriate and adaptive to the context specific situation.

Factor 4: Role of DSS is supportive, decision-making happens in collaboration between DSS and worker.

Factor 5: Involvement of stakeholders in the design of DSS.

3.3.3 Factors influencing adoption at a multi-stakeholder system perspective

In the scoping review, a number of factors related to stakeholder interactions were found. As the focus of this project is to explore adoption in a multi-stakeholder system, these factors are further highlighted.

First, the term multi-stakeholder system is defined as a system where collaboration among diverse actors occurs, for example, in public institutions, private companies, and regulatory bodies [74]. And more specifically, the stakeholders have influence on the decision-making process. This influence can be manifested in different forms, for example by being the executor of the decisions or by directly or indirectly determining when decisions have to be taken. The involvement of stakeholders in decision-making creates a different context and likely also influences the adoption of DSS.

In the literature, different factors influencing the adoption of DSS in multi-stakeholder systems can be identified. First of all, conflicting priorities between stakeholders related to the DSS. Stakeholders often pursue different objectives, such as regulatory compliance versus operational efficiency [43]. Without early alignment, these differences can hinder adoption. Second, power asymmetries, where some stakeholders exert greater influence over system design and decision-making, potentially marginalizing others and reinforcing existing hierarchies [35].

Also, interdependencies and resistance to change can have an influence on adoption. The introduction of a DSS disrupts established workflows and power structures, leading to resistance from actors who perceive a loss of control [27]. And lastly, trust and transparency issues can occur. Decision-making processes supported by DSS can introduce algorithmic biases or intransparecy, raising concerns about accountability [8, 66]. To account for these issues, explainability alone is insufficient; stakeholders must also have mechanisms to contest decisions.

Funer et al. [25] has investigated the possible impacts of the introduction of a DSS on the relationship and shared decision-making between patients and health care professionals. In this paper, they explain the potential to increase the involvement and empowerment of patients in the decision-making processes through transparency, but also the need for additional communication between patients and health care professionals. The need for additional communication was also identified by Pontefract et al. [49]. In Figueras et al. [24] concerns are raised about the negative consequences of automation on stakeholder relations, potentially causing less engagement of actors and an increase of confrontations instead of collaboration.

Factor 7: Concerns about intransparancy and accountability for decisions can lead to trust issues between different stakeholders

Factor 8: Pursue of conflicting objectives of different stakeholders can hinder the adoption of a DSS.

Factor 9: Introduction of DSS in a multi-stakeholder environment requires additional involvement of stakeholders and additional communication.

Conclusion section 2

- The aim of this section was to explain the existing literature related to the research question proposed in this project. First of all, DSS were explained and several different applications were named, also adoption and multi-stakeholder systems were defined.

- For this project, a framework was found that explains the importance of investigating interactions between the technology, users and their environment.

- Afterwards, several factors were identified that might have a negative influence on the adoption, related both to adoption of workers and adoption within a multi-stakeholder system. In the next phases of the project, especially the factors related to the design of the DSS as highlighted in this section are taken into account. As well as the effects the introduction of a DSS on the multi-stakeholder system might have.

- In the next sections, the case study will be presented and investigated.

Background

passenger flow control at Schiphol Airport

For studying the adoption of Intelligent Decision Support Systems in a multi-stakeholder system, a case study was used to investigate the topic in the real world. In this section the necessary background information about this case study is provided. This contains information about the decision-making process, the relevant stakeholders, the reasons for the project to be started for the organization, and the relevance of the case study. The information in this section is retrieved by the researcher by immersing in the organization and speaking to different involved employees in an open-ended way.

- 3.1 Capacity constraints at Schiphol Airport
- 3.2 Flow balancing to control capacity constraints
- 3.3 Automation technology as the proposed solution for capacity constraints
- 3.4 Relevance of case study for research objectives

3

3.1 Capacity constraints at Schiphol Airport

Schiphol Airport is the largest international airport in the Netherlands. Its size, both in terms of passenger volume and physical area, surpasses what might be expected from a relatively small country like the Netherlands. And as passenger numbers remain to increase over the years. Schiphol Airport is facing capacity constraints. The airport is located in the Randstad, the most crowded area in the Netherlands. It is surrounded by different large cities and towns and therefore has very limited possibility to expand, see Figure 5. The terminal of the airport has kept the same amount of square meters, but the amount of flight movements and therefore passengers moving through the terminal has risen significantly over the past years.

The airport is facing capacity constraints on both the airside, in terms of gate and runway capacity, and on the amount of passengers moving through the terminal. In this case study, the focus is on the passengers, where a number of hotspots, in terms of capacity problems, can be pointed out. One of those is the border control filters where arriving passengers from outside of the Schengen area are checked for their passports. These are called the arrival filters.

Due to the capacity constraints of the airport, the crowd norms, within the arrival filters, are reached on a regular basis and waiting times of passengers are exceeding the targets set by RSG on a weekly basis.

Fig. 5. Map of location Schiphol Airport

Fig. 6. Queues at Schiphol

Currently, the management of this passenger flow requires a high number of human resources and it significantly decreases the scores in passenger experience the airport receives. Within the arrival filters, the Royal Marechaussee (KMar) conducts passport checks to protect the safety of the border and to prevent unauthorized people from entering the country. The speed of these checks and the amount of employees available for the checks differ per day and throughout the day. Combined with the irregular arrival of passengers due to flight schedules, this results in peak periods and long queues in the terminal, see Figure 6. Waiting time at the passport control is one of the indicators for measuring passenger satisfaction, which is a key performance indicator for the company. This problem has gained attention within the company and several projects have been set up to improve the situation.

Therefore, in the past months, several control measures have been implemented that can be taken to prevent exceeding of crowd norms in the arrival filters. In the next section, the most important one, flow balancing, is explained.

3.2 Flow balancing to control capacity constraints

The focus of this case study is the Passenger Arrival Flow, where capacity constraints in and around the Arrival Filters (AF) create operational challenges. A schematic overview of the area where the arrival flow occurs is shown in Figure 7. These two different factors influencing the passenger flow are explained in more detail below. Passenger flow management is the responsibility of the Process Coordinators Passenger (PC PAX). Their primary goals are to ensure that the fire safety norm is never reached and to minimize passenger waiting and walking times.

2.2.1 Key players in flow balancing

The decision to flow balance is made by PC PAX, supported by Passenger Assistants (PAs) and Floor Managers as the executors and guiders of the passenger flow. Passengers arriving on flights at Schiphol Airport are the key stakeholders impacted by this process. Additionally, the Koninklijke Marechaussee (kMar) plays a role in processing passengers through arrival filters. In this project, the PC PAX will be referred to as the flow controller, the Floor managers as the flow guiders and the Marechaussee as the flow moderator.

2.2.2 Goals and importance of flow balancing

The primary objectives of flow balancing are to prevent exceeding fire safety norms in arrival filters, to enhance passenger experience by reducing wait times and avoiding overcrowded spaces, and to maintain operational efficiency while ensuring compliance with safety regulations. Passenger volumes arriving at the terminal vary throughout the day based on flight schedules; usually, volumes are not spread evenly over the day, but the distribution is rather with peaks and quiet moments. Without flow balancing, occupancy issues can lead to bottlenecks and safety risks. Flow balancing can create more walking time for passengers, and as walking times at Schiphol Airport are already relatively long, this is also experienced negatively by passengers. Therefore, flow balancing must be applied thoughtfully.

3.2.3 The process of flow balancing

Flow balancing is a control measure aimed at redirecting selected groups of passengers to different arrival filters to prevent overcrowding and ensure smooth operations. This involves monitoring passenger flow and terminal occupancy, rerouting passengers to less crowded areas, and temporarily holding passengers in buffer zones when necessary.

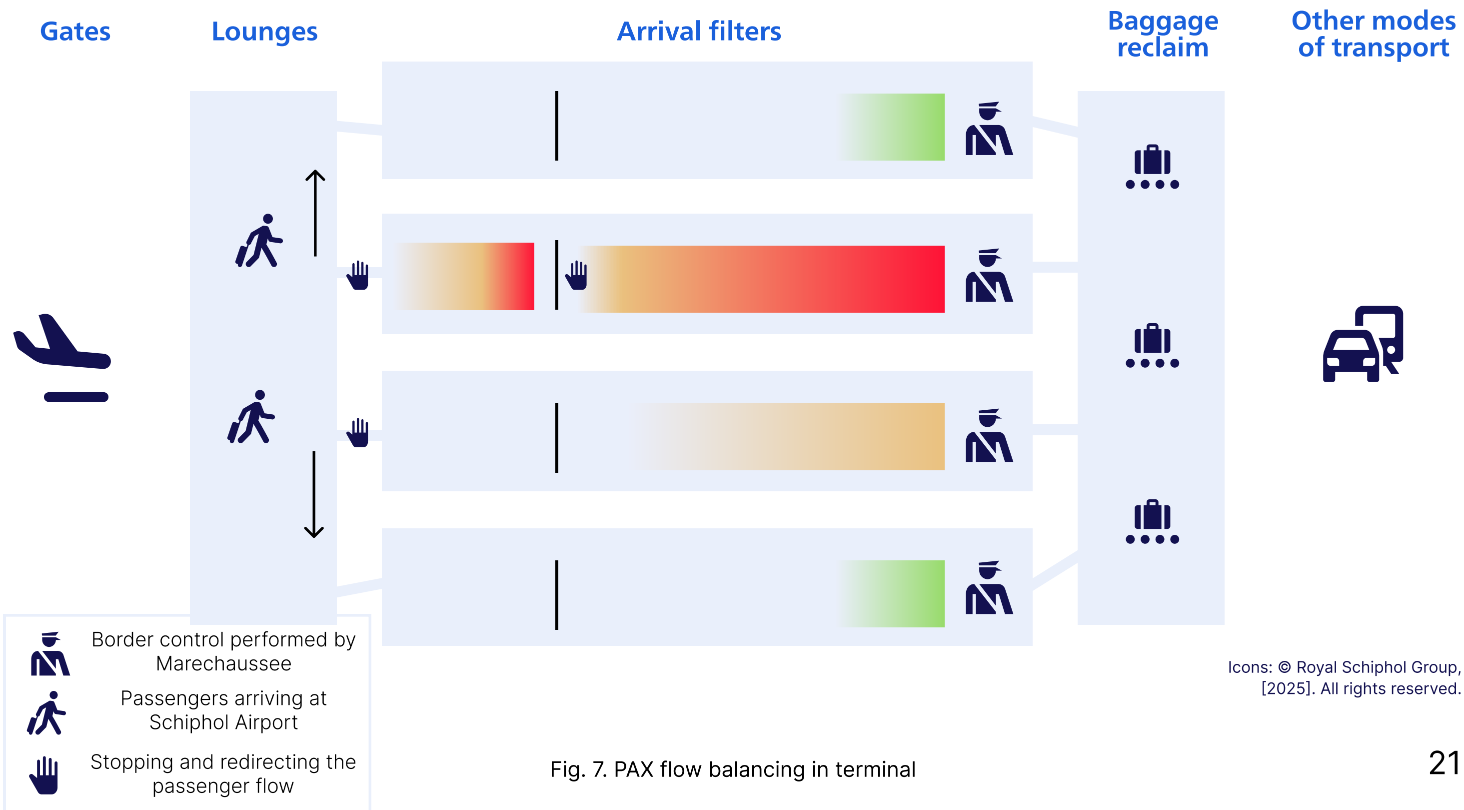

Fig. 7. PAX flow balancing in terminal

PC PAX utilizes Wilbur, an in-house software tool that integrates predictive and real-time data. Wilbur visualizes crowd density in specific terminal areas and provides information about arriving flights and passenger volumes. In Figure 8 an annotated screenshot of the page within Wilbur that is used for flow balancing can be seen.

The flow balancing process begins with monitoring real-time data using Wilbur, which enables PC PAX to track passenger volumes and density across arrival filters. Based on this data, groups of passengers are directed to alternate filters, such as rerouting them from one arrival filter to another if their default filter is overcrowded. Additionally, passengers may be temporarily held in designated buffer zones and released in smaller groups to prevent congestion. Collaboration with the Marechaussee ensures that adequate staffing levels are maintained for both manual and automated passport checks.

Flow balancing is a dynamic process that occurs throughout the day, particularly during peak periods. It requires real-time decision-making based on flight schedules, terminal occupancy levels, and staffing availability.

3.2.4 Challenges in flow balancing

Several challenges make flow balancing a complex task. Variations in flight schedules and passenger behavior result in unpredictable inflows, making it difficult to predict occupancy levels accurately. Redirecting passengers to alternate filters or holding them in buffer zones can lead to longer walking distances, delays, and dissatisfaction, which affects the overall passenger experience. Non-transparent scheduling and low availability of Marechaussee staff impact the efficiency of passenger processing. Balancing the need for safety and efficiency with passenger satisfaction is challenging, especially since arrival processes are not prioritized as highly as departures and transfers.

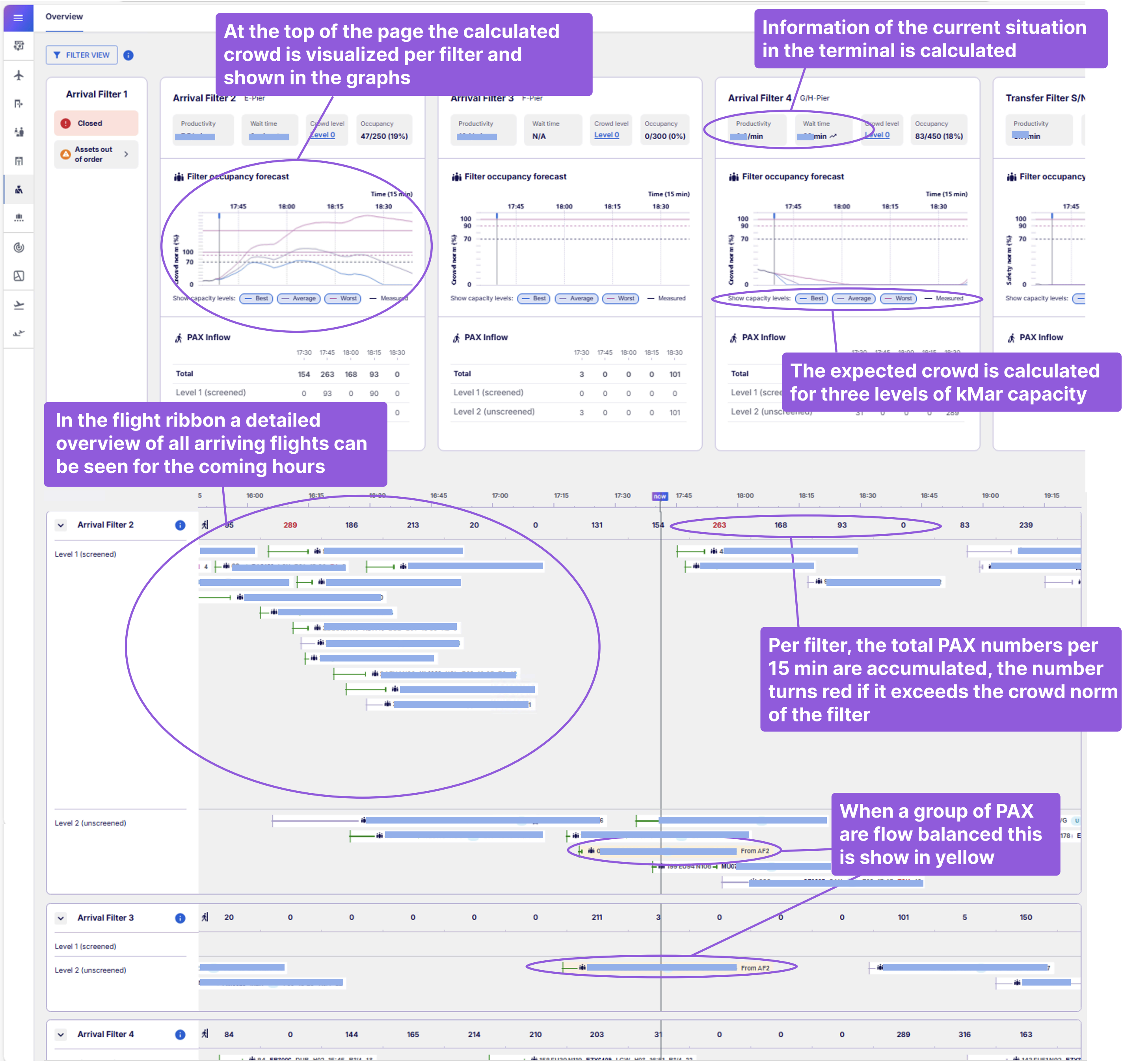

Fig. 8. Workflow for flow balancing

3.3 Automation technology as the proposed solution

3.3.1 Implementing augmented decision-making in a DSS
As just explained, the operation of Schiphol is working on ways to improve the passenger experience in the short term by implementing processes such as flow balancing. But also in the long term, Schiphol has plans to improve the passenger experience. According to RSG's strategy [56], passengers should experience a seamless flow through the airport, while the airport itself evolves into an autonomous operation. As part of this emphasis on automation, the human touch remains a vital element of their service proposition. As a high-tech hub, Schiphol thinks it gains the opportunity to distinguish itself from competitors.

Currently, several projects are in development to advance the vision of an autonomous airport, both within the terminal and on the airside. These projects range from autonomous vehicles and baggage lifts to chatbots for assisting passengers and systems that support and augment operational workflows. Also, for the challenges mentioned before, of managing the pressurized passenger flows, RSG wants to leverage automation to improve operational efficiency.

One of those projects, relevant to the problem framed in the previous sections, is automating passenger flow oversight by introducing augmented decision-making (ADM) capabilities within Wilbur. Specifically, the system aims to enhance decision-making related to flow balancing. The augmented system is envisioned to provide PC PAX with actionable recommendations for flow balancing measures, along with simulations that predict the outcomes of different options. The goal is to optimize the effectiveness of these actions, reduce passenger waiting and walking times, and stimulate a uniform workflow of all different PC PAX.

The crowd management challenges, combined with RSG's ambition to become an autonomous airport, are key drivers of the ADM development effort, which represents a significant investment for RSG. The strategic objectives from RSG for this project are threefold:

1. Maximize airport efficiency and capacity for handling large volumes of passengers, baggage, and aircraft while maintaining safety and service standards under dynamic constraints.
2. Proactively and holistically monitor and control operational activities and processes, ensuring safe, efficient, and orderly airport operations on a daily basis.
3. Enhance staff efficiency, effectiveness, and engagement while facilitating alignment with RSG's broader objectives.

Schiphol aims to improve the effectiveness of flow balancing to be able to digest more passengers through the arrival filters while maintaining a positive passenger experience. The organization believes this can be done by augmenting the capabilities of the operators with additional functionalities to the decision support system they use. These functionalities should improve integral flow control through collaboration with stakeholders.

3.3.2 Designers of Wilbur and flow control processes
The initiators of the ADM project are the Process Owner and the Service Owner. Who have a more long-term orientation and manage and initiate projects related to their process or service. They are responsible for the work instructions of the people working in the operation, such as PC PAX and FLM. And are also ultimately responsible for the results of the passenger experience and therefore monitor the waiting time measure and the scores that passengers rate the airport.

Their main aim of augmenting the flow controller’s job is to make sure decisions are taken more proactively and uniform across different employees, as they believe this is could improve the effectiveness of the control measure and improve the predictability of the passenger flow.

The second team within Schiphol that is involved in the ADM project is the design team, consisting of several people including interaction and service designers. They are responsible for the interface design and the integration of the system within the workflow of the users.

And the last main party involved is the development team of ADM. This team consists of data scientists and AI experts that are responsible for the design and development of the algorithm of ADM and also partly determine the functionalities that the DSS is going to have. This is also done in collaboration with the design team.

3.4 Relevance of case study for research objectives

This project was selected as a representative and relevant example for this research because the development of the system is in an advanced stage, such that we can test the adoption. Furthermore, the envisioned users are available and interested in the project and therefore likely willing to participate in this research.

As previously mentioned, flow controllers are responsible for making decisions regarding control measures to manage passenger flows. Currently, these controllers already receive decision support from an existing DSS, which helps them monitor passenger movements and identify potential congestion points. However, Schiphol is in the process of developing additional functionalities that incorporate artificial intelligence (AI) to further enhance decision-making. This next step in automation raises concerns among users regarding the adoption of this enhanced DSS, particularly in terms of how it will integrate into their workflows and how much control they will retain over decision-making.

Additionally, the passenger flow control is situated in a multi-stakeholder system, with different internal and external stakeholders having significant influence on the process. For these two reasons, this case study is relevant to study for answering the research questions mentioned in section 1.

The initiation of this project was done in collaboration with employees of Schiphol. Their main aim for this project was to get guidance in the design and development process of the DSS that is currently being developed, ADM. Especially regarding the inclusion of human factors.

Conclusion section 3

- In this section, the background information about the case study has been provided.
- Schiphol Airport is currently facing capacity constraints within the terminal, causing long queues and decreasing passenger satisfaction rates. Royal Schiphol Group currently aims to control passenger flows more efficiently by applying control measures such as flow balancing.
- Also Schiphol Group, believes that in the future there is more potential to be gained from flow balancing by applying (partial) automation in this decision-making process. Therefore, several teams within Schiphol Group are developing augmented decision-making systems to be used in the operation.
- This case study is relevant to study for this research as Schiphol Group is designing a DSS to support decision-makers situated in a multi-stakeholder system.

Context Research

observations and interview study

In this section, a deep dive into the context of the case study is made. To understand this context, an ethnographic research study has been conducted with the objective of understanding the decision-making process and the multi-stakeholder system in which it occurs. First, the decision-making process for flow balancing actions is explained from the perspective of the decision maker and flow controller. In this part, we aim to understand what challenges they face and which steps they undertake. Second, we have mapped the stakeholders that are part of this decision-making process and analyzed their power and interest in this process. And thirdly, the existing tensions between the flow controller, flow guider and flow moderator are analyzed.

- 4.1 Methodology
- 4.2 Flow balancing as a decision-0making process
- 4.3 The involved stakeholders in flow balancing, their role and perspective on the process
- 4.4 Current tensions between stakeholders regarding the decision-making process

4

4.1 Methodology for context research

To get an understanding of the context of the case study, ethnographic research has been performed into the context flow balancing, which is applied in the arrival PAX flow within the terminal of the airport. This is done by performing several observations, open-ended conversations with different stakeholders in the process, and finally semi-structured interviews. A combination of different research methods of both observing and speaking to people was employed because this enabled the researcher to get a deeper understanding of the context and workers [57].

We aimed to answer the following research questions:

1. *How is the decision-making process for flow balancing performed currently?*
2. *Which stakeholders are involved and what is their role regarding the process?*
3. *When in the decision-making process are interactions happening between the stakeholders, and what information is being exchanged through which communication channels?*
4. *What tensions are present between the stakeholders regarding the decision-making process?*

In Appendix A.3 more information about the detailed method, participant selection, ethics, and data collection and analysis can be found. The data was analyzed using the analysis on the wall method, which is especially useful for collecting insights from research results with different forms and that are not structured [57].

4.1.1 Method used for shadowing and open-ended interviews

Two different research methods were used in this first part of the ethnographic study, namely shadowing and open-ended interviews. First of all, the qualitative technique known as 'shadowing' was used. Shadowing is an ethnographic approach concentrated on the everyday activities of one person operating within a complex institutional social context. This method is especially relevant to use when studying the execution of a specific task and can expose otherwise unseen facets of people's work [41]. Second, the open-ended interviews were used to get to know all the different stakeholders and get an image of their involvement and perspective on the decision-making process.

4.1.2 Method used for semi-structured interviews

The interview study is split up into two parts, one for the PC PAX, who are the responsible workers for the integral PAX flow management (over the entire terminal). And the second part for the other directly involved actors, from the kMar, the Floor Managers, and the Operations department of RSG. The PC PAX are asked to explain a situation they recently encountered in their work where a possible occupancy norm would be exceeded and the decision to flow balance was made. We will ask them to describe the process briefly, starting at the moment they noticed a problem might occur, until it was completely resolved. The participant will be asked to write down the steps taken, interactions with other actors, sources of information, problems experienced, and positive experiences on post-its and place those ina template.The template consists of a timeline and the researcher will guide the participant during its fulfillment. After the participant is finished, we probed for more details using probing questions which are listed in Appendix A.4. This interview method was inspired by the Critical Decision Method used by Zhang et al. [81], which is effective for eliciting expert knowledge on complex decision-making tasks. It was chosen because the decision-making for flow balancing is a complex process, and we wanted to ensure participants reflected on the complete process before discussing specific challenges and interactions. This approach helped capture the full process rather than narrowing the focus too early in the conversation.

For the semi-structured interviews, two different interview guides, see Appendix A.4, were used, and the interviews were conducted by one researcher. The interviews are audio-recorded and transcribed. Furthermore, the researcher collects some personal information, including the expertise level and job title.

4.1.3 Participants

In Table 3 the complete overview of all participants of both research studies can be seen. The aim was to get a good overview of the entire stakeholder context, but due to safety restrictions and operational limitations of the Marechaussee, only two participants were interviewed from the organization. The participants are divided between the observation study (O#) and the interview study (P#).

Participant number	Job title	Years of experience
P1	Process Control Passengers	5 - 10
P2	Process Control Passengers	0 - 1
P3	Process Control Passengers	0 - 1
P4	Floor Manager	1 - 3
P5	Floor Manager	3 - 5
P6	Floor Manager	0 - 1
P7	Floor Manager	10+
P8	Process Control Passengers	5 - 10
P9	Process Control Passengers	1 - 3
P11	Process Control Passengers	0 - 1

Table 3b. Participants of interview study

Participant number	Job title	Years of experience
O1	Process Control Passengers	3 - 5
O2	Process Control Passengers	3 - 5
O3	Process Control Passengers	1 - 3
O4	Process Control Passengers	5 - 10
O5	Process Control Passengers	0 - 1
O6	Process Control Passengers	1 - 3
O7	Floor Manager	1 - 3
O8	Floor Manager	3 - 5
O9	Floor Manager	1 - 3
O10	Capacity Advisor kMar	5 - 10
O11	APOC Performance Manager	3 - 5

Table 3a. Participants of observations

4.2 Flow balancing as a decision-making process

In Figure 9 the process of PAX flow management is visualized in a brief way; a more detailed version can be seen in Appendix B.3. In this chapter, the different steps of the process as executed by PC PAX will be explained. The different steps of this process are not necessary performed chronologically, but happen iterative where PC PAX move from one phase to the next and back again. The briefings, part of the preparation phase, are planned at standard moments during the day.

4.2.1 Preparation at start of shift

For the PAX flow control, different tools are used by the decision-makers. These are Wilbur, the cameras, and several communication tools, such as WhatsApp, the phone, and radio; the information sources are all summarized into tools. Within the work shifts of PC PAX, their attention is focused around the peak moments. In these moments, often several flights arrive, and the inflow of passengers in one or several arrival filters is relatively high. For example, between 8 and 10 AM every day is such a moment. As the moments with high passenger inflow can be chaotic, preparation and having a plan upfront are important.

At the start of the shift, several briefings occur; the different moments where problems might occur are discussed. During these briefings, PC PAX agrees with several stakeholders on a plan of approach for these moments. The most important briefings are with the floor managers and with the OKP; these will be explained in more detail in the next subsection. PC PAX prepares for these briefings by looking at the expected PAX inflow for the coming hours and possibly any disruptions that are important to take into account.

Notes during observation: **"During the briefings, moments of higher PAX inflow are discussed with the different stakeholders, and what control measures they are planning to take."**

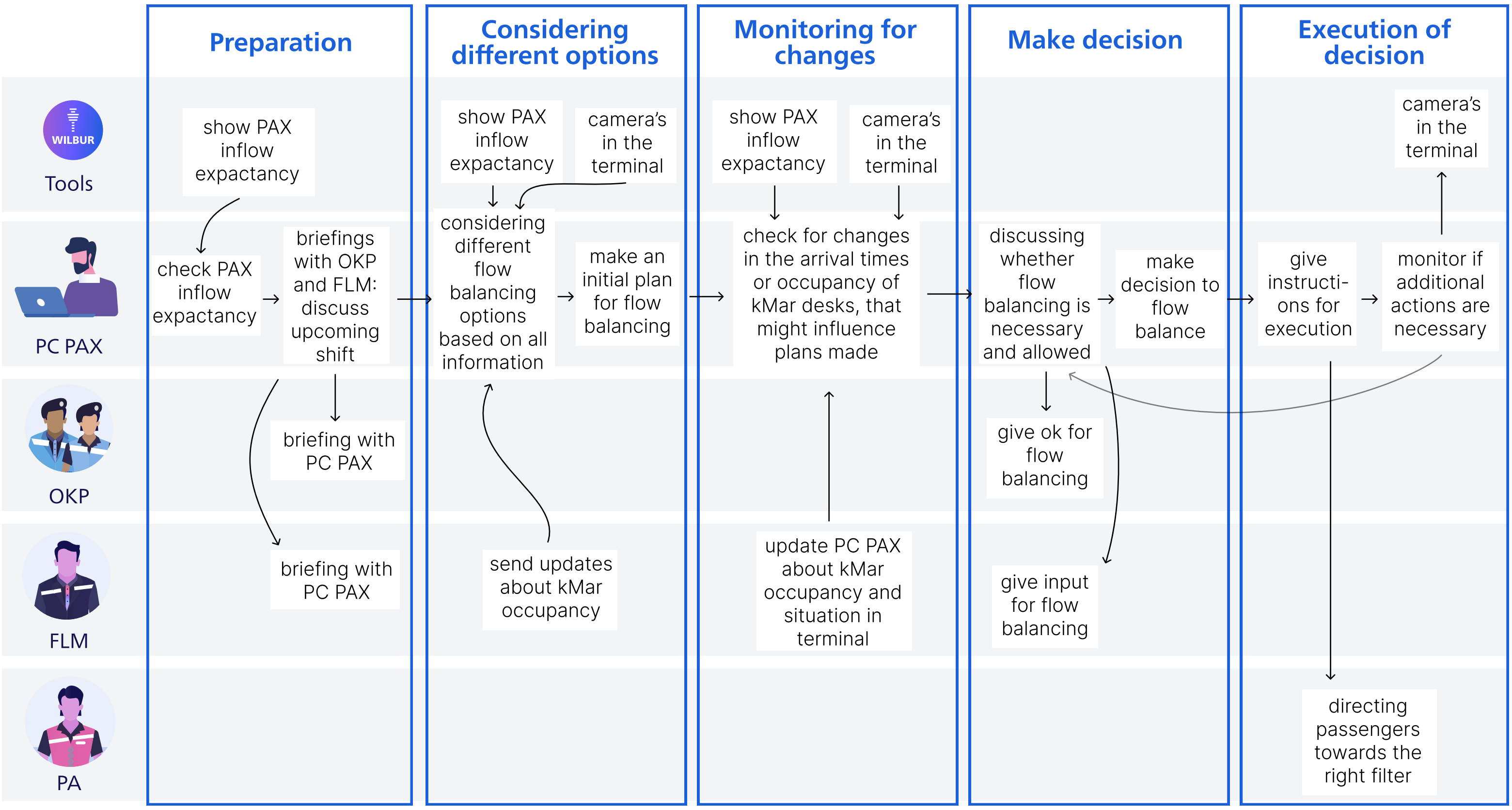

Fig. 9. Workflow of PC PAX regarding flow balancing

4.2.2 Considering different options by analyzing all information sources

Whenever a possible problematic moment is identified by PC PAX, they will consider the different possibilities to solve this problem. A problematic moment means that the expectation is that in one of the filters too many passengers will enter at the same time, causing a long queue. This creates long waiting times for passengers but also a possible safety norm exceeding in the arrival filter. PC PAX determines their decision based on a combination of different sources of information and also on a large part of their own experience. But it can also be difficult for them to foresee the development of the crowds in the filters.

Researcher: **"So how do you come up with such a picture in your head (about making a plan for flow balance actions)?"** P3, PC PAX: **"Well, that's actually a bit from experience. When you see those PAX numbers, you think of 'oops, this is going to be very busy' or 'this is not so bad'."**

P5, PC PAX: **"A peak in inflow on one day doesn't create queues in the filters and on the other day it does, with the same kMar occupancy. I want to know why a high inflow sometimes might cause problems and other moments it doesn't;I don't understand what causes that difference."**

They also mention that it can be difficult to empathize with passengers from their perspective.

O3: **"While being in the PC PAX position, it can be difficult to know what is pleasant or not pleasant for passengers. It can be easy to accommodate the requests from other stakeholders and neglect the passenger experience."**

Insight 1: During the decision-making process PC PAX is using other information sources in addition to information from Wilbur such as their own expertise, information from stakeholders and camera footage.

Next to flow balancing, several other control measure can be taken to control the passenger flow. For example, changing the arrival gate of a flight. PC PAX has to discuss this with busregie or gate planning. As the gate planning is often tight this is not always possible. PC PAX also occasionally try to increase the number of open kMar desks in filters that have to process a high number of passengers soon. This is usually the preferred option because this has the least impact on the passengers and Schiphol personnel, as they don't have to be redirected.

4.2.3 Monitoring and adapting to last minute changes

PC PAX has to pay attention to several areas at the same time. Often, nothing happens, but the situation can change quickly. The decision to flow balance is taken at the last moment, as PC PAX wants to keep monitoring and re-evaluating the situation. The main cause of this is that information in Wilbur can change; PC PAX are very aware of this and check often if this is the case.They also always use the cameras and input from employees in the terminal to create a full picture of the situation. Cameras are partly used as a verification of the information in Wilbur. But also provide more information about the exact moment that passengers are entering the terminal, the queues in arrival filters, the occupancy of kMar desks, etc.

From notes during observation of O5: **PC PAX is watching the camera footage; the aircraft arriving from origin X is already at the gate, but the previous aircraft is still at the gate.PC PAX checks the airside map to see where the origin X aircraft is. Meanwhile, switching back to the cameras in the arrival filters.**

Frequent notifications of gate changes can cause confusion, and alterations in the flight ribbon leave PC PAX unaware of significant changes impacting decision-making, such as delays, early arrivals, or gate adjustments. In some cases, flights may disappear and reappear due to gate planners experimenting with the schedule, leading to further uncertainty for PC PAX.

From notes during O1 (PC PAX): **"Minutes after the PC PAX called to request a bus gate change, the flight suddenly changed back to the original gate in Wilbur.After calling again, this turned out to be a mistake."**

P3, PC PAX: **"sometimes puts up flight radar on his desktop to check the current location of aircraft and accurate arrival times. And uses cameras to check where PAX are, if off boarding has started or ended, in case of last-minute flow balancing."**

As previously explained, frequent changes in the inflow of passengers, including last-minute adjustments, make it difficult for PC PAX to predict the inflow accurately. This is similar for the outflow of the filters, which is largely determined by the productivity of the Marechaussee. The staff scheduling by the Marechaussee is often intransparent and, at times, unpredictable for PC PAX. Furthermore, in certain moments, a high number of notifications, phone calls, etc. are received by PC PAX; this information has to be filtered as not everything is relevant.

Insight 2: PC PAX do make a plan upfront but wait until the last moment with finalizing their decision-making, as important information can change up until the last moment.

4.2.4 Decision-making and execution

Right before or just after the actual decision-making, PC PAX are in contact again with FLM and OKP. The main purpose of the interaction with FLM is to inform them, as they are responsible for the execution of the flow balancing actions. Therefore, it is important to be on one page with the FLM about when and what passengers are being flow balanced.

P3, PC PAX: **"Then I often call the floor manager first to say, okay, it's getting busy now at arrival, I'm going to flow balance in a minute now. So make sure all the PAs and everyone are ready."**

Occasionally, PC PAX are also in contact with OKP right before or after they have made the decision to flow balance. As OKP wants to be informed and be able to contest this decision-making. This is further explained in subsection 4.3. For the actual execution of the decision, PC PAX gives instructions to the PA's.

These instructions concern when to start redirecting passengers, but also when to stop. Monitoring the effects of a flow balancing action is also important for PC PAX, as they should determine whether the flow balancing action was sufficient to reduce the crowd or if additional actions are necessary.

P1, PC PAX: **"Of course, on camera footage, we can also see all those flow balancing actions. (...) So we can also see there, they are coming in now. And now the first group is in the filter. You can then also see if I can flow balance another group already or if we have to wait. Because then, of course, how fast does it run through such a filter. And on the basis of those images, and when you see how fast it goes, you decide whether or not to send another group through."**

4.2.5 Stakeholder interactions as part of the decision-making process

Most interactions with the relevant stakeholders happen during the preparation and monitoring phases. In the preparation phase, this consists of the briefings where the plans are communicated and agreements are made about the way of working.In the monitoring phase, information is exchanged that is relevant for the decision-making, as well as possibly discussing the decisions and stakeholders contesting these decisions. In the next subsection, the stakeholders and interactions are explained in more detail.

4.3 The involved stakeholders in flow balancing, their role and perspective on the process

After explaining the decision-making process performed by PC PAX, the different stakeholders that are already mentioned before are explained. In Figure 10 the different communication lines are visualized for the stakeholders mentioned before. The communication happens both on the day of operation and before and afterwards. Below the different stakeholders included in the Social Network Analysis [76] are presented, by explaining their responsibilities and goals regarding flow balancing.

4.3.1 PC PAX

PC PAX is the decision maker and responsible for deciding when flow balancing actions should be executed. In the previous subsection the workflow and challenges of PC PAX are already explained. PC PAX is the central point of contact for the different stakeholders regarding the integral arrival passenger flow. Especially in busier moments, they are almost constantly in contact with several stakeholders. The different parties contact PC PAX for information and with requests regarding flow balancing or other control measures.

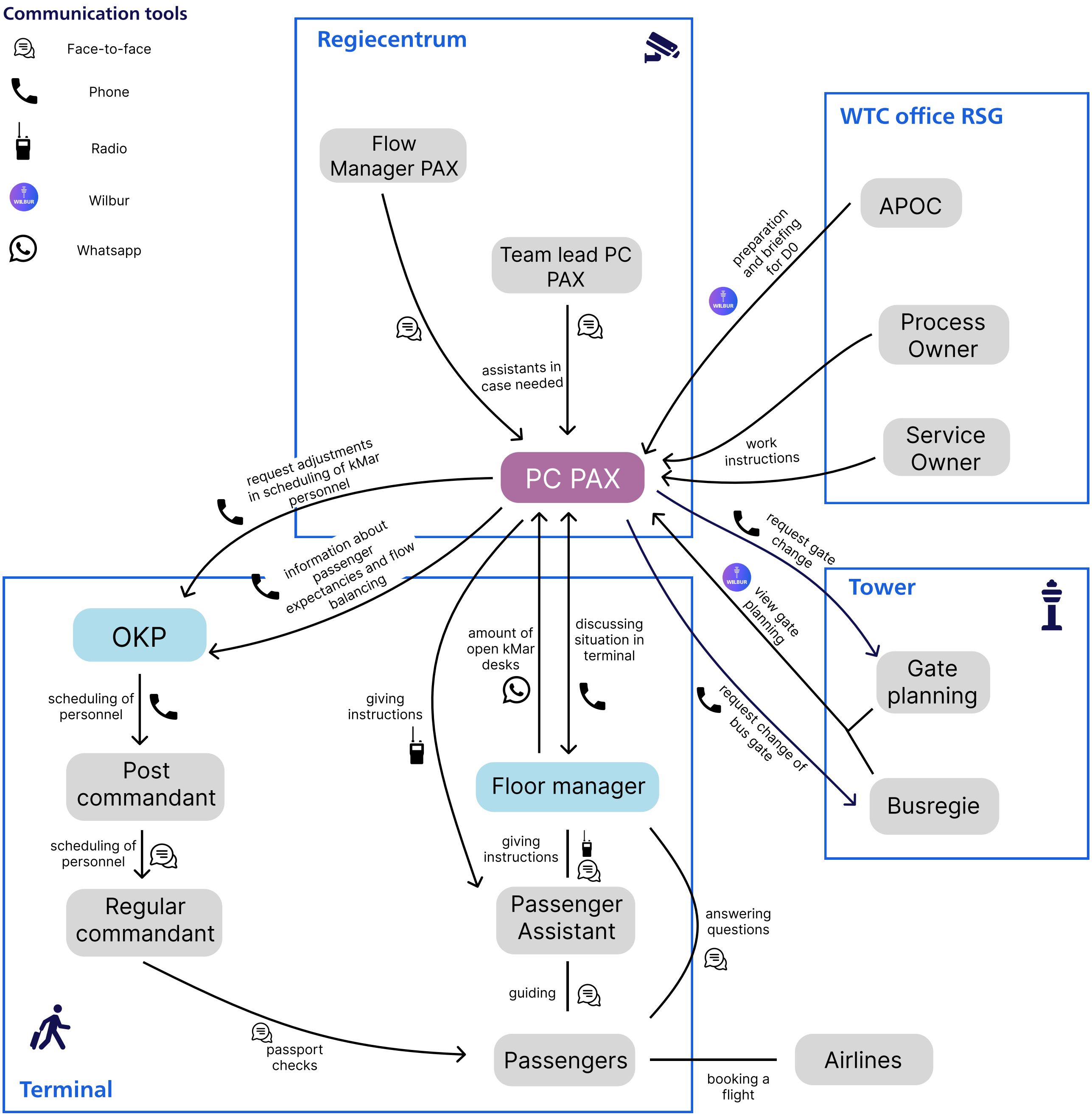

Fig. 10. Social network analysis [76]

Meanwhile, PC PAX tries to retrieve information from the different stakeholders as well. Besides plain information exchange, also a lot of discussion and alignment happens in the communication. The PC PAX often mention the need for a good relationship with the people they communicate with. This sometimes lacks with certain people, and this seems to affect their work in a significant way.

> P3, PC PAX: **"And with some Marechaussee you work more pleasantly than with others. That is something that can make or break your shift, though."**

For flow balancing, PC PAX aims to improve the passenger experience by limiting the amount of waiting time at arrival filters, but also making sure they don't have to walk through the entire terminal.

Insight 3: Interactions that PC PAX have with stakeholders are not only for the benefit of exchanging information, but also adds to f.e. alignment and other social aspect adhering to the decision-making process.

4.3.2 FLM and PA

Floor managers (FLM) and Passenger Assistants (PA) are both employed by Schiphol and the executors of the decisions made by PC PAX. The Floor managers are present in the terminal and are responsible for the entire operational process in their assigned area. Some of these areas have one or two of the arrival filters in them; those Floor managers are therefore involved in the flow balancing process. They are responsible for making sure a flow balancing action is executed well by the Passenger Assistants (PA). Next to this, the FLM also has several other responsibilities, such as emergency response officer.

> O7: **"Other responsibilities of FLM: BHV, storingsdienst, management of PA's (location and breaks), are in contact with PAX (answering questions)"**

In the decision-making process, the PC PAX often consults the FLM and discusses collaboratively what control measures could and should be taken. FLM and PC PAX collaborate closely for passenger flow control, and PC PAX often consults FLM regarding flow balancing.

> P8, PC PAX: **"With floor managers, you can sometimes call in advance and say: 'Hey, I have a certain plan in my head, do you think this plan will work? So you do sometimes call to discuss that."**

> From notes during observation of O4: **In busy moments for PC PAX, they are constantly on the phone or radio talking to different parties to discuss the situation and control measures they want to take.**

The Floor managers are also in contact with the Marechaussee, more specifically the one present in the terminal, called the post commanders. Floor managers provide the post commanders with an overview of the expected passengers per hour for the upcoming shift of eight hours. And the post commander informs the FLM about the number of desks they can have open in the upcoming shift.

> From notes during observation of O4: **FLM goes to the post commander's office within their area to discuss the upcoming shift.**

FLM focuses on maintaining a smooth passenger flow and is not really looking ahead, but rather acts according to incidents that occur in the terminal.

> From notes during observation of O7 (FLM): **Almost everything is done ad hoc; must be prepared for everything to be able to react quickly at any moment.**

Besides, they focus on their own area, consisting of either one or two arrival filters.For these reasons, the objectives of FLM and PC PAX can diverge, as PC PAX is responsible for the integral PAX flow over all of the filters and FLM is merely concerned with their own filter.

O2, PC PAX: **"Sometimes the people working on the floor, in the terminal, don't have a lot of patience. FLM are oftentimes very proactive in calling the PC PAX about busyness at their filters. Also, because not every PC PAX is very proactive."**

O8, FLM: **"Quite regularly the FLM must ask the PC PAX if it is possible to flow balance PAX away from their filter, as it is too busy there. At that moment it is already too late, PC PAX was not proactively working to manage the flow."**

Insight 4: FLM and PC PAX collaborate closely for passenger flow control, PC PAX often consults FLM regarding flow balancing.

PA's are responsible for executing the flow balancing actions, closing the bank lining, instructing passengers, and dividing them into the right queues.

P9, FLM: **"To flow balance. Yes, to actually carry it out. Yes, so they do the work execution." (about PA's)**

The past years, there has been a high turnover causing the quality and motivation of PA's to differ largely creating an extra unpredictability in the flow balancing process.

P9, FLM: **"But of course you have new PAs, who of course don't listen to porto's properly. Or are not in locations. Or misunderstood the message." P5: "And now we have such a turnover in that pool. (...) And if there is one of those again who is constantly cutting corners. Then I find that annoying, because it bothers me."**

For instance, the communication between PC PAX and PA doesn't always go smoothly. Some PAs don't always respond adequately or misunderstand instructions given by PC PAX. FLM has to monitor this to make sure PAs perform their job well.

P5, FLM: **"Well, where are you, too long on break, do your clothes right (..) Well, I can name a few more like that okay yes hang out, dating each other. But sometimes you do have a day (...) when things go difficult (...) with some PAs, where things don't work out."**

The quality and performance of PAs is mentioned by FLM and PC PAX as a limiting and obstructing factor in the management of PAX flow in general. But also specifically, the effectiveness of the flow balancing actions to be limited or influenced.

P6, FLM: **"So it's up to you as floor manager to take that into account as well. And then to point out to the PA that you should listen carefully to your radio, because we are now entering a peak and it is important that when you are called to stop, you stop immediately."**

P5, FLM: **"Well if you have the good, right PAs. Who you don't have to correct all the time."**

Insight 5: The effectiveness of flow balance actions is negatively impacted by the variability of the quality of the work executed by PA's.

4.3.3 OKP and other Marechaussee personnel

The Marechaussee (kMar) is part of the Ministry of Defence and their main priority is the safety of the borders and the country, and therefore checking if people may enter or exit the country. Related to flow balancing, they can be viewed as the flow moderator. Within the Marechaussee, several different roles are related to flow balancing. First of all, the people working at the Operationeel Knelpunt (OKP) have the complete overview of all of the border control filters where Marechaussee commanders perform passport checks. They distribute the available personnel over all filters.

The other important people are the post commanders (PC kMar), who have the overview of one of the border control filters, so for example one of the four arrival filters. They manage the scheduling of personnel assigned to their filter.

> O10, kMar: **"Marechaussee, as a government organization, has no interest in reducing waiting times. Interest is in guarding the security of land borders; if passengers, to do that properly, have to wait longer, that's what it is."**

PC PAX can be in contact with the OKP and FLM with the PC kMar. Interactions the kMar has with other stakeholders consist first of all, of briefings between the PC and the FLM at the start of a shift. Where the FLM gives thePC an overview of the expected PAX numbers at the specific filters on paper. The PC uses these numbers in their schedule for the shift. Also, the PC PAX and OKP have a similar briefing, but this is not in person but by calling, and all filters are discussed. During this briefing, the kMar doesn't share information with the stakeholders from Schiphol about their schedules and capacity as this can be sensitive information. Schiphol can see the occupancy of desks in real time on cameras, but it is agreed that they do not collect and analyze this data. Next to briefings, the OKP is currently being on boarded as users in Wilbur, gaining them access to the border control page. In Wilbur, they are able to see the flight ribbon, flow balance actions, and the expected amount of PAX arriving per filter per 15 minutes.

> O10, kMar: **"Since a year, cooperation has been intensified, including the agreement to call twice a day at a fixed time to prepare the shift together, also known as the briefing. During these moments, the bottlenecks (if any) of the upcoming shift are discussed and firmly agreed on what can be done next. Marechaussee indicates whether capacity can cause a bottleneck that day or not; capacity is not passed on in exact numbers."**

Usually, the OKP wants to be informed about flow balancing actions before the execution, as this can influence their operation.The arrival filters are especially important for the kMar, as here people are entering the country and the possible danger here is higher compared to f.e. the departure filters.

Insight 6: The Marechaussee is responsible for executing passport checks in the arrival filters, and therefore ultimately determine the speed of the passenger flow through the filters.

> O10, kMar: **"Marechaussee wants to have insight and a voice in flow balance actions taken, because it matters to them from which filter it is forwarded to which filter. Because: Possible second-line issues going on in the filter being sent through that reduce the capacity of their staff there. And it matters which passengers are sent through, whether they can go through the SSPC (if it can open, it makes little difference) or have to go through the manual desks (then capacity is needed)."**

PCkMar are in contact with the Floormanagers as mentioned before. They exchangeinformation at their briefing at the start of a shift.

> O8, FLM: **"FLM go to the post commander's office within their area to discuss the upcoming shift.FLM have written down the amount of PAX per hour in the specific filter and hand this to the PC. The kMar shares their current capacity in the filter and how well occupied they are, but don't want to share their maximum capacity of the shift. The breaks of the kMar personnel are, partly, scheduled based on the PAX numbers they receive from the FLM."**

One of the main challenges for the kMar is their limit in personnel, especially on weekends they deal with understaffing. Which is sometimes backed up from other departments in the country. Next to checking passports of passengers entering or exiting the Schengen area, the kMar deals with second line tasks. For example, when someone is declined access, paperwork must be dealt with. Or when someone is arrested, kMar personnel might be needed at another place besides the filters. Regarding flow balancing, the kMar (OKP or Post commandant) is sometimes hesitant to allow this; the exact reasons for this are not always transparent. This can relate to profiling for a specific person, in which case they don't want to lose track of this person. Other reasons are assumed to relate to a Post commandant that wants to prevent a busier filter which creates overwork for his people. The relationship between the Marechaussee and PC PAX differs from person to person. But in the past years, there have been problems due to media attention and taking responsibility for long queues and waiting times [38, 67, 79]. The main cause of this was both parties attributing the cause of (arrival) filter queues to each other and the lack of transparent communication. Communication between PC PAX and OKP kMar can be strained, with disagreements and conflicting priorities. But both parties have the intention to improve the collaboration.

> O1, PC PAX: **"Ideal collaboration with kMar means that they anticipate busy moments well ahead (by increasing their capacity). Some post commanders understand this better than others."**

> O10, kMar: **"The LTC (Landelijk Tactisch Commando), after agreement with the other chain partners, has ordered this (to intensify the collaboration with Schiphol) (..). This is in response to the situation during and after COVID, where the various parties, (..) started pointing fingers at each other for blaming the cause of the long queues. Marechaussee wants to achieve good cooperation and be a pleasant chain partner."**

The reason that the Marechaussee is not inclined and relatively difficult in sharing information is that data about their staff schedules is sensitive information. The Marechaussee is a governmental organization and can be seen as a partof theMinistry of Defense. Information regarding their tactics forpassport checks can be sensitive information.

In general,the Marechaussee is hesitant in sharing data and currently cannot allow Schipholto collect and processany data aboutthe number of desks that are occupied.

Insight 7: For security reasons, Marechaussee does not want Schiphol to collect and analyze any data about the division and scheduling of personnel from the Marechaussee, as this could contain sensitive information.

4.3.4 Other operational parties within Schiphol

The other parties with a role within the operational process of passenger flow control are the APOC, team managers of PC PAX, gate planning, and bus regie.

PC PAX are in contact with gate planning and bus regie to arrange gate changes of bus gate changes that are a form of flow balancing done before an aircraft arrives at the airport. Gate changes are often quite difficult and not very often possible as the gate planning is very tight and limited to a high number of restrictions. Bus gate changes are usually easier. Some gates are located further away from the terminal and passengers have to be picked up by bus. The bus drops them off at one of the bus ingestion points at the terminal. It is quite easy to redirect a bus to another bus ingestion point as there are limited restrictions to this. Therefore, this is done quite regularly by PC PAX.

The team managers of PC PAX occasionally help the PC PAX when they have a question and are responsible for the performance, training, and scheduling. In the process of flow balancing, they do not have an active role. The APOC is responsible for the preparation a few days ahead and the evaluation one day after the operation. They are not involved in the flow balancing process and, therefore, we will not go into their role any further.

4.3.5 Strategic parties within Schiphol

The last two people from Schiphol, involved are the ProcessOwner and the Service Owner.These two were already mentioned as well in section 3 as the initiators of the ADM project. They have a more long-term orientation and manage and initiate projects related to their process or service. They are responsible for the work instructions of the people working in the operation, such as PC PAX and FLM. And are also ultimately responsible for the results of the passenger experience and therefore monitor the waiting time measure and the scores that passengers rate the airport.

4.3.6 Passengers and Airlines

Passengers traveling to Schiphol Airport from a country outside of the Schengen area have to go through the entire arrival process, including the border control filters. They can be seen as the subjects in this process. There is currently no information about the arrival process (f.e. waiting times) available for airlines and passengers. This causes the process to be stressful for passengers, according to the PO. Airlines and handlers are responsible for filling in data about PAX amounts on their air crafts. This is not done thoroughly by all airlines and handlers, causing the quality of information to be lower. Furthermore, the passengers are the end-users and clients of this process. Interestingly, passengers don't distinguish between the airport and the airline, implying that airlines would have a large value in a smooth operation at the airport. But the involvement of the airlines in this process is very limited and they do not have influence on the process of flow balancing at all.

4.3.7 Stakeholder analysis

After having described the different involved stakeholders, a selection was made from these stakeholders to determine which ones are relevant to include in the scope of the multi-stakeholder system. In Figure 11 the stakeholder influence diagram can be seen [19]. All the previously mentioned stakeholders are plotted according to their interest in the decision-making process and the power they have in which decisions are made. In the diagram, we can see that PC PAX, OKP, and FLM are the players regarding the decision-making process; therefore, they should be included closely. PC PAX has the role of flow controller, FLM are the flow guiders, and OKP has large power and interest in the decision-making process as they are the flow moderators. It is important to note that for this analysis, the context of the day of operation has been taken. The process owner and service owner do have a large interest in the decision process but not on an day-to-day basis, as they are concerned with the longer term. In Figure 12, an example of the current way of working of PC PAX including stakeholder interactions is visualized in a storyboard.

Insight 8: PC PAX are the flow controller, FLM are the flow guider and OKP are the flow moderator, these three stakeholders are the main actors in the process of flow balancing.

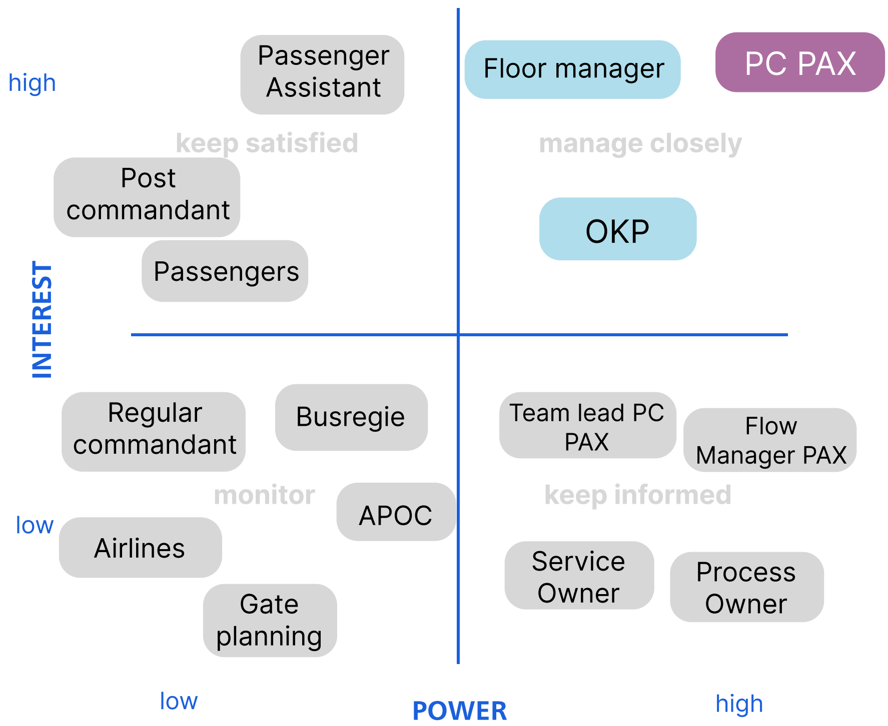

Fig. 11. Stakeholder analysis: power interest grid

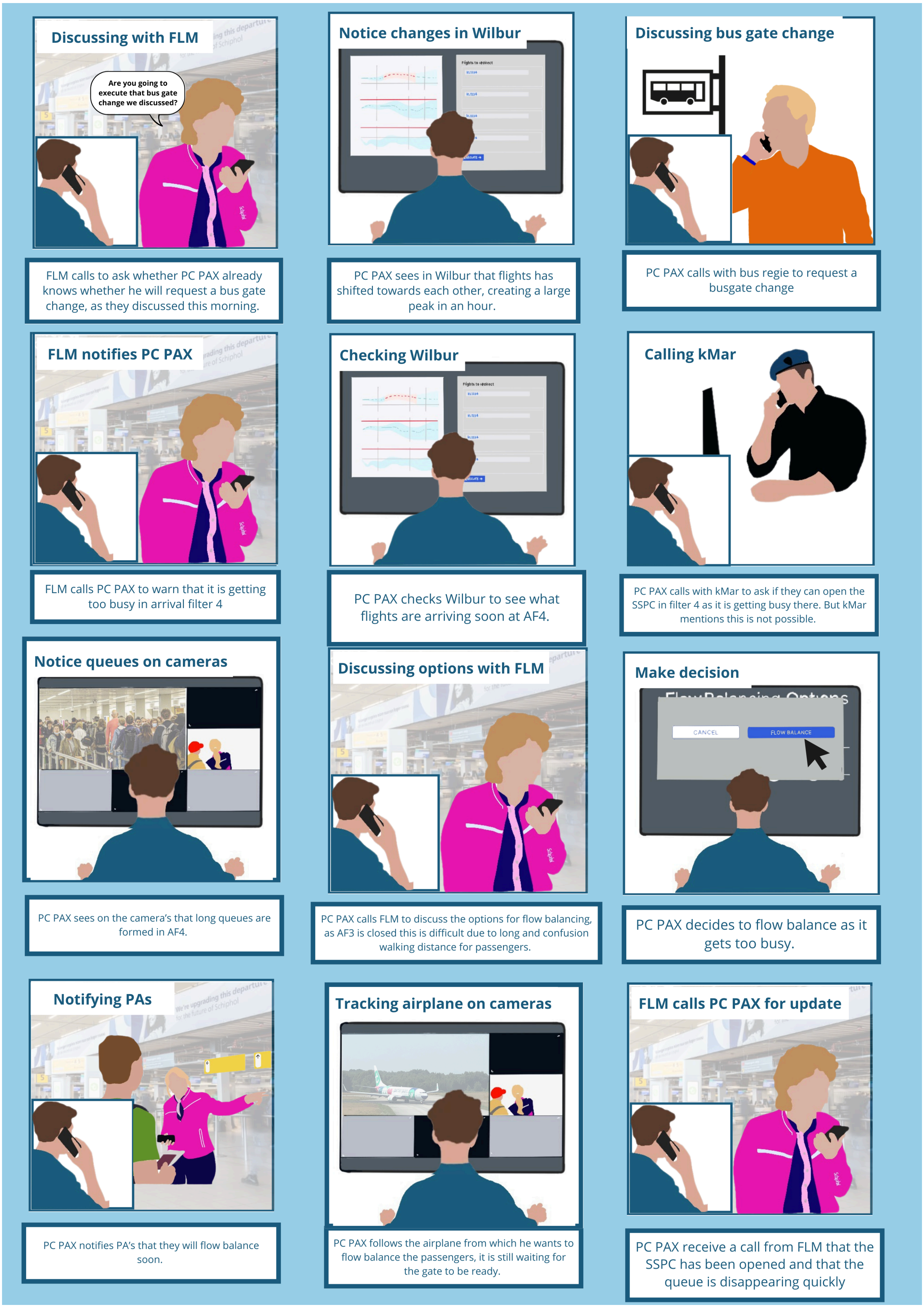

Fig. 12. Storyboard showing the current way of working of PC PAX, including stakeholder interactions

4.4 Current tensions present between stakeholders regarding the decision-making process

As we have seen in the previous chapter, there are many stakeholders regarding the decision-making process of flow balancing. In describing the multi-stakeholder system and tensions currently present, we have focused on the players of the decision-making process as described in Figure 11. In this subsection we will investigate the relationships and interactions between these three main actors and highlight the identified tensions between the flow controllers and the other two that are currently present regarding the decision-making process, visualized in Figure 13.

4.4.1 Different perspectives on and goals for the process

PC PAX and FLM have a good relationship and often discuss what flow balancing actions would work. Keeping this relationship close is also important for both parties. FLM visits the control center at the start of their shift to align with PC PAX and mentions understanding each other and being on the same page as most important in the collaboration. Besides, the FLM wants to feel as if the PC PAX has their back and supports them in the crowded and stressful moments.

P5, FLM: **"And then when several planes with a lot of passengers come down, it stagnates. And it's also up to us then to regulate that properly in collaboration with the control centre. They also have to monitor that for us. It is also their task. And it is still a discussion also with us."**

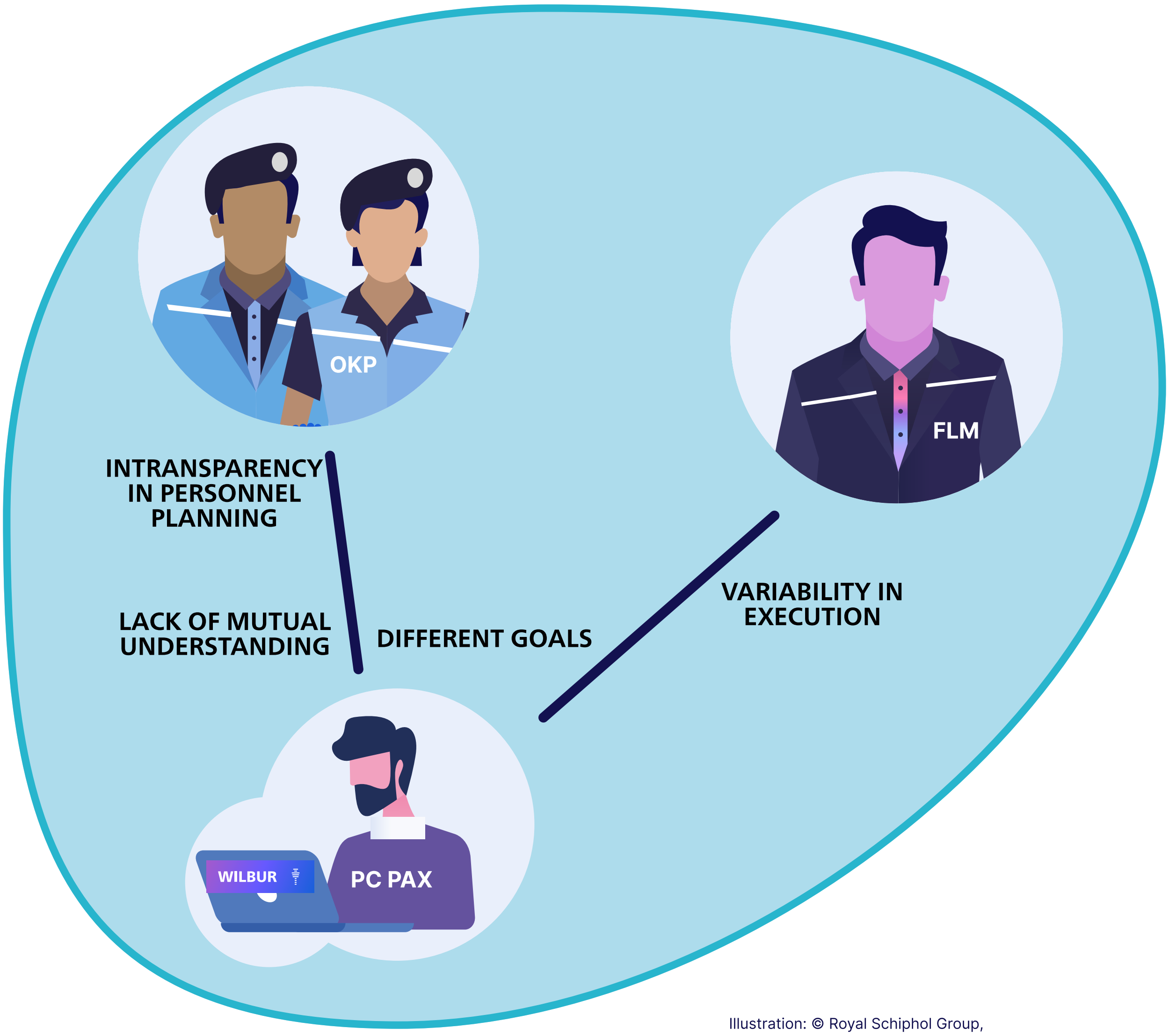

Fig. 13. Current tensions between flow controller, flow moderator and flow guider

P4, FLM: **That you are on the same page. I think that being on the same page together is the most important thing. (about collaboration with PC PAX)**

P11, PC PAX: **"Because the passenger assistants stand among those passengers. Those passengers sometimes get a bit angry if they have to wait for a long time. So they also ask every time: can we flow balance? What can we do? Then we explain that we can't do that now. Because this and that and so on."**

FLM can experience stress in crowded filters, due to the large amount of impatient passengers in front of them. In case that PC PAX do not execute control measures, like flow balancing, on time, the situation in the filter might become even more unpleasant for them. This often results in FLM urging PC PAX to flow balance in crowded situations in their filter. This can be helpful for PC PAX, but in other situations where flow balancing is not beneficial for the integral situation, it occasionally causes tension between the PC PAX and FLM due to a difference in opinion.

P8, PC PAX: **"There are floor managers who are very quick to panic. Wow, yes, no, it's busy and we have to stop. Yes, sometimes it's just not possible to do otherwise."**

In these situations, FLM can feel unheard and misunderstood by PC PAX when their suggestions are overlooked.

P6, FLM: **"maybe the colleague at the control center is not sharp enough, then I find it irritating. (...) I'm in the area with all those people, (...) sometimes circumstances prevent it, then of course there's no problem and then we make do with what we have. But very seldom do I notice that there are possibilities, but that the call is not made beforehand."**

Although FLM and PC PAX are working together closely, occasionally different responsibilities can have an influence on their cooperation as FLM has the responsibility over one of the filters whilst PC PAX carries the overall responsibility.

Tension 1: In some situations flow guiders have a direct need for flow balancing in their own filters, which is not awarded by the flow controllers as this has an overall negative effect for all the others filters.

The main responsibility of OKP is to maintain control over the border to ensure the security of the country. Therefore, their main interest is to carry out strict controls on the entry of people into our country. PC PAX on the entry has the responsibility to ensure a smooth flow of passengers through the airport and optimize their experience.

As a result of this, OKP wants to influence the decisions with respect to flow balancing, in order to protect their responsibilities. Currently, PC PAX does not fully embrace this desire from OKP, and no agreements are in place between these parties to formalize the influence of OKP in the decision-making process.

Tension 2: Flow controller and flow moderator have different goals for the passenger flow, Flow controller wants to minimize waiting and walking times of passengers and flow moderator wants to protect the border security by performing thorough passport checks. These goals can be conflicting.

4.4.2 Lack of mutual understanding

The collaboration between OKP and PC PAX can largely differ per shift and per person. For example, it is unclear whether the kMar should agree and can reject, or if they are only to be informed, as this differs per shift and no formal agreements are made about this. Some PC PAX call OKP before executing a flowing balancing action, and others do that afterwards.

> P8, PC PAX: **"I prefer it after (regarding calling OKP about flow balancing). I prefer having it as informing rather than asking for permission."**

> P8, PC PAX: **"And you collaborate more pleasantly with some Marechaussee than with others. That is something that can make or break your shift."**

Between the Marechaussee and Schiphol there is a large difference between the formal and informal behavior and interactions. Between the Marechaussee and Schiphol, limited formal agreements are made about information exchanges during the day of operation. This has caused the workers during the day of operation to develop informal relations and interaction moments with each other. Whenever they are in contact with someone they trust and like, there is often a lot possible, and more detailed information can be exchanged

> O12, APOC: **"The Marechaussee operates on person-to-person trust. Don't want to put agreements on paper. After the formal briefing, the real story comes."**

During their regular briefing, OKP and PC PAX usually agree on when PC PAX calls about flow balancing actions, in most occasions when more than 100 PAX are flow balanced. When this is agreed upon, PC PAX can also, on purpose, flow balance a lower amount per time, unless problems are larger. This briefing is not (yet) formalized in the work instructions for PC PAX.

> P8, PC PAX: **"Some operational capacity planners (OKP) of the Marechaussee want to know every flow balancing action. Some say, if it's over 100, give me a call."**

It occurs occasionally that OKP kMar does not agree with flow balancing actions that PC PAX wants to undertake. Sometimes PC PAX understands the reasons and is fine with this, but on other occasions, PC PAX doesn't understand the reasoning of kMar or they don't provide reasoning at all; this can cause frustration with PC PAX. For example, when the reason is lacking staffing in the empty filter.

> P8, PC PAX: **"Some who say I want to be called for every forwarding action. And then if you call, I want to start forwarding 50 passengers from 2 to 3. Then she says no you can't because we are in 3 badly occupied, or something. Whereas if 2 is full to the brim and on the first and second floor they are stopping people off and on, filter 3 it is completely empty but they don't have very many Marechaussee. Yeah then I'm like I just need the surface area to be able to put people down."**

OKP has frustrations about PC PAX calling often.

> P10, kMar: **"Marechaussee basically wants only necessary communication with the control centre, Schiphol. Marechaussee feels that the control centre can also sometimes call to let Marechaussee make the decision, out of uncertainty or to be able to shift blame for crowding onto Marechaussee. This is unnecessary and disruptive for Marechaussee staff."**

Due to differing goals between OKP and PC PAX, on both sides there is a misunderstanding regarding the drivers and actions taken, which leads to a lack of trust. Besides, due to the lack of formal agreements, there is a large dependency on informal relationships, causing a lack of uniformity and uncertainties.

Tension 3: Due to the lack of formal agreements between flow controller and flow moderator, there is a large dependency on informal relationships, causing a lack of uniformity and uncertainties how decision are taken and whether decisions can be contested.

4.4.3 Foresight of open kMar desks is unknown and uncertain to PC PAX

The prediction of the number of personnel on the kMar desks is unknown for FLM and PC PAX. In general, does the kMar not share their exact amount of personnel available, only whether it might form an obstruction that shifts.

P10, kMar: **"Marechaussee indicates whether capacity could cause a bottleneck that day or not; capacity is not communicated in exact numbers."**

The number of manned kMar desks changes often throughout the day. In some situations, these changes are communicated and discussed with FLM. But FLM has also regularly experienced situations where the actual amount of personnel at kMar desks turned out to be different than previously communicated, with or without explanation from kMar. The FLM communicates this information, if available, to the PC PAX as this is an important variable in whether flow balancing is necessary or not.

P4, FLM: **"With the Marechaussee, they can sometimes say to your face, yes I'm going to put down four positions and a no-Q. But then when it's just halfway through the day and you still only have three positions. And then I go to him, and he says but I didn't say anything at all. And then you're like but I need the fourth now, yeah but I don't have one."**

PC PAX also mentions that they view the communication with OKP as a game of negotiation, where they are not fully transparent as they want to get more information from the OKP than they receive.

O2, PC PAX: **"'Negotiation' game between PC PAX and OKP with information."**

The amount of manned kMar desks is an important factor for the development of queues in the filters; not knowing this is limiting PC PAX in making the right decisions.

P3, PC PAX: **"Occupation, kMar among others. Well, their available personnel was not very good. So then sometimes flow balancing doesn't make sense either."**

The intransparency regarding this is found to be obstructing by FLM and PC PAX.

P6, FLM: **"And by transparency, I mean, sometimes they can scale up, but they don't. Sometimes you have a post commander saying, well, it will be difficult, we're having second-line business. Whereas, if you then walk by, they are just sitting with more staff in the office, who could possibly step in. I have the feeling that I am not taken completely seriously because they are not, I feel, acting adequately. Then you can feel a bit fooled."**

Tension 4: The lack of transparency provided by flow moderator about the predicted productivity of the flow creates uncertainty for the flow controller, limiting them to make informed decisions.

Conclusion section 4

- The aim of this section was to investigate the current context of the case study, how flow balancing is currently performed by PC PAX, the stakeholders that are involved in this process, and how they all interact with each other.

- During this investigation, a number of insights were identified, consisting of challenges, and tensions that are currently present regarding the process of flow balancing. The current workflow of the flow controllers has been explained as well as the challenges they face. Also a stakeholder analysis has been performed, resulting in a selection of two main stakeholders, the flow guiders and the flow moderators. And lastly, between these three parties, 4 important tensions have been found. Regarding, differences in pursuit goals regarding flow balancing, the lack of formal agreements and lack of transparency between the flow controller and flow moderator.

- After gaining insight into the current context in which the decision-making takes place, how the introduction of ADM might have an influence on this context is discussed in the next section.

Discussion

potential effects of introducing ADM on current context

In this section, we move from the current context towards a hypothetical and future context, where the ADM system has been introduced. In order to envision how this future looks, we first determine how currently the ADM system is designed and how it could be functioning. Afterwards, we look at plausible effects that the introduction of ADM couldhave on the context that has been painted before.By looking at examples in the literature, we have formulated a number of barriers that potentially arisefor the adoptionof the ADM.

- 5.1 The introduction of augmented decision-making in the current context
- 5.2 Effects of the introduction of ADM on the multi-stakeholder system

5

5.1 The introduction of augmented decision-making in the current context

In this chapter, first, the augmented decision-making functionalities as they are currently envisioned will be explained. And second, the consequences of the introduction of this system to the process of decision-making will be explained. The information in this chapter has been retrieved from conversations with the Product Owner of ADM, the Service Designer, and from several internal documents about the project.

5.1.1 Strategy for augmented decision-making
As explained in section 3, Schiphol is aiming to become an autonomous airport, which is the key driver for the ADM project. More specifically, RSG aims to improve efficiency and increase the capacity of the airport by proactively and integrally controlling all operational activities.

For ADM specifically, the goals are to improve the efficiency and effectiveness of the control over the arrival passenger process, specifically regarding the border control filters. One of the ways that this should be done is by making more proactive and integral decisions regarding flow balancing. Meaning, flow balancing is done before large queues are formed in the filters, and other steps in the arrival flow, such as the location of baggage claim, are also considered in which passengers to flow balance.

Besides, RSG believes that currently the efficiency of passenger flow control and flow balancing is lacking due to a dependency on human performance. And by (partly) removing the dependency on human performance, Schiphol will be able to be more efficient in controlling (passenger) flows.

5.1.2 Envisioned augmented decision-making functionalities to be implemented in Wilbur
As mentioned before, in section 4, PC PAX currently uses Wilbur in their decision-making process. Wilbur has many different functionalities and user groups, of which PC PAX is one. In this project, we only go into one specific page of Wilbur, called border control. Within this page, ADM will be implemented to extend the current functionalities. The initiation of these functionalities and the project was done by the Process Owner Arrival and the managers of the PC PAX. ADM has three main objectives, which are listed below.

- Preparation: PC PAX will been abled to simulate and compare different flow balancing scenarios, allowing them to better prepare for high-occupancy periods.
- Real-Time Support: The system will provide real-time assistance to help PC PAX anticipate and respond to dynamic changes in passenger flow.
- Post-Shift Reflection: PC PAX will have tools to evaluate and reflect on their performance, enabling continuous learning and process improvement.

A fourfold of new features is determined; the detailed design of these features is not yet made. But several different versions of designs have been made; currently, a prototype has been made that will be tested in the coming months. In Figure 14 annotated screenshots of this prototype can be seen.
First of all, ADM should be able to predict the occupancy within the arrival filters. This is based on flight information including passenger numbers, the expected time they arrive at the filters, and last, the processing speed of the Marechaussee. Second, ADM has to be able to run through all the different scenarios that are possible with flow balancing, taking into account the boundary conditions of the context. Third, based on the different scenarios, a few of the best flow balancing actions are recommended to the user accompanied by a scoring.

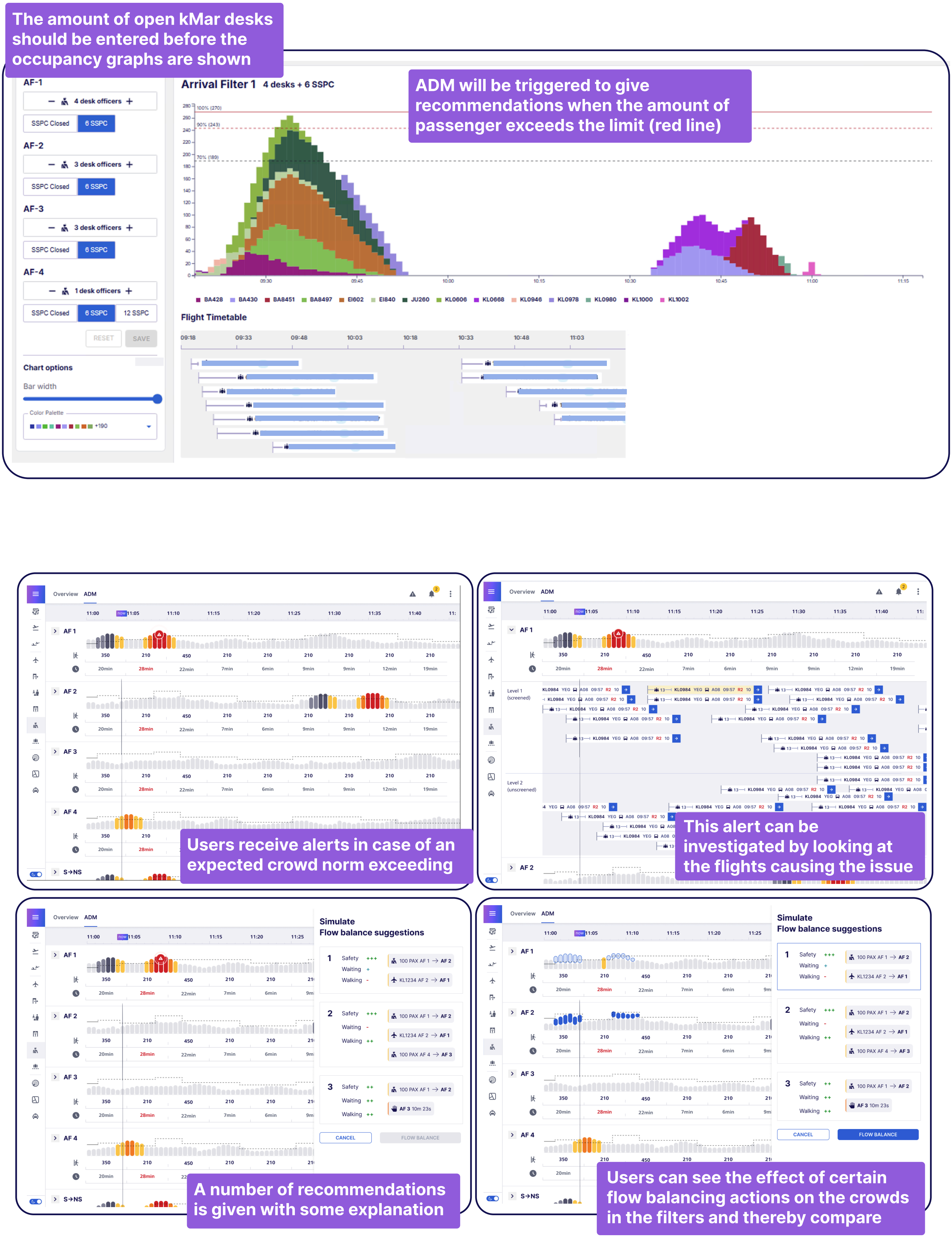

Fig 14. Annotated designs of ADM

Recommendations are scored based on the extent they reduce the crowd norm exceeding and on waiting and walking time. From these recommendations, the PC PAX can decide which flow balancing action to take, based on the scores that are shown by the system. And lastly, the system should also enable the user to reflect on their own performance. ADM will be triggered to provide recommendations if the crowd norm is predicted to be exceeded in at least one of the arrival filters. The main goal of the recommendations will be restoring the predicted amount of passengers below the crowd norm within all of the filters.

Besides the passenger information of all arriving flights, the amount of Marechaussee desks open is an important variable in the algorithm. As this influences the throughput speed of passengers through the arrival filters. Currently, Schiphol is not allowed to collect and process this information; therefore, PC PAX would have to manually enter this to receive predictions and recommendations. To account for inaccuracies in the data and the generated predictions, in the current design, a bandwidth is included indicating the uncertainty in the prediction generated.

5.2 Effects of introducing the DSS in the multi-stakeholder system

In the previous section, the current design of ADM was explained. Now we will discuss the effects that this might have on the current context as described in section 4. These effects are both opportunities and potential adoption barriers, and are split up into two different levels of interactions that are going to be affected by the introduction of ADM. The two different levels are visualized in Figure 15, both the stakeholder interactions and the user interaction with the DSS. By discussing the effects, we aim to formulate potential adoption barriers that might occur when introducing ADM in the context. In order to support the likelihood of these problems occurring, we look at the literature for barriers commonly seen in other similar contexts. By looking at the effect through the lens of these general barriers, we aim to formulate the potential adoption barriers for ADM.

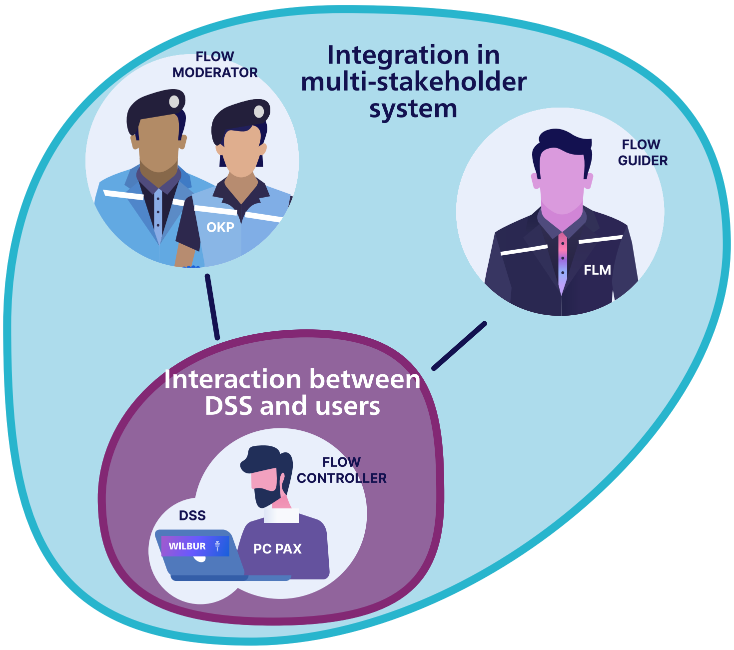

Fig 15. Two different levels of interactions occuring

The research question that we aim to answer in this section is the following:

- *How could the introduction of these new functionalities, which are collectively called ADM, influence the current multi-stakeholder system and the interactions and tensions that are currently occurring in this system?*

If we look at the problems, challenges faced by PC PAX and the tensions between stakeholders, currently present in the multi-stakeholder system, the functionalities of ADM will have a positive effect on some of these problems and might even, partly, resolve some. And therefore could be seen as facilitators to the adoption. But others are not solved or even increased by the introduction of ADM. We will first go into the positive effect of ADM and the problems it might help. The potential adoption barriers as formulated below were verified with several context experts and the decision-makers. Based on the feedback, multiple iterations were done to improve their quality and formulation. This was done in the workshops with context experts, as described in Appendix A.4, and during different presentations of the barriers to the participants of the interview study.

5.1.3 Opportunities of the introduction of ADM

In order to investigate the effect that ADM might have on the current context, first of all the opportunities of implementing ADM on the current challenges and tensions in the context are investigated. Meaning, how the interactions between stakeholders and the workflow of PC PAX might be improved due to the introduction of the ADM as currently designed. First, we go into the stakeholder interactions by highlighting two opportunities and afterwards, the interaction of PC PAX with ADM with three opportunities. The opportunities are formulated based on the current design of ADM, as explained before supported with knowledge from the literature.

First of all, ADM would make it easier to produce several different flow balancing options [31], making it easier to deal with, for example, limitations of OKP. As AI can quickly process high amounts of data and run high numbers of scenarios. If OKP, for example, might no want PC PAX to flow balance passengers to one of the filters, ADM could quickly come up with another scenario that would still solve the problem, but doesn't include this filter.

Opportunity 1: Flow balancing could be more flexible regarding meeting needs of flow guiders and flow moderators.

By using ADM, PC PAX could be able to better argue the decisions they make for flow balancing. This could result in easier and less intensive communication with FLM, as this currently entails discussing these decisions for a large part. But also possibly reduce tensions due to the lack of understanding between the PC PAX and OKP.

Being able to argue decisions better towards stakeholders can only be done if the DSS provides clear and understandable explanations to users. Rajiv [53] explain the need and also complications that arise with explanations in DSS. There is a clear need from users for accompanying recommendations with suitable explanations to improve trust, understandability and engagement of users.

Opportunity 2: ADM could provide explanations with recommendations, to gain understanding and trust from flow controller.

Opportunity 3: PC PAX could gain the ability to argue their decisions in a betterand more uniform way towards stakeholders.

Regarding the interaction between PC PAX and ADM, PC PAX currently spends significant attention on monitoring for changes that would affect their plan made for flow balancing, as explained in section 4. As computers, and AI especially, are capable of filtering and identifying specific items [78]. ADM would be very capable of doing, filtering changes and only alerting PC PAX in case of relevant changes.

Opportunity 4: ADM might make it easier for PC PAX to monitor changes and filter whether changes would have a significant impact on their decisions made.

In the current workflow of PC PAX, evaluation is not included. PC PAX does not know whether they have made the right decision. Also, between different PC PAX, there is little opportunity to discuss insights. This limits their learning ability and improvement in the effectiveness of decision-making. Through simulations of the effect of different flow balancing options, as is currently included in the design of ADM, this might give PC PAX the ability to evaluate and learn. This is especially relevant to ADM, as it will be able to predict the passenger flow with higher accuracy compared to the current Wilbur system [78].

Opportunity 5: ADM might give PC PAX the opportunity to evaluate and learn about the effects of flow balancing decisions on the passenger flow.

As included in the functionalities of ADM, a bandwidth shows the accuracy of the predictions generated. With this bandwidth, PC PAX can easily determine when they can trust the recommendations or when they should pay additional attention and gather contextual insights themselves.

When DSS predictions are presented without indicating the degree of uncertainty or data gaps, users may assume the system is more precise than it actually is or have trouble determining its quality, which could ultimately undermine trust in the DSS and negatively impact adoption [7].

Opportunity 6: The bandwidth allows PC PAX to calibrate their trust in the predictions generated by ADM.

Zhang et al . [81] proposes to make sure the DSS is appropriate for the user to accompany their specific needs at that moment and to reduce the burden of continuous trust calibration. This can be done through directability, enabling users to adjust the DSS output and through continuous support, such as a warning system. Research also suggests that a highly interactive DSS can improve user trust, particularly when users have a positive attitude toward knowledge sharing. If ADM allows PC PAX to incorporate their insights or adjust recommendations, it could mitigate the risk of low trust [23].

Opportunity 7: ADM should be appropriate for the flow controller and their needs, this can be done through enabling flow controllers to adjust the output and for ADM to provide continuous support such as a warning system.

Van De Velde et al . [72] found that DSS recommendations are more likely to be followed when the system facilitates stakeholder access and involvement. In cases, where stakeholders also had access to the DSS, this increased their adherence and understanding in the process.

Opportunity 8: ADM could facilitate mutual understanding and more involvement of flow moderator and flow guider in the decision-making process through providing them access and increasing involvement.

Potential adoption barriers related to the integration in the multi-stakeholder system

In Figure 16, the potential adoption barriers explained in this subsection are visualized.

5.2.1 Deterioration of relationship between flow controller and flow moderator and flow guider

Currently, PC PAX and OKP have different goals for the passenger flow; PC PAX wants to minimize waiting and walking times of passengers, and OKP wants to protect border security by performing thorough passport checks. These goals can be conflicting; for example, in certain high-risk flights where the Marechaussee wants to perform thorough checks, causing the passenger flow to move slowly through the filters. This tension arises especially in situations where OKP wants to reject flow balancing actions and PC PAX doesn't understand this and creates a resistance towards it. This causes them to try to avoid this interaction with OKP, which creates a tension between the two parties.

ADM presents flow balancing options that aim to distribute the arriving passengers in an efficient way, and thereby passenger flow is optimized. Therefore, ADM is designed to support the goals of PC PAX (minimizing waiting and walking times of passengers), while the goal of OKP (protecting border security) is not taken into account. As a result, ADM can strengthen PC PAX's position towards OKP as they can use objective data to better inform their flow balancing choices. Also, this may lead OKP to see ADM's recommendations as a threat to their security priorities. A potential side effect would also be that, as the OKP do not support the usage of ADM, they might also cause them to share less information about their staff capacity. The cause of this is that the Marechaussee is in general protective towards data sharing, as in this case data about their staff schedules is sensitive information about their strategies.

The perspective of FLM is not included in ADM, even though FLM provides critical insights into the pressure experienced by personnel managing passenger flows at arrival filters.

This can lead to ADM recommending flow balancing actions that may not be necessary, impacting the accuracy of its outputs. Therefore, the relation between PC PAX and FLM might be impacted, as PC PAX might rely more heavily on the advice from ADM (which is based on objective data and decision rules), occasionally ignoring the advice from FLM, which is based on their opinion and perspective.

In a study by Mireia Yurrita et al. [43] conflicting priorities between stakeholders regarding the DSS were identified as a potential barrier in the adoption of the DSS by workers.As ADM does not support the goals of OKP, protecting border security, this might cause degradation of the informal relationship between the users of the DSS and the flow moderator (OKP). Also, Funer et al. [25] explores the effects of introducing a DSS, possibly causing a deterioration of the relationship between clinicians and patients if clinicians focus too much on the technology, leading to reduced attention for the patient.

Barrier 1: The introduction of a DSS may lead to deterioration of the relationship between flow controller, flow guider and flow moderator, if their operational goals are not incorporated in the decisions made.

5.2.2 Lack of transparency causing increased misunderstanding by flow moderator

Current misunderstandings and intransparency that OKP has regarding the flow balancing process performed by PC PAX are exacerbated by ADM, as this system is inaccessible for OKP.

As previously explained in section 4, there is limited mutual understanding of each other's workflow and values for the passenger flow process betweenPC PAX and OKP. This especially causes problems when OKP wants to contest the decision-making of PC PAX, as there is also ambiguity among PC PAX about whether OKP should always be able to contest decisions made. PC PAX will be the main users of ADM and OKP has no or limited access, which can create a lack of transparency and understanding of the workings of ADM for OKP. Braun et al. [9] states that a lack of transparency for stakeholders in a DSS can exacerbate existing tensions, potentially disrupting informal networks and working relationships. This would, especially, apply to the relationship and interactions that PC PAX has with OKP. If OKP is not given visibility into ADM's decision-making process, they may resist its recommendations, viewing them as unilateral rather than collaborative.

Barrier 2: Due to a lack of transparency and understanding, flow moderator might create resistance towards the usage of the DSS.

5.2.3 Reduction of informal interactions between flow controller and flow guiders and flow moderators

FLM and PC PAX collaborate closely for passenger flow control, and PC PAX often consults FLM regarding flow balancing. But in some situations, Floor Managers have a direct operational need for flow balancing, which can be different from the integral management needs of PC PAX. The predication of crowd development in the filters generated by ADM will be based on flight schedules, walking time from gate to filter, passenger information (amount of PAX, types of passports) and the amount of open kMar desks. But currently, PC PAX also relies on the expertise and contextual awareness of FLM in decision-making, as they consider this input valuable for decision-making. If ADM advice and FLM advice clash, PC PAX has to choose, which may harm their relationship or cause PC PAX to neglect recommendations by ADM. PC PAX relies on the expertise and contextual awareness of FLM in decision-making, as they consider this input valuable for decision-making. If ADM advice and FLM advice clash, PC PAX has to choose, which may harm their relationship or cause PC PAX to neglect recommendations by ADM.

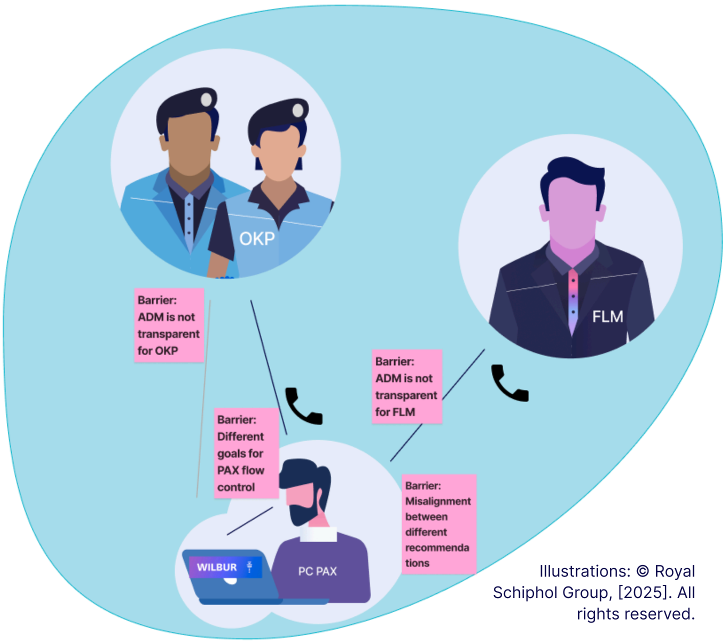

Fig 16. Potential adoption barriers related to the integration of DSS into the multi-stakeholder system

And the last important contextual insight was that FLM and PC PAX collaborate closely for passenger flow control, and PCPAX often consults FLM regarding flow balancing.PC PAX relies, to some extent, on the expertise and contextual awareness of FLM in decision-making, as they consider this input valuable for decision-making.

But in some situations, Floor Managers have a direct operational need for flow balancing, which can be different from the integral management needs of PC PAX. ADM bases its predictions on flight schedules, walking time from gate to filter, and passenger information (amount of PAX, types of passports).

The interactions between OKP and PC PAX that currently happen are not formalized; there are no agreements about what is discussed and whether these happen. The lack of formal agreements poses a risk, as these interactions are important for the success of ADM and the performance of PC PAX.
In shared decision-making, a DSS introduces additional evidence that must be jointly evaluated by stakeholders [9]. However, conflicting recommendations from DSS and stakeholders, or lack of transparency between users and stakeholders, can lead to tensions and distrust in the system.

If flow balancing recommendations conflict with FLM judgment and there is no clear explanation provided by PC PAX, PC PAX might struggle to reconcile the two and possibly cause them to reduce their trust in ADM.

Barrier 3: The introduction of a DSS might cause a reduction in interactions between flow controller and flow moderator and flow guider, limiting the exchange of important information that is exchanged during these interactions.

Potential adoption barriers related to the interaction between DSS and users

In Figure 17, the potential adoption barriers explained in this subsection are visualized.

5.2.4 Junior decision-makers over-reliance on DSS
As we have seen in the context of research, PC PAX depend to a large extent on their own expertise in decision- making; in training junior employees, this is also valued to a great extent.

Esmaeilzadeh et al. [23] highlights that users are less likely to adopt a DSS if they feel it diminishes their professional judgment and autonomy. This can be caused because the DSS offers rigid recommendations that aren't open for alteration by the user.

Regarding professional autonomy, there is a difference between junior and more senior employees regarding this barrier, as for junior employees, studies point at the possibility of them over-relying on the recommendations the DSS gives them [45]. More senior workers express concerns about their expertise being undermined by the DSS [32]. Both will cause adoption barriers, as the workers are not going to use the DSS in the way it was intended.

If ADM is perceived as rigid and users cannot include their own situational and contextual awareness in the decision-making, this might cause problems with the adoption. This might be more problematic for junior workers, as they might over-rely on the recommendations provided by ADM and therefore do not develop the capabilities to have contextual overview and awareness themselves. For senior workers it might be more difficult to combine their own judgment with the recommendations given by ADM. PC PAX depend on their own expertise in decision-making; junior employees are trained to also get this. In ADM design, all users have the same interaction, and contextual expertise cannot be included.

Barrier 4: Junior decision-makers may over-rely on the DSS and its recommendations without contextual understanding. In case of high uncertainty in the data input, it might be difficult for them to judge whether or not to trust the recommendations.

5.2.5 Missing subjective information and lack of verification opportunity

In the current context, we have also seen that PC PAX gathers and analyzes information from different sources for decision-making, like Wilbur, camera images, and by calling FLM. Besides, the variability in PA performance currently, among others, creates unpredictability in the effectiveness of flow balancing actions.

The impact of flow-balancing actions is difficult to predict as execution varies, and ADM does not consider their complexity. PC PAX might prefer simpler actions that are more likely to be effective, but ADM does not distinguish between them. Additionally, as ADM simulates the theoretical effect of flow balancing actions, which can then be compared to the actual effect it has on PC PAX.

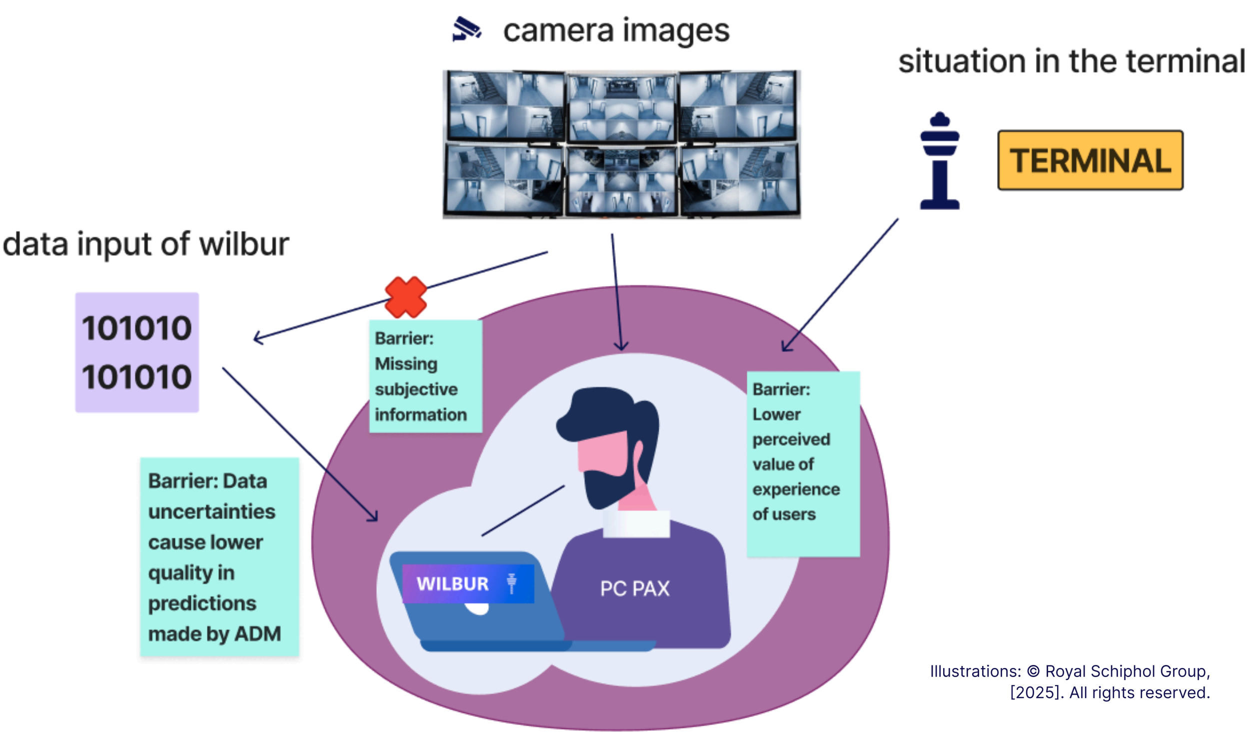

Fig 17. Potential barriers related to the interaction between DSS and users

ADM presents recommendations as objective truths, without encouraging verification from other sources. It only considers passenger numbers per filter, ignoring subjective factors like passenger mood, which PC PAX currently values in decision-making. It only considers passenger numbers per filter, ignoring subjective factors like passenger mood, which PC PAX currently values in decision-making.

PC PAX might also reject ADM recommendations if they believe certain actions are too complex or disruptive to implement.ADM provides recommendations that are shown as the objective truth, and verification through other sources of information is not necessarily supported or encouraged. Also, ADM presents recommendations when it predicts the crowd norm will be exceeded.The crowd norm is a specific amount of passengers per filter, and this is the only threshold included. Subjective information, such as the current mood of passengers in the filter, that is currently valued by PC PAX in the decision-making process and can be used as a threshold is not included in the algorithm of ADM. In the development process of ADM, the flow balancing process and terminal dynamics have been simplified to fit the algorithm, and therefore, the information mentioned before is not included. This could, tho, potentially make ADM's recommendations feel detached from real-world complexities, especially in the experience of PC PAX. Similarly, Bankes [5] warns that models are often presented as objective truths, whereas they are merely one possible representation of reality. ADM generates flow balancing recommendations purely based on objective data, while PC PAX's current approach integrates experience and contextual, subjective insights that are not captured by the DSS. The reasoning of the algorithm is not in line with the current mental model of PC PAX, which can create misunderstandings and a reduction of performance expectancy, causing adoption barriers by PC PAX [30].

Therefore, concluded can be that, because certain subjective information, currently valued by PCPAX, is missing in the algorithm of ADM, as well as the opportunity for verification, users may perceive its recommendations as inadequate or not trustworthy.

Barrier 5: Because certain subjective information, valued by the decision-makers, is missing in the algorithm of the DSS, as well as the opportunity for verification, decision-makers may perceive its recommendations as inadequate or not trustworthy.

5.2.6 Uncertainty in data input of DSS and its impact on decision makers

Information about a foresight of the amount of desks the Marechaussee will have open in the coming hours is formally not shared with Schiphol and PC PAX. But informally this does happen from time to time and the current situation is always known, as PC PAX can see this on the camera images. This information is one of the two determining factors for the prediction of the development of the amount of passengers in the arrival filters.So if this information is not available for ADM, the prediction will be of little value.The informal connections and trust between OKP personnel and PC PAX are of large influence on how much of this information is shared and therefore available for PC PAX. If the relationship with the Marechaussee is put under more pressure with the introduction of ADM, as discussed before, these informal connections might be damaged, putting the information available in danger.

The predicted number of open kMar desks is usually insecure for PC PAX, despite being a crucial variable in ADM predictions. This will cause large insecurities in the predictions of the passenger flow through the filters. Currently there already is a lack of transparency provided by kMar about the foresight of the amount of manned desks, which creates uncertainty for PC PAX, and this limits the PC PAX in making informed decisions. But with the introduction of ADM, this transparency will likely still exist or even be amplified as the Marechaussee might not agree with Schiphol using this data in an algorithm like ADM.

As the predictions made by ADM are based on flight schedules, walking time from gate to filter, passenger information (amount of PAX, types of passports) and the amount of open kMar desks. Having accurate information about both the flight schedules, passenger information, and the amount of open kMar desks is crucial for the accuracy of the predictions. Incomplete data on the number of open Marechaussee desks will structurally limit the accuracy of ADM's predictions, as this information will not always be available or reliable. Consequently, ADM will inevitably produce forecasts that are not entirely accurate. If these inherent uncertainties are not clearly communicated to PC PAX, it may lead to a perceived lack of reliability in the system. Literature emphasizes that even minor inaccuracies in DSS predictions can lead to user rejection [33], particularly when users are unaware of the limitations in the data input. Moreover, a key focus in DSS development should not be on ensuring absolute correctness but rather on providing recommendations that appropriately support users in their decision-making processes [81].

If the kMar capacity information is not accurately shared, it may cause large uncertainties shown in the ADM predictions. This might cause PC PAX to not see the added value of ADM for their job.

Barrier 6: If important data input is not accurate, it may cause large uncertainties shown in the DSS predictions. This might cause decision-makers to not see the added value of the DSS for their job.

Conclusion section 5

- In this section, we have first introduced the design and functionalities of the DSS that is planned to be implemented in the context of the case that we study, called ADM. Afterwards, we discussed the effects that the introduction of this DSS might have on the current context, and especially on the tensions and challenges that we have identified in section 4. Several opportunities, where ADM could improve the decision-making process, were identified.

- But also, a number of negative effects were identified, where existing challenges or tensions might be amplified by the introduction of ADM. These we combined with insights from the literature study in section 2, to formulate a number of potential adoption barriers that can be foreseen in this context. In this chapter, a separation was made between the integration in the multi-stakeholder system and the user interaction of the DSS. But these two levels also have influence on each other. As important (subjective) information is exchanged between the different parties, such as the predicted amount of open Marechaussee desks from the OKP and the current mood or situation in the terminal from the floor managers. And if this information is not, or in a limited manner, received by PC PAX, this has influence on their ability to make accurate decisions. And the other way around, the understanding and overview that PC PAX has over the situation and the decisions they make also influence their ability to argue and discuss the decision-making with floor managers and OKP.

- In the next section, we will move towards the ideation for ways to account for these barriers and, therefore, enhance the adoption of the DSS.

Interaction design

ideation of interactions with ADM and between stakeholders

In the previous chapter, the potential effects of introducing ADM in the multi-stakeholder system have been discussed. In this chapter, the aim is to design the interactions to overcome the barriers and take benefit from the opportunities; this will be done by (re)designing interactions for the usage of ADM. Both user and DSS interactions and interactions between stakeholders will be designed, by using storyboarding.

- 6.1 Methodology
- 6.2 Storyboards of interactions with ADM and stakeholders

6

6.1 Methodology for ideation

Before formulating guidelines, ideation for the interactions that would be desirable in the context was performed based on the adoption barriers as formulated in section 5. For the ideation, the artifact that was chosen is storyboarding. This was chosen because we aim to design interactions, and storyboarding is a good way of showing interactions and the context surrounding a new technology in general [37]. In the design of the storyboards, we have focused on reducing complexity as much as possible, including people and their reactions to enhance empathy and text in a conscious way to ensure easy understanding [69]. Later on, guidelines were formulated based on the storyboards for the designers to design the interactions and interface design, which can be read in section 8.

Input for the ideation was taken from several sources. First of all, by making use of the opportunities of ADM introduction as explained in section 5. Secondly, from a workshop that was held with context experts, a more detailed approach for this workshop can be seen in Appendix A.4. During this workshop, as also mentioned in section 5, the participants have brainstormed about possible solutions for the potential adoption barriers specific to the context of ADM. And last from the contextual knowledge that was gathered during the context research as described in section 4.

This storyboard consists of two different situations where the DSS is being used. In the previous chapter, a clear distinction between the two levels of interactions have been maintained. However, in reality, these levels significantly influence each other. For example, stakeholders like OKP provide information that PC PAX relies on, enters in ADM and therefore also have influence on the output generated by ADM and seen by PC PAX. The accuracy and manner in which PC PAX receives this information also affect how they choose to act on it within the DSS.

For this reason, the storyboards combine both levels of interaction, as keeping them separate would not reflect real-world dynamics. Instead, a distinction is made between interactions with the two main stakeholders, as their roles and perspectives differ. While there is some overlap, the focus remains distinct for each stakeholder. This separation ensures that the storyboards are validated in a way that is relevant to each stakeholder's context. In the storyboard in Figure 18 the interaction with the flow guider is central and in Figure 19 the interaction with the flow moderator has the central role.

6.2 Storyboards of interactions

In Figure 18 and Figure 19 the proposed interactions are visualized.

6.2.1 Storyboard 1

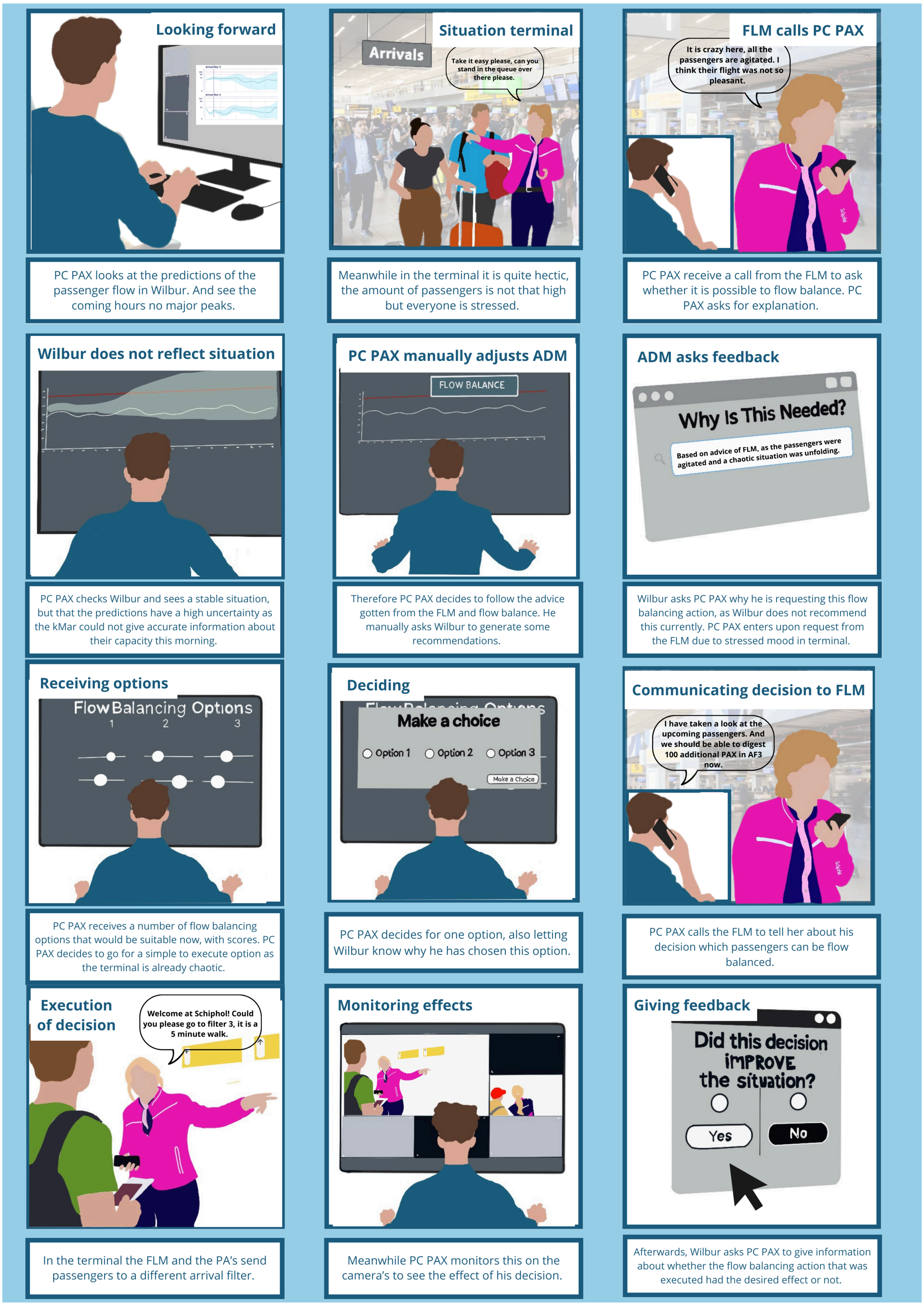

Fig 18. Storyboard of interactions between DSS, flow controller and flow guider

6.2.2 Storyboard 2

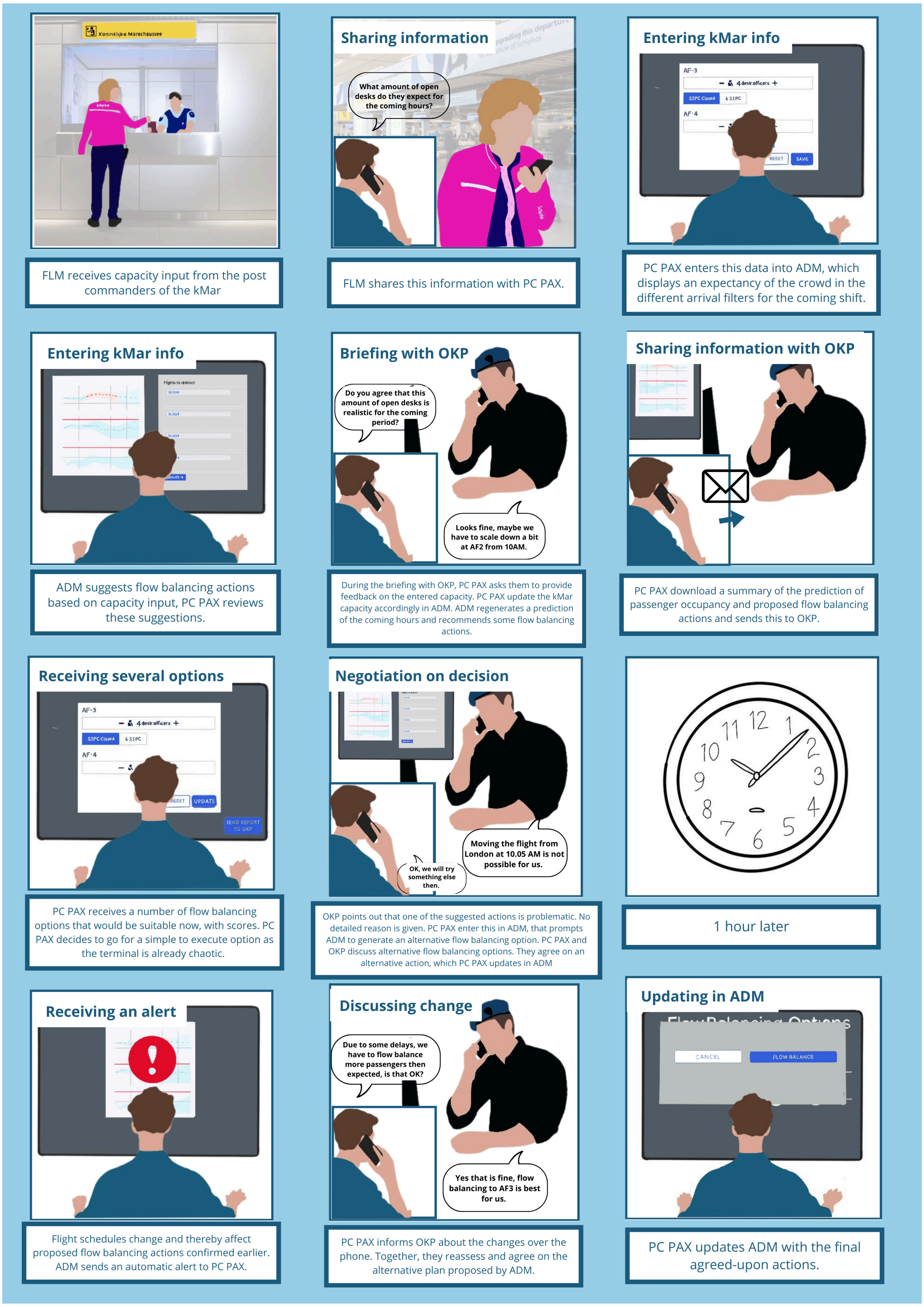

Fig 19. Storyboard with interactions between DSS, flow controller and flow moderator

6.3 Explanation for storyboards

6.3.1 Storyboard 1

If subjective operational knowledge is missing from ADM, as well as the opportunity for verification through other sources, PC PAX may perceive ADM as inadequate or not trustworthy. ADM should, therefore, enable PC PAX to evaluate the decisions they made with the stakeholders and internally. And to adjust recommendations in case their judgment is different. Also, this is necessary to support the ability for stakeholders to give input and restrictions to the flow balancing actions. This stimulates PC PAX to reflect on the situation that has occurred and the effectiveness of the actions they have put into motion. Maintaining their situational awareness and training their expertise, while still benefiting from the support of ADM. Besides, ADM could learn from PC PAX, as they have a different, more complete overview of the situation in the terminal.

6.3.2 Storyboard 2

In the decision-making process, their are different goals (waiting time for passengers and thorough controls) and restrictions that should be taken into account, from both Schiphol and the Marechaussee. But as the tactics and procedures of the Marechaussee contain sensitive information, information about their restrictions and goals can not be included in the algorithm of ADM. Only the goals of Schiphol and PC PAX are included. Which might create a power and information imbalance between the two stakeholders. In order for the multi-stakeholder system to still collaborate and for both of the goals to be achieved, the stakeholders should been abled to voice their restrictions and input at the crucial moments in the decision-making and enabled to look at the same information. As the party with less information cannot properly judge the situation and participate equally in the process. Therefore, in the multi-stakeholder system, procedures should be included that enable stakeholders to have insight into the decisions proposed and the reasoning for it.

To achieve this, the current interactions present an opportunity to create more understanding and alignment between stakeholders in the usage of ADM. But these interactions are not formalized and especially the content is not uniform and agreed on. By formalizing these interactions, all stakeholders could gain certainty and clarity. ADM presents an opportunity to facilitate these interactions and create more structure and understanding.

Lastly, in the interaction with ADM, entering the kMar capacity should not create a barrier for the usage. Therefore, this should be included in the standard workflow and also be done at a moment that PC PAX has this information available to them. Having accurate information about this is crucial to the accuracy of the predictions and recommendations generated by ADM. But PC PAX cannot (yet) depend on accurate information from the Marechaussee. Currently, for the generation of predictions, every time the amount of open kMar desks has to be entered.This could create a barrier in the usage for PC PAX, as this is an additional step in their workflow and they do not always have this information available to them.

Conclusion section 6

- In this section, the ideation phase was described, interactions have been redesigned and prototyped based on the effects of ADM discussed in section 5. This has been done through storyboarding, resulting in two storyboards involving all three main parties involved in this research, the flow controller, flow guider, and the flow moderator. The storyboards were created based on the input from a workshop held, the insights from section 5, and the contextual knowledge gathered by the researcher during the context research.

- In the next section, the insights are translated to eleven guidelines that will be validated afterwards.

Guidelines

final version of the guidelines for interaction designers

In the previous chapter, storyboards were made and from these storyboards, guidelines are formulated again based on the previous knowledge gathered in this project. In this section the final version of the guidelines are presented, after the validation had been performed in section 8. The guidelines are again separated in two levels of interactions as mentioned before. The main user groups of the integration guidelines are designers of operational processes and for the user interaction guidelines, DSS interaction designers.

- 7.1 Guidelines
- 7.2 Guidelines for integration in multi-stakeholder system
- 7.3 Guidelines for user interaction design

7

7.1 Guidelines

The goal of this project was to formulate guidelines to enhance the adoption of DSS in a multi-stakeholder system. We aimed to formulate design guidelines in this research, as design guidelines can serve as intermediate knowledge bridging between real-world contexts and theoretical knowledge, utilizing generative formulations [36]. Therefore, they are suited to serve as a translation between theory and practice and be of value to both Schiphol and the HCI research community.

In the literature, formats of design guidelines vary from recommendations to requirements or do's and don'ts [6, 47, 61]. The form is chosen to fit the context and the aim of the guidelines, and the most important is to be consistent across the guidelines in format and formulation. The formulation of the guidelines in this project is used from Tener and Lanir [68], that use short active sentences to introduce the guideline and below have a longer explanation. In their paper the explanations entail a paragraph, but for understandability the explanations are kept shorter. In Appendix B.4 the connection between the insights from the research to the guidelines can be seen.

The guidelines are formulated for interaction designers of DSS. They are intended to help designers to consider the adoption barriers as formulated in this project in the design of the DSS. The guidelines could, for example, be used to connect with other departments and discuss the functionalities and aim of the DSS with each other.

The guidelines are not exhausting in covering all potential adoption barriers for DSS in a multi-stakeholder system. But can be used as an initial step in investigating this for the specific context of the DSS that is going to be designed.

7.2 Guidelines for integration in multi-stakeholder system

The introduction of DSS might cause a reduction in stakeholder interactions, limiting the exchange of important information and alignment regarding the decision-making process that is currently valued by all stakeholders. Therefore, the following guidelines should be considered in the integration of a DSS in a multi-stakeholder system.
Stakeholders:

Have transparency in decision-making
Flow moderator and flow guider should be able to know which decisions are made and what the reason for these decisions is, to enable them to pursue their operational goals.

Have formalized interactions with the flow controller
Flow moderator and flow guider should have standard interaction moments, that fit within their and the flow controller's current workflows and are formally agreed on.

Engage in the decision-making process
Flow moderator and flow guider should have the opportunity to give input supporting their goals during the decision-making process, at an early stage where the initial plan is made, but also right before the execution.

Negotiate with the flow controller
Flow controller should discuss different decision options with flow moderator and flow guider to reach a consensus about a decision that has integral benefits.

7.3 Guidelines for user interaction design

Decision makers might not see the added value of the forecast and proposed actions of DSS, as subjective information is not taken into account and it is difficult for them to combine this with the recommendations generated. To enable them to combine the two, the following guidelines should be considered by interaction designers.
Users:

Plan decisions ahead
The DSS should enable decision makers to make an initial decision plan and record this in the DSS before the critical moments, that can be adjusted in case of large changes in predictions.

Receive alert in case of change
DSS should filter changes in information according to relevance on previously made plan and only alert decision maker in case it might require reconsideration of the plan.

Know the confidence of predictions
The DSS should show the quality of the predictions made based on the quality and certainty of the data input used that should enable decision makers to determine whether they can trust the recommendations made.

Decide based on consequences of actions
The DSS should provide decision makers with the option to simulate the consequences of flow balancing decisions through simulation of the effects and therefore select the most effective option.

Receive explanation of recommendations
DSS should provide explanations to decision makers that explain why decisions are taken, based on the effect these decisions on the situation.

Gather subjective insights alongside predictions
The DSS should stimulate decision makers to gather subjective insights, either from their own experience or from stakeholders, helping them to maintain their contextual awareness and validate recommendations.

Give feedback on recommendations
The DSS should enable decision makers to give feedback on the recommendations generated by DSS after peak moment has passed, which are used to improve the algorithm.

Validation

validating guidelines with the intended users

The guidelines are validated with the intended user groups. To test whether the guidelines are perceived as usable, actionable and valuable by the user.

8.1 Methodology

8.2 Results of validation session

8

8.1 Methodology for validation

The aim of this study is to validate the perceived usability and actionability of the proposed guidelines by their envisioned users. The validation process will focus on how these guidelines fit into the workflow of DSS designers and their perceived value in practical application. An older version of the guidelines was used during the validation sessions, which can be seen in Appendix A.4. In Table 4 the participants of this study can be viewed.

The research questions we aim to answer are the following:

- *To what extend are the proposed guidelines usable, actionable and valuable for DSS interaction designers?*

The following requirements were formulated for the guidelines; the guidelines should be:

1. perceived as valuable by the intended user group
2. feasible to implement
3. fit the development / design process
4. be written in understandable language
5. be clear and pragmatic enough

Inspiration for these requirements was taken from Cila et al. [18]. Where they have also assessed proposed guidelines according to similar requirements. After the validation sessions minor adjustments to the wording of the guidelines have still be done, but not all the results of the validation sessions are yet implemented.

In Appendix A.4, the interview guide used can be seen.

Characteristics	Distribution
Gender	5 Male, 2 Female
Occupation	4 Designers, 1 Business Analyst, 1 System Engineer and 1 Process Designer
Experience level	1 junior (0 - 5 years), 1 medior (5 - 10 years), 5 seniors (10+ years)

Table 4, Participants validation study

8.2 Results of validation

8.2.1 Value for intended users

The guidelines served as a conversation starter between the researcher and participants, encouraging them to reflect on their relevance to their work and the DSS they are currently designing.

> V3: **"The guidelines make me think about certain functionalities that I haven't thought of before."**

Participants noted that the guidelines would be particularly useful at the early stages of a design project, especially for preparation or during brainstorming sessions and discussions about DSS design.

> V3: **"Would use this in a meeting we will soon have about what we want the design of new DSS functionalities to look like with the whole team."**

> V1: **"Would put it in the Miro board, at the start of the design process. To support design choices."**

DSS interaction designers found the interaction guidelines particularly relevant to their role, while they perceived the integration guidelines as more applicable to the operations or process design teams.

> V4: **"The interaction guidelines are obviously meant for the design teams, but the integration guidelines are the responsibility of the process designers."**

> V5: **"To me the integration guidelines are the responsibility of the operations team, that are concerned with the process and the design team could focus on the product."**

> V5: **"With the interaction guidelines things start to boil up for me, that isn't the case for the integration guidelines."**

Some participants working on other DSS projects noted that their DSS was not yet at a stage where these guidelines could be applied. In some cases, their systems did not yet incorporate recommendations, or stakeholder involvement in the process was minimal. However, they recognized the value of the guidelines and considered them relevant for future implementation.

8.2.2 Understandability and fit in workflow

The understandability of the guidelines was also assessed. While the content was perceived as valuable, designers noted that reading and interpreting the guidelines required time and effort. The guidelines are specific and dense in information, which is necessary due to their broader applicability beyond Schiphol. However, their level of abstraction may have hindered comprehension for Schiphol-based designers.

> V4: **"Terminology of the different stakeholders is not clear, don't really understand it."**

> V5: **"Difficult to grasp, the interaction guidelines seem to be linked together in the user flow, but the way they are presented this is missing."**

During validation sessions, the guidelines were printed on paper. Some participants suggested that presenting them in PowerPoint slides would be more effective, particularly for team meetings and stakeholder discussions.

Others proposed incorporating the guidelines into Miro boards as an inspiration tool during the research phase. In this format, they could serve as reference points to substantiate design choices, similar to the 'product principles' currently used at Schiphol.

8.2.3 Implementation of guidelines
Overall, discussions during the sessions remained relatively abstract, with limited focus on concrete implementation steps. It was expected that translating these guidelines into actionable steps would require further effort and discussions. However, some participants did begin considering feasibility, particularly regarding stakeholder integration, where challenges were still apparent.

> V2: **"Would be the best if the kMar would want to engage in the decision-making process, but right now that is not feasible yet."**

> V2: **"Some of these integration guidelines could be short-term and others would maybe follow on the longer-term, like a roadmap."**

> V3: **"Currently, we do not at all take the wishes or needs of stakeholders into account in the decision-making, this is all based on assumptions."**

Similarly, for interaction guidelines, participants started considering how they could be implemented in their specific work context.

> V2: **"We would need to determine a what point in time they would make a plan. If that is done too early you mind be busy with adjusting it all the time."**

Beyond DSS design itself, participants also highlighted other key factors for successful DSS adoption, such as adequate training and having ambassadors among users. While implementation falls outside the scope of this study, these insights are valuable for ensuring long-term adoption.

> V6: **"Currently, I try to achieve adoption by involving users closely in the design process and need to explain how the DSS works to every separate user."**

8.2.4 Improvements proposed
The validation sessions confirmed that the guidelines hold value for DSS designers, particularly in early design discussions and brainstorming sessions. However, refinements in presentation, terminology, and structure are needed to improve accessibility and ensure better alignment with user needs.

One improvement would be adjusting the layout to create a more guided reading experience by incorporating different layers of detail to make the guidelines easier to digest. Additionally, refining the terminology and structure of the guidelines could improve comprehension, particularly by clarifying stakeholder-related terminology and ensuring that the guideline titles are intuitive and descriptive.

Another challenge identified during the validation sessions was that the interaction and integration guidelines were perceived as relevant to different teams. The interaction guidelines were seen as the responsibility of the design teams, while the integration guidelines were more aligned with the responsibilities of process designers. Presenting them as a single set may create misalignment. To address this, the guidelines could be positioned as a communication tool between these teams to encourage better collaboration and shared understanding.

Conclusion section 8

- In this section, the guidelines as presented in section 7 were validated with the intended user group. In the validation sessions, the perceived value, the understandability and fit within workflow, and the feasibility and tangibility were tested.

- Although, it did take the participants some effort to understand the guidelines, the participants saw the value of using them in their work. The value of the guidelines as perceived by interaction designers is to have a reference and starting point of considering the inclusion and needs of stakeholders in the design of a DSS. Implementation of the guidelines is considered feasible to a large extend. For a few guidelines, questions were raised, especially regarding the close collaboration with stakeholders, such as the flow moderator might be difficult. Improvements could be made in the presentation of the guidelines, to make it easier to understand.

Conclusion

discussing the insights and concluding the report

In this final section of the report, a summary of the results will be given. Subsequently, these results will be discussed and their applicability to other similar context will be discussed. Afterwards, the contribution that this research has made to both Royal Schiphol Group and academia will be discussed. Then the limitations of the research are explained. And lastly, a number of directions for future research are proposed and a personal reflection on the project is given.

- 9.1 Summary of insights
- 9.2 Discussing the results
- 9.3 Implications
- 9.4 Limitations
- 9.5 Future work
- 9.6 Personal reflection

9

9.1 Summary of results

This research investigated the adoption of Decision Support Systems (DSS) within a multi-stakeholder system, focusing on the Augmented Decision-Making (ADM) system at Schiphol Airport. The research question addressed was:

What should be considered in the design of Decision Support Systems in multi-stakeholder systems to enhance the adoption by users and within the multi-stakeholder system?

To answer this, literature research was conducted on DSS adoption, supplemented by context research at Schiphol, including observations, unstructured interviews, and structured interviews with stakeholders. The study identified challenges in DSS adoption specific to a multi-stakeholder system and formulated design guidelines to improve adoption. In the following paragraphs a recap is presented going through the different sections of this report.

9.1.1 Investigating adoption of DSS from a multi-stakeholder perspective

From the literature study, several factors related to adoption by workers were found. Like, trust in the technology, the expected and perceived performance of the DSS, and the need for the DSS to fit into the workflow of users. Concerning the multi-stakeholder system, different papers note the possibility that introducing a DSS could have a negative impact on the relationships between stakeholders. But others also highlight the possibilities it creates for shared decision-making.

9.1.2 Current challenges and tensions between stakeholders regarding flow control

During the context research it became clear that PC PAX currently use Wilbur in combination with their own expertise and several other sources of information. Stakeholder interactions are one important example of this, especially with OKP and FLM. But between these stakeholders also tensions are present. Such as, misunderstanding regarding each others workflow, lack of transparency and most importantly different goals regarding the control of the passenger flow.

9.1.3 Potential effects of introducing ADM in the multi-stakeholder system

From the insights retrieved during the literature and context research, the potential effects of introducing ADM in the multi-stakeholder system are discussed. First the functionalities of ADM as currently designed are presented. Both the potential adoption barriers as well as the potential opportunities that this system has on the multi-stakeholder system and workflow of PC PAX are discussed. Two main adoption barriers were found, the first one relates to the possibility of a reduction of stakeholder interactions and deterioration of the relationship between the stakeholders due to the introduction of ADM. And the second one is regarding the lack of inclusion of subjective information in the prediction and recommendations generated by ADM, which might cause PC PAX to see less value in the usage of ADM in their work.

9.1.4 Design guidelines for the interaction and integration of ADM

As a result of the research, recommendations, in the form of guidelines were formulated. Both regarding the integration of a DSS in the multi-stakeholder system and regarding the interaction between user and DSS. The guidelines are especially valuable for the case studied in this research, but could also serve as a starting point and inspiration for DSS designers in other contexts. The value of the guidelines as perceived by interaction designers is to have a reference and starting point of considering the inclusion and needs of stakeholders in the design of a DSS.

9.2 Discussing the results

The objective of this subsection is to compare the results as mentioned in subsection 9.1 with the results known in the literature (as included in table 2.1 in section 2) in order to stipulate the added value of this project.

The performed scoping review, as summarized in Table 1, identified various factors influencing DSS adoption by workers. However, these factors lacked detail regarding the role of stakeholders in the adoption process. This study revealed that flow moderators and flow guiders significantly impact adoption and should be considered in DSS design, as their influence on operational decision-making is substantial.

This research has examined the influence of stakeholder relations on the adoption of a DSS, as currently predominantly studied in healthcare contexts, which is different compared to the operational context of the case study. While prior studies emphasize the need for additional communication between different parties closely involved in the decision-making process to support DSS adoption, this case study found that the primary need was for formalized interactions and deeper, more transparent communication, rather than simply increasing communication frequency.

Another key adoption barrier identified in this research is the difficulty users experience in combining DSS recommendations with their contextual awareness and expertise. While Zhang et al. [81] acknowledge the need for users to adapt DSS outputs to their specific needs, their focus is primarily on system flexibility and directability. This study, however, builds on the argument by Bankes [5], emphasizing that DSS-generated representations of reality should be seen as one possible perspective, which users must critically evaluate against their own situational understanding.

This challenge was not explicitly covered in the adoption factors listed in Table 1 but emerged as a significant concern in the context of the case studied.

Although in Table 1, worker attitudes were mentioned as a crucial factor in DSS adoption, this study did not directly assess this aspect. A more tangible DSS interface could be developed from the guidelines proposed and tested with users to evaluate the influence of their perceptions on the adoption.

This research supports the framework proposed by Sitorus et al. [62], who argue that different types of interactions with new technology are interconnected and collectively influence the adoption by workers. Specifically, this study confirms that user-stakeholder interactions are closely linked to user-DSS interactions. The way users engage with stakeholders influences both the tasks they perform in the DSS and the type of information they require from it, reinforcing the importance of stakeholder-informed interaction design. The interaction with the task and the importance of considering this interaction as well has became evident, as the position and relevance of the operations department and the fit between process and DSS arose during the project, although this was outside of the scope of this research.

Compared to previous studies on DSS in multi-stakeholder systems, which focus primarily on how DSS adoption affects stakeholder interactions [24, 25, 49], this research extends the discussion by explicitly linking stakeholder interactions to DSS interaction design. The guidelines formulated in this study aim to adjust DSS design to enhance both stakeholder collaboration and system usability, ensuring that users can effectively engage with both the DSS and relevant stakeholders. This integrated approach addresses a gap in the literature by demonstrating how DSS design should not only consider system functionality but also the dynamics of multi-stakeholder decision-making.

9.3 Implications

The objective of this research was to contribute to research relating to the design of DSS and its adoption from a multi-stakeholder perspective. Besides, the aim for Schiphol was to improve the current design of ADM and get insight into the likelihood of its adoption among the users, flow controllers, and how to include the position and goals of the different stakeholders, flow guiders and flow moderators, in the design process. In this subsection the most important contributions which can be adopted by both researchers as Schiphol are highlighted.

9.3.1 Implications for Royal Schiphol Group

This research highlights the need for an integrated strategy to align ADM and Wilbur within the multi-stakeholder system for flow control. The guidelines developed in this study can serve as input for starting up the discussions on DSS design and its integration into the operational process, ensuring that different teams involved in the development and implementation align their perspectives.

A key finding is that PC PAX must combine the recommendations provided by ADM with their contextual awareness of the terminal's situation. Simply relying on ADM's suggestions without considering on-the-ground insights may lead to ineffective decision-making. Additionally, the research emphasizes the importance of clear training and guidance for PC PAX regarding Wilbur's use, particularly in defining their role in the decision-making process when ADM is implemented. Without clarity on what is still expected from them, adoption of ADM may be hindered.

Another key contribution of this research is the documentation of the current flow balancing process, the stakeholder interactions that influence it, and the challenges faced by PC PAX in navigating these complexities. By mapping these elements, the study provides Schiphol with a foundation for improving operational efficiency and supporting PC PAX in their role.

Furthermore, while Schiphol aims for a more integrated operational approach and closer collaboration with key stakeholders such as the Marechaussee, practical implementation has proven difficult due to organizational structures. The divide between operational process design department and the system design department, has resulted in differing perspectives on the challenges faced by operational teams. This research offers insights into these barriers and contributes to a more holistic approach that connects workflow dynamics with the digital integration of Wilbur and ADM.

Additionally, the study aimed to broaden the perspective of the development team, which has primarily focused on ADM's system performance. By bringing attention to user adoption and integration challenges, it highlights the importance of designing not only for technical effectiveness but also taking into account the needs of flow controllers, flow guiders and flow moderators.

9.3.2 Implications for academia

Beyond Schiphol, the findings of this research contribute to a broader understanding of DSS adoption in multi-stakeholder systems. Other organizations developing DSS could face similar challenges, where different teams involved in the design process operate with divergent perspectives and priorities. If these teams are not aligned on the intended functionality and interaction of the DSS, tensions can arise, leading to a system that does not effectively integrate into existing workflows.

This study underscores the importance of stakeholder alignment in DSS adoption and the influence the implementation of a DSS can have on stakeholder relations.

By mapping decision-making workflows, stakeholder relationships, and existing tensions, it demonstrates how a DSS must be designed with careful consideration of the operational processes it supports and the multi-stakeholder system it will be part of.

Furthermore, while a DSS can enhance decision-making by providing recommendations, human expertise remains essential. Decision-makers must be equipped with the ability to integrate their contextual awareness with system-generated insights such as recommendations, ensuring that the DSS does not replace but rather complements human judgment.

By documenting these challenges and providing concrete guidelines, this research contributes to the academia on DSS design, particularly in large organizations and decision-making processes occurring in multi-stakeholder systems. The insights gained from Schiphol's case study are relevant for other DSS development projects where stakeholder dynamics play a significant role in system adoption and effectiveness.

9.5 Limitations

9.4.1 Limitation based on sample
Access to Marechaussee personnel was restricted, with only two individuals interviewed. Further access was denied due to staff shortages and operational pressures, as well as concerns over sensitive information. This limited interaction reflects the Marechaussee's stance toward Schiphol, as researchers were introduced via Schiphol contacts. Due to limited time available the sample size of the interview study, the workshop study and the validation study were limited. In the future the amount of participants could be increased.

9.4.2 Researcher bias
While researcher familiarity with Schiphol facilitated access to information and personnel, it also could have introduced a bias favoring Schiphol's perspective. Limited access to the Marechaussee may have resulted in an incomplete understanding of the multi-stakeholder decision-making system. Furthermore, the study's outcomes were tailored to Schiphol's specific needs and Wilbur's development context, posing challenges in maintaining neutrality.

9.4.3 Limitations in the scope
The research scope was limited to stakeholder interactions and DSS user interactions, excluding task-level analysis. Future studies should consider the entire framework proposed by Sitorus et al. [56]. Besides, some adoption barriers identified in the literature were not observed within the specific research context. It is necessary to explore the reasons for this discrepancy and assess whether these barriers require further investigation.

9.4.4 Limited involvement of the Operations department
This research focused on the daily execution of flow balancing operations, thereby excluding the operations department from the stakeholders. However, the operations department significantly influences ADM development and the broader flow balancing workflow. This department, and especially the Process Owner, was excluded as they were considered the initiators of the ADM project and therefore took the role of part of the design team instead of being a stakeholder in the decision-making process of flow balancing. Besides, their influence on the day-to-day decision-making as performed by the PC PAX was found to be limited.

At the project's onset, the responsible Operations representative was unavailable, delaying their involvement. Consequently, engagement with Operations regarding the research was limited. Additionally, Operations employees have different perspectives on ADM compared to the design team, lacked in-depth knowledge of Wilbur and ADM, and had alternative expectations for its functionality. While the research findings aligned with Wilbur's team vision, making collaboration easier, the outcomes were ultimately presented and discussed with Operations representatives. This discussion revealed newfound appreciation for human factors, such as stakeholder collaboration, which had not been initially considered in their conceptualization of ADM. Due to this lack of involvement some results in section 4 might have been viewed differently as the operations department do have additional knowledge regarding the current agreements and possible limitations in the relationship with stakeholders such as the Marechaussee.

9.4.5 Limitations due to sensitivity of topic
As already mentioned in the first limitation, the involvement of the Marechaussee in this project has created some limitations in the results of this research. Besides the limited amount of participants, also the results retrieved during the interviews could be biased due to the sensitivity of the topic discussed.

9.6 Future work

Future research could explore the interactions of the task with the DSS and the users and their influence on the adoption and the design of the DSS.

Besides, the relationships and tensions between the various teams involved in the design of a DSS could be researched into further depth, as well as their differing understandings, perspectives, and expectations regarding DSS roles. Especially regarding the role and relation of the operations department to the design and development of ADM and DSS in general.

Additionally, strategies for engaging stakeholders, encouraging participation, and facilitating information-sharing should be examined, particularly concerning concerns over decision-making autonomy. Finally, research could investigate how to translate the formulated guidelines into concrete DSS design implementations.

9.7 Personal reflection

This project has been both challenging and rewarding, requiring me to navigate the fast-paced environment of Schiphol while maintaining the distance, precision, and abstract reasoning of research. One of the key challenges was effectively communicating my thought process and keeping my different supervisors engaged with my work. At the same time, I had to balance the needs of both academic and practical perspectives, ensuring that my findings were not only rigorous but also understandable, insightful, and actionable. And capturing the dynamic context of Schiphol's operation taught me to shift between different levels of abstraction and to translate insights from a specific context into broader knowledge that others can engage with.

The project has taught me about the different facets and elements of the design process of a DSS and supportive tool in general. And beside the hard skills, I also got to know myself a lot better. Got to know my sensitivity for unclarity and interesting tensions, driven by my curiosity and eagerness to understand. Besides, during the process, I noticed that my personal approach to work is highly intuitive and driven on the content of previous steps, whereas scientific research requires careful planning of future steps. This difference was sometimes challenging. But, it helped me recognize my strengths and, at the same time, learn to adapt to different working methods.

Moreover, working with users who had strong opinions made the project challenging but also very educational and fun. Their openness and willingness to discuss their work, provided me with valuable insights into their challenges. As a result, this interaction reinforced my motivation to understand their needs and collaborate with them to design solutions that would benefit them.

Furthermore, during the context research I gained an understanding of Schiphol's operations and could look behind the scenes of a place that I visited myself quite often. This was very enjoyable, also because of the enthusiasm of all the PC PAX and Floor managers that showed me around! Again thank you a lot for that! I also learned how to immerse myself within a company and navigate the complex dynamics between departments. In particular, I discovered that I enjoy speaking with different people and building connections. This experience highlighted a strength of mine, earning people's trust and creating an environment where they feel comfortable sharing their challenges with me. Also, I have discovered that including social and human factors in the design and development of new technologies is what I want to pursue in my career.

Ultimately, I want to say thank you for everyone that helped me during this project, I have learned a lot from all of you!

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