COMPLEXITY FACTORS IN MULTIPLE- AND REMOTE TOWER OPERATIONS

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Bachelor Thesis

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I, Joost Schimmel, hereby declare that this thesis entitled "COMPLEXITY FACTORS IN MULTIPLE- AND REMOTE TOWER OPERATIONS " is my own work.

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Preface

This thesis report was as part of the Amsterdam University of Applied Sciences' Bachelor of Science in the Aviation Operation programme.

This study is supported and guided by the KDC Centre of Excellence (CoE), which supports the transition towards sustainable aviation in the Netherlands and particular for Schiphol airport. Addressing challenges such as airspace limitations, weather conditions, and environmental concerns. The research program at the CoE offers opportunities for students to delve into areas such as Air Traffic Management (ATM) and Capacity Management, providing a relevant context for investigating the operational challenges faced by air traffic controllers at Schiphol. By engaging in research within the CoE, students not only contribute to meaningful projects that can impact the development of Schiphol mainport but also gain valuable insights that can inform their research endeavors, such as exploring the effects of simultaneous movements on workload and safety perception in a multiple remote tower environment, as highlighted in previous studies conducted by the CoE.

I want to give a special thanks to my company supervisors, Evert Westerveld for providing me with a tailored research subject and feedback throughout the internship period, and Koos Noordeloos for providing weekly sessions discussing progress and feedback. Also a thank you to my university supervisor, Margriet Klompstra, who guided me through the graduation period providing valuable feedback as well.

Furthermore, I would like to thank the supporting employees at LVNL and NLR, who agreed to participate in expert sessions and conducted interviews as part of my study. The research was built on the data collected from the sessions and interviews.

Finally, I would like to thank my fellow graduate students for creating a enjoyable and educational period at LVNL. Together we formed a team and helped each other, contributing to the quality of this research.

Joost Schimmel

Schiphol, 02-07-2024

Management Summary

Amsterdam Airport Schiphol (AAS) currently operates with two active Air Traffic Control (ATC) towers; Tower-Centre (TWR-C) and Tower-West (TWR-W). TWR-W handles air traffic for the Polderbaan runway, while the main control tower, TWR-C manages the remaining runways and manoeuvring area. Originally considered necessary for safety and efficiency, maintaining two separate towers has come at a cost, including increased staffing requirements and diverse training needs for air traffic controllers (ATCOs).

The main objective and methodology behind this research is to enhance operational efficiency and reduce personnel costs, LVNL is investigating the feasibility of consolidating operations back to a single tower concept. This study subject explores the potential of implementing Remote Tower Operations (RTO) at TWR-C for managing Polderbaan runway traffic. The study compares traditional RTO variants with LVNL's preferred scenario, which involves using live camera feeds from a remote location within TWR-C.

Main research findings concluded, identified safety, efficiency and environmental impact as most important factors in the change of operations. Stakeholder analysis indicated no anticipated negative impacts based on simulations with the proposed solution, but further testing in the proposed TWR-C environment and under non-nominal situations is recommended. Safety criteria and proxies will be utilized to quantify potential safety hazards during these evaluations.

A key finding is the advantage of LVNL's preferred scenario in case of complete RTO system failure. Unlike traditional RTO, this approach allows for continued air traffic control from TWR-C with limited visibility out the window view of the airport, preventing a complete operational shutdown.

The research recommends a phased approach to implementing RTO. The initial priority is conducting comprehensive simulations replicating the TWR-C environment, with a focus on non-nominal situations. The use of safety proxies is crucial for objective assessment. Additionally, expanding the functionalities of the RTO system should be considered if simulations demonstrate its effectiveness under non-nominal conditions. Looking towards long-term implementation, establishing robust backup and redundancy systems within the RTO infrastructure is recommended to minimize downtime in case of partial failures. Finally, continuous monitoring and evaluation of the RTO system is essential, particularly regarding its impact on roster occupancy, a key driver for LVNL's decision-making.

This study contributes to the knowledge base on RTO implementation by analyzing the specific case of integrating RTO with the pre-existing dual-tower system. The findings and recommendations offer valuable insights for LVNL as they navigate the potential transition towards a single-tower RTO configuration at AAS, potentially setting a precedent for similar implementations in the future.

Table of contents

List of Tables

List of Figures

Acronyms

A

AAS: Amsterdam Airport Schiphol.
ALRS: Alerting Service.
APR: Approach.
AR: Augmented Reality.
ATC: Air Traffic Control.
ATCOs: Air Traffic Controllers.
ATM: Air Traffic Management. ; Air Traffic Movements.
ATS: Air Traffic Services.

C

CMA: Capacity Management & Analytic.
CoE: KDC Center of Excellence.
CTR: Control zone.

E

EASA: European Aviation Safety Agency.

F

FIS: Flight Information Service.

G

GC-C: Ground Control-Centrum.
GC-W: Ground Control-West.
GM: Guidance Material.
GND: Ground.

I

ICAO: International Civil Aviation Organisation. ; International Civil Aviation Organization.

K

KDC: Knowledge & Development Centre.

L

LVNL: Air Traffic Control The Netherlands.

M

MER: Millieueffectrapportage.
Multiple-RTO: Multiple Remote Tower Operations.

O

ORM: Operational Risk Management.
OTW: Out-the-window. ; Out-the-Window.

P

PoC: Proof of Concept.
PTZ: Pan, tilt & zoom.

R

RC-W: Runway Control-West.
research & development: R&D.
RTO: Remote Tower Operations.
RVR: Runway Visual Range.

S

S&I: Systems & Infrastructure.
SAR: Sear and Rescue.
SARPs: Standard and Recommended Practices.
Single-RTO: Single Remote Tower Operations.

T

TWR-C: Tower-Centre.
TWR-W: Tower-West.

1. Introduction

Amsterdam Airport Schiphol (AAS) currently operates with three Air Traffic Control (ATC) towers, including one fallback tower. There is the main control tower, Tower-Centre (TWR-C) and a secondary control tower, called Tower-West (TWR-W). These are used in a dual-tower operation for ATC ground handling and runway control. Tower-West handles the air traffic at runway 36L/18R (Polderbaan). TWR-C is responsible for providing traffic control to the remaining runways and aerodrome manoeuvring area of AAS.

LVNL is conducting a study to integrate the existing two control towers into TWR-C; the motivation behind these considerations is to reduce costs and especially personnel deployment. Additionally, LVNL is exploring the possibility of remotely managing smaller regional airfields from a remote tower centre. This includes considering the option of multiple remote towers, where two airports could be managed simultaneously from one controller working position. In the following sections an elaborate explanation is done on the exact problem statement which sparked necessity for this research in section 1.1. Sections 1.2, 1.3 and 1.4 are focused on determining the specific objectives research objectives and questions, including the relevancy of this research. Finally the research scope is discussed in Section 1.5 and research structure in Section 1.6. With these main introductory topics discusses, relevant literature and definitions will be addressed in Chapter 2.

1.1 Problem statement

The problem statement is separated in multiple subsections, Subsection 1.1.1, discussing the current situation and some background information on the initial problems that occurred with the construction of the Polderbaan runway. Subsection 1.1.2, will be covering the overall research problem specific to this particular project.

1.1.1 Current situation

Since the introduction of the Polderbaan (36L/18R), TWR-W was first introduced as a temporary solution to meet the visual requirements for providing safe air traffic services. These visual limitations stemmed from distance and line of sight related issues, Figure 4.1 shows the distances from TWR-C to the newly constructed Polderbaan runway.

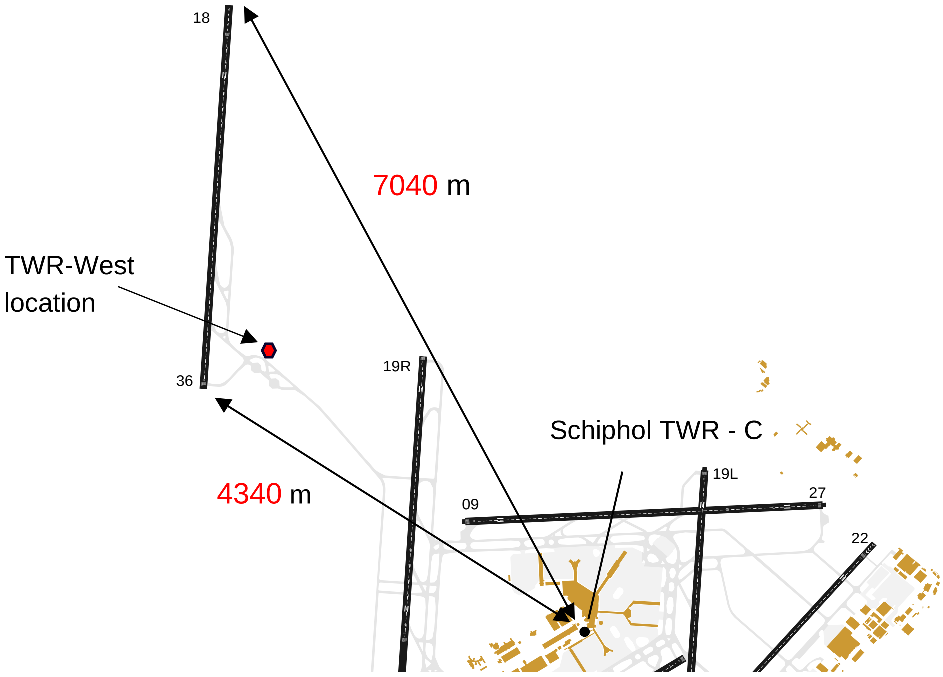


Figure 4.1
Runway system Amsterdam Airport Schiphol

Shortly after investigating several options, the creation of TWR-W was thought to be the most reliable long-term solution, TWR-W went operational in 2003. The demand for improvements has increased in the modern period for a number of reasons, foremost amongst them being the necessity to simplify tower operation. That must lead to a reduction in operational inefficiencies and scheduling issues. Also, the current setup results in an inefficient staff deployment because TWR-W positions are being filled with overqualified tower controllers.

1.1.2 Research problem

Current ATCOs involved in TWR operations recognize a variety of short-term but less desirable options. These options include using non-preferred RWYs, which is contrary to the regulations in noise reduction protocols, secondly handling 18R/36L with BZO (limited visibility conditions) procedures, which reduces capacity, and going back to full occupancy in TWR-W, which requires more staff that is not available(Air Traffic Control the Netherlands, 2019). Ultimately, a well-defined and remote tower operation (RTO) solution with upgraded equipment and a specialized controller for the Polderbaan RWY is a viable alternative. This option is still feasible in a variety of ways, all of which derive back to the one-tower concept.

RTO are a known topic at LVNL and Aviation in general, LVNL experimented by using complete remote tower operations for Maastricht Aachen Airport (MAA) and Groningen Airport Eelde (GAE) in a multiple remote tower concept. In this concept multiple smaller airports are operated simultaneously from one controller working position. While this is more known concept, the combining of regular TWR operations and RTO is a newer and more unknown concept for LVNL. This newer partial remote tower operations conclude a different design of operations, procedures and equipment compared to the more traditional/common fully RTO. This study has therefore been designed to clearly map the complexity factors of the different forms of RTO in the tower operations.

1.2 Research objectives

The following objectives guided the formulation of the main research question, to ensure that it covers the essential areas to be studied and is consistent with the study's overall aim. The identified objectives for the research assignment result from the need to address the previously mentioned challenges in the problem statement and streamline the TWR operations. Each objective is carefully crafted to provide a systematic approach towards achieving this overarching goal of simplifying the TWR operations:

I - Characterize Current TWR Operations: Understanding the existing operational landscape is crucial for identifying areas of improvement and formulating effective solutions. This includes a thorough investigation of the initial TWR-W requirements. The findings from this investigation will then be used to identify bottlenecks and challenges within the current solutions. This analysis will further on enable an effective evaluation of how well these solutions address the current situation.

II - Identify Bottlenecks and Challenges: Identifying complexities and challenges in the current operation allows for targeted interventions to address the root causes of inefficiencies, which resulted within the current ATC tower operations.

III - Reviewing Literature on Remote Tower Operations (RTO): utilizing insights from existing literature on RTO implementation provides valuable guidance and best practices for transitioning towards a simplified ATC model through the use of RTO.

IV - Explore Operational Complexities of RTO, including both full and partial RTO models: Investigate the operational complexities associated with RTO implementation, encompassing both full RTO and partial RTO models.

V - Define Implementation Parameters: Establishing clear implementation parameters ensures a structured and systematic approach to evaluating and comparing potential scenarios for optimizing ATC operations. Also assessing regulatory requirements and compliance standards which is essential for ensuring that proposed solutions align with established aviation regulations and safety standards.

VI - Analyse Available Solutions for Simplifying TWR Operations: Based on the findings from the literature review, operational analysis, and exploration of RTO, evaluation of the existing solutions tailored to the specific needs of LVNL's ATC operations. Formulating an evaluation of these solutions, considering their effectiveness in addressing identified challenges and opportunities uncovered during the research process.

By pursuing these objectives, the research aims to generate actionable insights and recommendations that facilitate the transition towards a simplified and more efficient ATC system at the Polderbaan Runway, ultimately enhancing safety, operational efficiency, and stakeholder satisfaction.

1.3 Research relevance

The COVID-19 pandemic restricted the training process of ATCOs, which resulted in increasing scheduling shortages especially for the ATCOs in TWR positions. A trial conducted in 2022 to handle Polderbaan traffic from TWR-C under night procedures, which highlighted the importance of a robust remote tower operation for a future-proof solution (LVNL, 2022). Therefore, the decision to explore transitioning the Polderbaan operations to TWR-C arises, aimed to address rostering challenges and maintain operational continuity. Bringing the overall ATC tower services back together in the centralized main ATC tower, keeping the initial thought of having TWR-W as a temporary solution. Additionally, consolidating the now separated Runway Controllers and Ground Controllers of TWR-W and TWR-C at a single location is expected to enhance safety and coordination, aligning with future ground traffic handling requirements.

1.4 Research questions

The primary research question guiding this study is given below, and it aims to optimize TWR operations while resolving the issues mentioned in the problem description.

Main research question:

What are the key complexities and workload division aspects within the air traffic control (ATC) ground/tower operations, and how could LVNL simplify and improve their operations through multiple- and remote tower operation aspects?

Sub-questions:

1. *What are the current operational practices and challenges within the ATC tower operations at the Polderbaan Runway?*

Sub-question one addresses the objectives of characterizing current TWR operations and identifying bottlenecks and challenges, laying focus on the Polderbaan runway activities. This involves gaining a comprehensive understanding of the existing operational landscape and pinpointing specific complexities and inefficiencies within the current ATC tower operations.

2. *What insights and best practices from existing literature on Remote Tower Operations (RTO) can be collected to support LVNL's transition to a simplified tower concept?*

Sub-question two addresses the objectives of reviewing literature on Remote Tower Operations (RTO) and exploring operational complexities of RTO., including both single- & multiple-RTO models. This entails leveraging insights from existing literature to provide specifications and guidance material for the transition towards a simplified ATC model, investigating the operational trade-offs associated with the different RTO implementations.

3. *What are the operational, specifications, complexities and requirements of implementing a partial Remote Tower Operations (RTO) models, regarding the specific LVNL scenarios?*

Sub-question three focuses on defining the specifications and implementation parameters, which involves establishing clear guidelines for evaluating and comparing the potential scenarios for optimizing ATC operations at LVNL. This also includes assessing regulatory requirements and compliance standards to ensure safety standards are met.

4. *What solutions are available for simplifying TWR operations at the Polderbaan Runway, and how effective are these solutions in addressing the identified challenges and enhancing operational efficiency?*

Research question four covers the objective of analysing available solutions for simplifying TWR operations, comparing it to the standard forms of RTO. Based on findings from the literature review, operational analysis and exploration of RTO, this question evaluates the existing solutions tailored to LVNL's specific needs. While considering their effectiveness in addressing the identified challenges and opportunities uncovered during the research process.

These sub-research questions are designed to address the various aspects of the research objectives, ensuring a comprehensive investigation into the current ATC operations, challenges, literature insights on RTO, implementation parameters, and potential solutions for simplifying TWR operations.

1.5 Research Scope

The introduction of the Polderbaan in 2002 led to the creation of Tower West (TWR-W) due to the limitations in visibility from TWR-C, to be able to ensure safe and efficient air traffic handling. While TWR-W was initially perceived as a permanent solution, the advancements in technology and knowledge on remote tower operations (RTO) have sparked the need for innovation.

This research aims to explore the operational complexities of RTO, both in multiple- and remote tower operations to be able to compare these to the desired scenario for LVNL. It will also be used in the assessment of their impact on the current operations. By evaluating the various scenarios and perspectives, the study seeks to provide valuable insights that may be used in the decision making process during the implementation phase.

Within this research the focus is set on identifying general operational trade-offs related to traditional forms of remotely operating airports, these will be analysed and compared to the remote solution specific to LVNL. The scope of this project is focused on investigating the first phase of a transition from the current situation towards a remote scenario for TWR-W operations.

1.6 Thesis structure

This thesis report consists of literature review in Chapter 2. In which certain relevant definitions like RTO will be thoroughly described using relevant sources, an overview of related studies can be found that refers on where previous studies will be utilized in answering the sub-questions. Chapter 3. Methodology, is going to explain how the research is conducted. There is an overview of the different data collection methods and research design. In chapter 4. an in-depth look at the current operation is provided, including the exact reason why Tower-W was required. The effects of the implementation are also discussed in order to get a good idea of why this change in operation is desired. Chapter 5. contains additional research findings on topics like single- & multiple-RTO, including interviews conducted and new insights gained outside of the literature. The report will be finalized with, Chapter 6 Discussing the results and answering the sub-questions, Chapter 7 which concludes the research and finally Chapter 8 providing recommendations resulted from this research. An reflection of the thesis project is, including lessons learned is provided in Chapter 9.

2. Literature review

It is essential to have a solid understanding of the basic ideas and terminology supporting this research project before beginning an in-depth analysis of the relevant literature. Section 2.1 aims to provide precise definitions. Furthermore, in section 2.2, the relevant studies and reports are mentioned, including how and in what way these different studies support this research and help achieve high validity.

2.1 Definitions

This section establishes a common ground for understanding the terminology used throughout this research report. For clarity, key terms associated with Air Traffic Services (ATS) are defined here. Grasping these fundamental concepts will provide a strong foundation for delving deeper into the specific chapters of this report.

- **ICAO SARPs and Guidance Material**

International Civil Aviation Organization (ICAO) set op standard and recommended practices (SARPs) containing standard specifications necessary for the safety or regularity of international air navigation, as well as recommended practices containing specifications desirable in the interest of safety, regularity or efficiency of international air navigation. (*Standards and Recommended Practices (SARPS)*, 2022)

These SARPs are defined in different Annexes, a crucial SARPs document related to this study is Annex 11 – Air Traffic Services, the definition of ATS will be exclusively covered within this section further on. Annex 11 defines air traffic services and specifies the worldwide SARPs applicable in the provision of these services. (*Annex 11 - Air Traffic Services*, n.d.)

Guidance material (GM) are provided in ICAO Documents, covering a range of matters from regulations to guidance. Two relevant ICAO documents used in this study are the ICAO Doc 4444 – Air Traffic Management, an complementary procedural document to Annex 11. And secondly ICAO Doc 9426- Air Traffic Services Planning Manual, which offers guidance on how to plan and implement ATS systems effectively. (*ICAO Annexes and DOC Series*, 2022)

- **Air Traffic Services (ATS)**

As defined by ICAO in Annex 11, the objectives of ATS are to prevent collisions between aircraft, collisions between aircraft on the manoeuvring area and obstructions on that area, expedite and maintain an orderly flow of air traffic, provide advice and information useful for the safe and efficient conduct of flights and finally notify appropriate organizations regarding aircraft in need of search and rescue aid. (*Air Traffic Service (ATS)*, 2022)

In the context of this research, the ATS is provided by the air traffic control unit LVNL (Air Traffic Control The Netherlands). The relevant section of LVNL for this research is situated in the control zone (CTR) of AAS, CTR is a controlled airspace extending from the surface, this case AAS, to a specific upper limit which is controlled by a different section of ATC at LVNL. Understanding the role of CTRs and the functions of ATC providing ATS within them lays the groundwork for exploring the specific responsibilities of Tower ATC in the following definition.

- **Tower ATC**

Tower air traffic control is a specific ATC service provided by LVNL from different control towers, the two relevant control towers for this study are TWR-Centre and TWR-West. The primary ways a control tower operates is with Out-the-Window (OTW) visual controls, the traditional method of providing ATC services that heavily relies on the ATCOs visual observations of aircraft on the manoeuvring area. Secondly radar assisted ground control is used, where radar technology is used to supplement the OTW visual control, it allows controllers to track aircraft positions with lower visibility conditions and beyond visual obstructions in terms of range, the visual observation remains an essential element for situational awareness and ensuring safety. (*The Tower Controller*, 2022)

In the context of this research the two key roles in the ATC towers are Runway control (RC) and Ground control (GC). As the name suggests, RC is responsible for the sequencing and separation of aircraft during take-offs, landings and go-arounds on the designated runways. This includes ensuring a safe spacing between aircraft and issuing clearances for these flight phases. The GC is responsible for managing the movements of aircraft on the ground, this includes taxiing to and from runways, holding areas and parking positions, at AAS the role of GC is separated in different sections due to the size of the airport, TWR-West is responsible for providing both runway- and ground control services to runway 36L/18R and surrounding area.

- **BZO-phases and limits**

BZO is a Dutch term ‘Bijzondere Zichtsomstandigheden’ used by LVNL, it translates to limited visibility conditions. BZO refers to weather conditions that impact the ATC tower’s ability to maintain visual control of aircraft on the movement area. These BZO conditions typically involve reduced visibility due to factors like fog, low clouds, or rainfall. Runway Visual Range (RVR) is a measurement which indicates the farthest horizontal distance a pilot can see down the runway (*Runway Visual Range (RVR)*, 2023). The RVR is a crucial factor in determining the safe operation of an ATC tower during BZO conditions. The designated tower supervisor can declare the different phases of BZO. Table 2.1, shows the correlated limits per phase, with phase A being the least impacted BZO phase and phase D being the most impacted, resulting in a possible runway or tower closure.

Table 2.1

BZO-phases and limits of AAS

Phase	Limits
A	A RVR in the field of ≤ 1500 m and/or 200 ft ≤ cloud base ≤ 300 ft
B	A RVR on the active runway(s) of < 550 m and/or cloud base of < 200 ft
C	A RVR on the active runway(s) of < 350 m
D	A RVR on the active runway, either runway 24 or runway 27, of < 200 m

(Aircraft Process Management, 2022)

- **Remote Tower Operations (RTO)**

RTO represents a significant advancement in ATC technology, it refers to providing aerodrome ATS from a remote position that is facilitated by the streaming the OTW of the situated control tower. The remote positions are commonly station in a remote control centre, in which multiple remote positions designated to different aerodromes are supervised from a single location. These remote positions are used to provide ATS from a location other than the aerodrome whilst maintaining a level of operational safety equivalent to using a manned tower. Same as the standard ATC tower, the remote positions oversee both air and ground movements at the aerodrome (*Remote Tower Service*, 2023). The overarching goal of RTO is to increase flexibility and enhance efficiency. The remote control centres can be located more tactically, potentially leading to improved working conditions and reduced infrastructure costs. These centres also allow for a much more efficient resource allocation and management across multiple airport, especially effective in regions with a high density of smaller airfields.

- **Multiple Remote Tower Operations**

The concept of multiple remote tower operations involves a single remote tower position managing ATS for multiple aerodromes simultaneously. This concept offers a compelling solution for smaller airports -airports typically not exceeding 40.000 movements annually- addressing the challenge of balancing safety and operational costs. Although Multiple-RTO offers a variety of benefits especially in resource efficiency, the concept is mainly effective with smaller airports with a non-complex traffic mix and low traffic volume. (*SESAR Joint Undertaking* **|** *Multiple Remote Tower Module*, n.d.)

2.2 Related studies

A variety of internal and external sources will be utilized with the preparation of this study, internal documentation will primarily be used to obtain the necessary background information and external sources will be used to gain new insights and knowledge that will be used in the preparation of the final evaluation report.

To define the current operational complexities of general ATC tower operations, relevant to the first sub-question, a comprehensive review of regulatory literature was conducted. This included documents regarding runway usage prioritization (Ministerie van Infrastructuur en Waterstaat, 2022) and international standards for providing ATM and operational requirements (International Civil Aviation Organization [ICAO], n.d.). Examining these sources offering essential context for understanding the operational considerations and constraints faced by ATCOs, enabling further establishment of complexities in the current TWR-W operations.

To be able to establish insights and best practices into the traditional forms of RTO, relevant to the second and also third sub-question, an analysis is done on demonstrating reports concluding exercise results regarding RTO implementation (SESAR JOINT UNDERTAKING & Irish Aviation Authority, 2015). Additionally, academic journals explored topics like workload management challenges faced by ATCOs as discussed by Fürstenau et al. (2009). Utilization of these sources helped in forming specifications and trade-offs, providing comparable means to the LVNL scenarios.

The literature review explores the potential of RTO and helps describing the operational benefits of augmented reality, as covered by Teutsch et al. (2022). In this regard, Hagl et al. (2019) analysed the perception of safety, workload, and task difficulty in a multiple RTO environment with simultaneous movements. Analysing their findings offers valuable insights into the potential challenged posed within a RTO environment, further supporting the second and third sub-question.

These sources offer valuable insights into various aspects of ATC operations, including remote tower operations, workload management, regulatory frameworks, and the impact of emerging technologies. This review's conclusions will guide the next steps in the research process, including data gathering, analysis, and formulation of recommendations.

3. Methodology

This chapter discusses the research methodology in this study. First the research design and instruments are discussed in Section 3.1, including the approach on the main research question. The focus here is on describing the type of research that has been done and why this is fitting for this particular subject. The data collection methods are covered in Section 3.2, to give insights into how certain information is collected. In Section 3.3, the research objectives are described these have been combined into three separate research phases. Per phase, the approach and process of how the objectives are obtained is described.

3.1 Research Design & Instruments

An overall qualitative research approach is applied in this thesis project, focusing on capturing the complexities, perspectives and challenges related to the implementation of partial remote tower operations (RTO). In order to understand the complex interactions between variables affecting ATC operations and the success of RTO implementation, this study uses, interviews, and participant observation on concepts and procedures. Certain observation will be limited in operational availability, but procedural observation will be complementary to address the missing operational insights. Use of procedural observation is still a very reliable instrument, due to the strictness of these procedures.

To gather a comprehensive understanding of both the current state of LVNL's TWR operations and the broader landscape of Remote Tower Operations (RTO), a complementary analysis will be conducted. This will involve a thorough examination of internal LVNL documents, including operational manuals, procedures, reports, and internal guidelines. These documents will offer insights into current TWR workflows, communication protocols, and the organization's decision-making processes. Simultaneously, an extensive review of academic literature, industry reports, and relevant publications will be undertaken. This external perspective will provide a broad understanding of RTO concepts, technologies, implementation strategies, and the potential impacts on ATC operations observed globally. By examining both internal practices and external knowledge, this research will be well-positioned to assess the feasibility and potential benefits of RTO implementation within LVNL.

Semi-structured interviews will involve engaging with key personnel from LVNL, including air traffic controllers, technical experts, safety experts as well as researchers from partnering organisations like NLR. The interviews will be guided by a set of open-ended questions tailored to each participant's role and expertise. This method will allow for a rich and nuanced understanding of current TWR operations, RTO implementation considerations, and organizational perspectives. The corelated goals to be accomplished from these interviews are summarized for the interviewees in Table 3.1.

Table 3.1
Interviewees for this study

Company	Role	Goal
LVNL	CMA (Capacity Management & Analytics)	Determining the effects in terms of capacity with the change of operations
LVNL	ORM (Operational Risk Management)/safety	Exposing the potential operational risks of the change of operations also in terms of safety
LVNL	System & Infrastructure – ATMS (Air Traffic Management Systems)	Exposing the technical limitations and advancements regarding the new systems to be used.
LVNL	GND (ground control)	Gain perspectives of current ACTOs
LVNL	APR (Approach) / supervisor	Gain perspectives of current ACTOs
NLR	R&D Engineer	Gain insights into different perspectives and solutions of RTO

3.2 Data Collection Methods

To ensure the robustness and comprehensiveness of the research findings, a targeted selection of data collection methods will be employed in this project. These methods have been chosen to directly address the research objectives of assessing the feasibility and potential benefits of RTO implementation within LVNL. While other methods could be considered, focusing on these specific approaches allows for a deeper dive into the specific context of LVNL and RTO.

Certain data collection is done by conducting semi-structured interviews. This data collection method has it strengths in, enabling in-dept exploration of participants' experiences with TWR operations and perceptions of RTO. It will allow for flexible questioning and adaption to emerging themes specific to current research, and provides contextual understanding of the current operational culture and procedures within LVNL. Some potential limitations with this data collection method are the sensitivity to interviewer bias and participant subjectivity. It is also time-consuming and resource-intensive, demanding efficient scheduling and interview planning, and the potential for non-response bias if key personnel are unavailable or unwilling to participate.

Rejected data collection methods like surveys can be efficient for gathering quantitative data from a large population, they may not be ideal for exploring the nuanced experiences and opinions of key personnel within LVNL. A survey format might not capture the depth and detail required to understand the specific challenges and potential benefits of RTO implementation within LVNL's unique environment. Another rejected method of focus groups can be helpful for generating ideas and fostering discussion, they may not be as effective in gathering in-depth, individual perspectives on complex topics like RTO implementation. Semi-structured interviews allow for a more focused exploration of each participant's knowledge and experience. (Diefenbach, 2008)

Secondary data collection methods are focused on document and literature reviewing, with strengths in providing access to historical data and institutional knowledge specific to LVNL's TWR operations as well as RTO. It Allows for verification of information obtained through interviews, and offers insights into formal procedures. It helps to identify best practices and emerging trends in RTO technology and adoption strategies, and offers theoretical frameworks for analysing and interpreting data collected from LVNL personnel.

Limitations with these secondary data collection methods will need to be mentioned too, so may document reviewing not capture informal practices or evolving procedures within LVNL. Literature reviews may not be directly applicable to the specific context of LVNL, and potential for publication bias and selective reporting of findings in the literature.

By employing a diverse range of data collection methods, carefully managing the data, and implementing strategies to minimize methodological limitations, this research will strive to produce reliable, valid, and insightful findings that inform decision-making regarding RTO implementation

3.3 Research Phases

This section outlines the specific phases that will be produced through the research process. It delves into the methodology employed to gather and analyse data, highlighting the utilization of interviews and various analytical techniques. Additionally, it specifies the involvement of different departments throughout each phase of the research and the corresponding objective.

3.3.1 Identifying current TWR operations

The first research phase will be covering the first two objectives that have been set out for this research. Characterizing the current TWR operations (objective I) and identifying bottlenecks and challenges within these operations (objective II), these objectives are strongly dependent from each other and therefore combined into the first phase. Included under the current tower operations analysis are the workload division between TWR-C and TWR-W, the initial requirement for TWR-W and the effect of the introduction of TWR-W. The second part of this phase is to identify the bottlenecks and challenges. These will be made apparent with the gained information from the tower analysis and targeted interviewing regarding the analysed situation.

Utilization of reviewing documents will serve as the primary data collection method for identifying current TWR operations in this first phase. This choice is driven by several factors. Firstly, documented materials like manuals, procedures, and reports offer a promptly available and efficient means to get a better understanding of the established workflows, responsibilities, and overall functionalities within TWR. Secondly, documents provide a standardized and unbiased perspective on TWR operations, minimizing the influence of individual memory or bias that can occur during interviews. Additionally, for the specific case of initial TWR-W requirements documented back in 2002, reviewing these documents allows for a clear understanding of the original goals and functionalities envisioned for this system.

However, it's important to acknowledge that document review has limitations. Formal documents might not capture the nuances of real-world practices or informal workarounds that ATCOs might have adopted. Furthermore, outdated information or a lack of context within documents can be potential drawbacks. To address these limitations and to gain a more comprehensive picture, semi-structured interviews will be conducted with ATCOs and . These interviews will serve to challenge the documented information, gather deeper insights into the effectiveness of current procedures, and identify any unforeseen consequences of TWR-W implementation. By combining document review with targeted interviews, this research will establish a solid foundation for understanding current TWR operations and subsequently identifying potential bottlenecks and challenges.

3.3.2 Remote Tower Operations analysis

The analysis of Remote Tower Operations (RTO) in this second phase will be a complementary analysis. First, a comprehensive literature review will delve into academic journals, industry reports, and relevant publications to gain a broad understanding of the RTO concept and current best practices (objective 3). This review will focus on the technological advancements and functionalities of RTO systems and existing research on their impact on air ATC operations (objective 4). Regulatory frameworks and guidelines governing RTO implementation will also be examined.

Complementing this broad knowledge base, a series of internal interviews will be conducted within LVNL and partnering organizations such as NLR. Targeting personnel from various departments that are likely impacted by RTO, these interviews will gather insights on the perceived impact of RTO on operational efficiency and safety within LVNL. The interviews will also explore potential challenges and opportunities associated with RTO implementation, along with the alignment between existing infrastructure, procedures, practices, regulations, and human resources with the requirements of RTO operations.

By combining the wide-ranging knowledge from the literature review with the specific perspectives within LVNL, a holistic understanding of remote tower operations will be established. This information will be crucial for identifying potential benefits and drawbacks of RTO implementation within the organization in the subsequent phases.

3.3.3 Determining and comparing implementation parameters

The final phase will shift gears to focus on determining and comparing implementation parameters for RTO within LVNL. This process will unfold in three distinct stages. First, a comprehensive field research is embarked. This will involve identifying and evaluating potential RTO solutions acknowledged by LVNL. There will be a delve into the technical capabilities, functionalities, and performance of each system, along with the implementation strategies (objective 5).

Next, a comparison of these potential solutions is done against LVNL's current tower operations. This comparison will be a versatile analysis, considering factors like compatibility with existing infrastructure, procedures, and regulations. Also an assessment is done on how well each solution addresses previously identified bottlenecks and challenges, and how well it aligns with LVNL's specific operational needs and future goals (objective 6).

Based on this in-depth analysis, a single, preferred RTO solution will be selected. For this selected system, the key implementation parameters will be determined. These parameters will encompass a wide range of considerations, including technical specifications for contingency in hardware and software, network and communication infrastructure requirements, integration needs with existing ATC systems, and a thorough cost-benefit analysis.

4. Foundations and background Tower-West

This chapter will delve into the initial requirements to handle air traffic safely and sufficiently from the then new runway, discussing the usage problem, limitations and regulations in providing Air Traffic Services (ATS) and initial project scope and scenarios. Further on in the chapter the current situation is discussed, providing the importance of the Polderbaan, a workload division between the control towers and the current operational complexities.

4.1 Initial Tower-West requirements

The limited visibility of activities on the newly constructed Polderbaan (Runway 18R/36L) from the existing central control tower (TWR-C) at AAS posed a significant challenge for Air Traffic Control (ATC). This section explores the initial requirements for Tower-West in 2002, the second control tower built specifically to address these limitations.

The section begins by outlining the "usage problem" associated with operating at the Polderbaan from TWR-C. It details the specific limitations encountered and their impact on providing safe and efficient Air Traffic Services (ATS). Next, it examines the regulatory landscape for aerodrome control towers, focusing on International Civil Aviation Organization (ICAO) regulations that define the required capabilities of such towers.

Finally, the section explores the initial project scope for Tower-West, outlining the project's primary objectives and the initial scenarios envisioned for its operation.

4.1.1 Usage problem 18R/36L from TWR-C

Despite favourable visibility conditions with a range exceeding 8 kilometres and a cloud base above 300 feet, the existing central control tower at AAS faced significant limitations in observing activities on the newly constructed Polderbaan (Runway 18R/36L) (LVNL, 2002).

These limitations stemmed from factors such as distance and line of sight obstructions, resulting in operational challenges and safety concerns. See *Figure 3.1: Runway system Schiphol* for a visualization of the distances and relative locations of TWR-C and the Polderbaan.

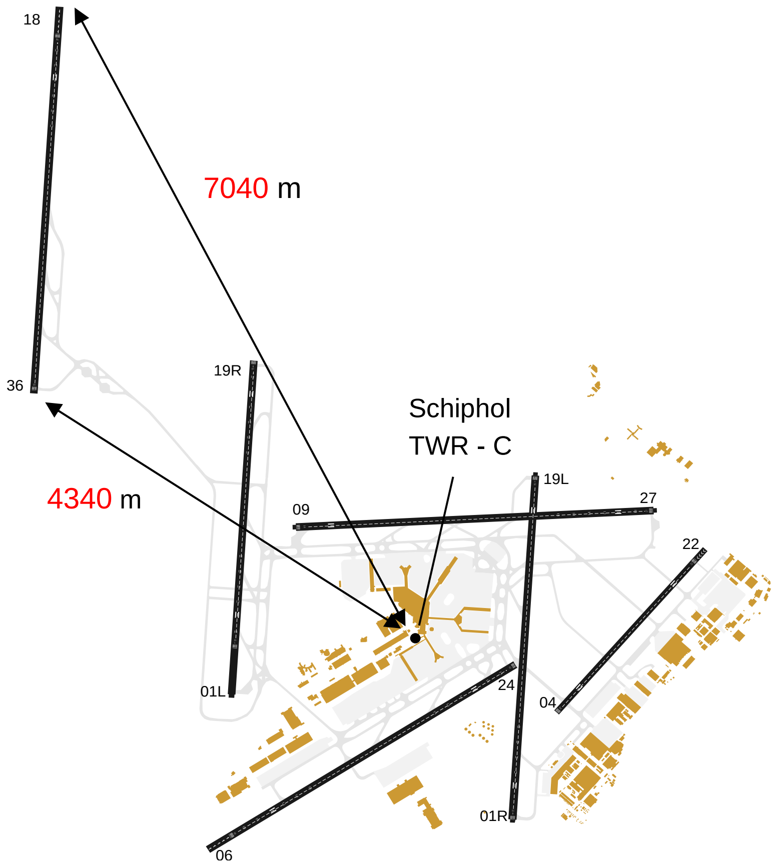


Figure 4.1
Runway system Amsterdam Airport Schiphol

Distance-related limitations:
1. **Object size:** Objects on the Polderbaan, including aircraft, vehicles, and personnel, were too small to be clearly observed due to the distance between the runway and TWR-C.
2. **Exits and taxiway visibility:** The exits and taxiway associated with the Polderbaan were also difficult to observe from TWR-C due to their distance from the tower.

Line of sight obstructions:
1. **Exits alignment:** The exits of the Polderbaan lay directly in the line of sight from TWR-C, further hindering observation of runway activities.
2. **Parallel runway Victor:** Parallel Runway Victor also fell within the line of sight from TWR-C, creating uncertainty when distinguishing aircraft on the two runways.

These limitations had a direct impact on the provision of safe and efficient Air Traffic Services (ATS) for the Polderbaan.

Operational consequences:
1. **Delayed start clearances:** The uncertainty in aircraft positions around the head of Runway 36L and on the taxiway led to delays in issuing start clearances.
2. **Increased separation during final approach:** The disappearance of traffic on short final for Runway 18R over the horizon necessitated increased separation during final approach to ensure safety.
3. **Challenges in Determining Runway Clearance:** The inability to clearly observe the position of an aircraft relative to the exits made it difficult to determine when the runway was clear for landing, delaying landing clearances.

4. **Uncertainty about Runway Occupancy:** The difficulty in distinguishing between aircraft on the parallel runway (Victor) and Runway 18R/36L led to delays in issuing landing clearances.
5. **Hindered Visual Verification of Traffic Sequence:** The limited observation of aircraft or vehicles on taxiway Victor made it challenging for controllers to visually verify the inbound and outbound traffic sequence.
6. **Impaired Alerting Service:** The inability to observe smoke, tire blowouts, birds in the vicinity and other hazards on Runway 18R/36L hindered the alerting task, potentially compromising safety.

The limitations in visual observation from TWR-C posed significant challenges to the provision of safe and efficient ATS for the Polderbaan. These operational concerns, coupled with regulatory considerations, underscored the need for a second tower, Tower-West, to provide unobstructed visual observation of the Polderbaan and its surroundings.

4.1.2 Air Traffic Services and Regulations

This subsection delves into the consequences of the visibility limitations on providing Air Traffic Services for runway 18L/36R.

Handling air traffic on the Polder runway involves providing air traffic services (ATS). These ATS comprise the following services Flight Information Service (FIS), which is defined as "*a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flight. FIS may be provided to all aircraft that receive Air Traffic Control and all other known traffic*". (ICAO Annex 11, International Civil Aviation Organization [ICAO], n.d.-b)

Alerting Service (ALRS), which is defined as "a service provided for the purpose of notifying and assisting Search and Rescue (SAR) organisations in case of an incident or accident involving airspace users that receive air traffic control service, and – as far as practicable – airspace users that have filed a flight plan and other known traffic" (ICAO Annex 11, International Civil Aviation Organization [ICAO], n.d.-b)

Air Traffic Control Service, defined as "a service provided for the purpose of preventing collisions between aircraft and obstacles, as well as expediting and maintaining an orderly flow of air traffic" (Ref. ICAO Annex 11, International Civil Aviation Organization [ICAO], n.d.-b). In this specific case of handling traffic on and in the vicinity of the airport area, it is referred to as Aerodrome Control Service, which is defined as "Air Traffic Control service for all traffic on the manoeuvring area of an aerodrome and all aircraft flying in the vicinity of an aerodrome (aerodrome traffic)"

These services are provided from a so-called Aerodrome Control Tower. The ATS Planning Manual from. ICAO in Doc 9426 outlines two important operational requirements for an Aerodrome Control Tower:

2.1 OPERATIONAL REQUIREMENTS

2.1.1 An aerodrome control tower has two major operational requirements for an air traffic controller to be able to properly control aircraft operating on and in the vicinity of the aerodrome. Those requirements are:
a) the tower must permit the controller to survey those portions of the aerodrome and its vicinity over which he exercises control;
b) the tower must be equipped so as to permit the controller rapid and reliable communications with aircraft with which he is concerned.
(International Civil Aviation Organization [ICAO], n.d.-a)

In subsection 2.1.2 of ICAO Doc 9426 the following relevant guideline is also stated:

“The controller must be able to discriminate between aircraft and between aircraft and vehicles while they are on the same or different runways and/or taxiways.” (International Civil Aviation Organization [ICAO], n.d.-a)

The manner in which the tower air traffic controller maintains oversight of traffic from the tower typically involves visual observation supplemented with binoculars, or electronically through radar or a closed-circuit television (CCTV) system. A noteworthy aspect in the ICAO guidelines is that in the event of inadequate visual observation, various other documents (e.g., ICAO PANS-RAC Doc 4444) simultaneously provide room for handling traffic based on procedural air traffic control techniques.

Based on the study of the ICAO guidelines outlined in Procedure for RC Runway 18R/36L, the following conclusions have been drawn:

> "*Airport ground traffic must be handled by the tower. This primarily occurs based on visual observation and/or through procedural handling (radio position reports). To assist, the controller may use a range of tools including ground radar. While the use of such tools cannot replace visual observation or procedural handling, they can serve as an additional check/verification. If visibility conditions are such that traffic is not visible from the tower but pilots can see each other and report mutual visibility, responsibility for maintaining separation may be delegated to the pilots. If traffic cannot be handled based on visual observations and requires procedural handling supported by a radar display, this significantly increases the workload of the controller. Maintaining the same level of safety in such conditions may have personnel and/or capacity implications*." (International Civil Aviation Organization [ICAO], n.d.-c)

An aspect of ATS deserving specific attention in this context is the alerting service. ICAO stipulates in Doc 4444 in Part V "Aerodrome control":

> “*2.1 Aerodrome control towers are also responsible for alerting service and shall immediately report any failure or irregularity of operation in any apparatus, light or other device established at an aerodrome for the guidance of ther aerodrome traffic and pilots in command.*
> *2.2 Aircraft which fail to report after having been handed over to an aerodrome control tower, or, having once reported, cease radio contact and in either case fail to land five minutes after the expected landing time, shall be reported to the area control centre or flight information centre*.”

Strictly speaking, visual contact with the landing or take-off runway is not necessary to meet these requirements. Concern arises primarily from the inability to observe birds, smoke, debris on Runway 18R/36L, etc. The only information ICAO provides regarding this is also stated in ICAO Doc 4444:

> *“4.1 Aerodrome controllers shall maintain a continuous watch on all visible flight operations on and in the vicinity of an aerodrome, including aircraft, vehicles, and personnel on the manoeuvring area, and shall control such traffic in accordance with the procedures set forth*.“

This rule does not impose a strict requirement for visual traffic observation. However, it does emphasize that the controller should visually monitor the pilot where possible. Since Runway 18L/36R is too far away for visual observation, this service cannot be provided to the pilot.

Conclusion:
The limitations presented hinder the provision of the mentioned services for Runway 18R/36L from the current tower (TWR-C). The question of whether these limitations render handling from the current tower genuinely impossible is not straightforward to answer from various perspectives (legal, operational, practical). Although there appear to be no legal or procedural constraints working from the current traffic

tower contradicts the operational staff's perception regarding the nature of tower traffic control, namely the inability to handle Runway 18R/36L with the same quality of service as the other runways at AAS. This forms the basis for the usability problem.

4.1.3 Initial project scope

With the given regulations a research & development (R&D) team was challenged in developing a solution on a very short term to address the usage problem of the Polderbaan runway. The given project had the following scope:

"*Develop and implement a temporary solution for the usability problem for Runway 18R/36L to ensure operational readiness by 28/11/2002*." (LVNL, 2002)

The project had an initial solution duration of 3-5 years, however TWR-W is still fully operational. In the following subsection 3.1.4, the initial scenarios will be discussed acknowledging the different solutions that were identified.

4.1.4 Initial scenarios

To address the visibility limitations on the Polderbaan runway and ensure uninterrupted air traffic operations across AAS, four initial scenarios were evaluated by the R&D team. (LVNL, 2002)

Scenario 1: Centralized Tower Traffic Control (TWR) from the Existing Tower:
This scenario proposed utilizing the existing control tower (TWR-C) for TWR services for all runways. However, due to the significant visibility limitations for runway 18R/36L, this scenario was deemed impractical and unable to effectively manage air traffic for that runway.

Scenario 2: Specialized TWR for Runway 18/36 and Existing Tower for Other Runways:
This scenario aimed to establish a dedicated second control tower near runway 18/36 to handle TWR services specifically for that runway, while the existing tower would continue to manage TWR for the remaining runways. This approach aimed to address the visibility limitations for runway 18/36 but introduced complexities in coordination and workload distribution between the two towers.

Scenario 3: Hybrid TWR Approach with Time-Based Division:
This scenario proposed a hybrid approach where TWR services for the entire airfield would be divided between the existing tower and the second tower near runway 18/36 based on the time of day. The existing tower would handle TWR during certain periods, while the second tower would take over for runway 18/36 during the remaining hours. This option aimed to balance workload and address visibility limitations but presented challenges in scheduling and handover procedures between the towers.

Scenario 4: New Central Tower Construction:
This scenario envisioned constructing a new, taller central control tower at a suitable location within the airfield. This tower would provide a more comprehensive view of the entire airfield, potentially addressing the visibility limitations for all runways. However, it was considered infeasible for a temporary solution due to the extended timeline required for construction and the significant investment involved.

Building upon the evaluation of the four initial scenarios, some further considerations are worth mentioning regarding different costs and benefits. The first scenario, while aligning with the Polderbaan runway's initial planning, became irrelevant due to the identified "usability problem" described in subsection 4.1.1. Scenarios 2 and 3, while featuring the operational complexity of two control towers, offer the significant advantage of maintaining full Polderbaan capacity without capacity reduction. Scenario 4, while eliminating the need for a second tower, presents a major drawback, a significant reduction in runway capacity. This reduction is a consequence of the proposed new central tower's considerable height (170-200 meters), which would trigger earlier BZO phases and marginal visibility conditions due to its proximity to the runway thresholds.

The ultimate decision, involved the implementation of a second control tower, Toren West, situated near the head of the Polderbaan. This solution addresses the usability problem while maintaining operational efficiency. The following section 4.2 will delve deeper into the current work distribution and responsibilities among the various control towers.

4.2 Current situation

Following the exploration of various solutions in 2002 to address the usability problem for runway 18R/36L (Polderbaan), this section delves into the current operational configuration at AAS. The analysis begins by identifying the current operational control towers involved AAS, including their respective functions. The focus will then shift to workload division, examining how responsibilities are distributed and coordinated between these towers, particularly TWR-W and TWR-C. This will provide a clear picture of how air traffic management is structured for efficient operation.

The importance of the Polderbaan runway will be discussed, analysing its significance for AAS. Discussing the preferential runway use and governing regulations on the usage of different runways at AAS, which focuses on the generation of noise pollution. Finally, the section delves into the complexities associated with managing air traffic under the current operational setup. This examination will reveal any challenges or limitations inherent in the system, highlighting areas requiring ongoing attention which is of great importance for this research.

4.2.1 Current Operational Towers

Amsterdam Airport Schiphol currently has three operational towers, see Table 4.2. Tower-centre is responsible for providing ATS in vicinity and manoeuvring area of all runways except for the Polderbaan runway. The Polderbaan runway is operated by tower-west, responsible for the remaining air traffic in the vicinity of the Polderbaan runway.

Specifically built in 2002 as a result of the "Temporary Solution Usage Problem 18/36" project (LVNL, 2002) described in section 4.1, Toren-W addresses the usability issue for runway 18R/36L (Polderbaan). It manages air traffic specifically in the vicinity of the Polderbaan, ensuring smooth operations and minimizing noise impact on surrounding communities. Currently, Toren-W operates from 6:30 AM to 10:30 PM local time (LT), with a single runway controller and one ground controller handling all Polderbaan activities during those hours. A more detailed analysis of individual responsibilities and collaboration between Toren-C and Toren-W will be provided in subsection 4.2.2.

Finally, AAS maintains a third, non-participating tower: the Emergency Tower (Toren-E). While not used for daily operations, this tower remains operational for contingency situations. In the event of an emergency at either TWR-C or TWR-W, Tower-E would be activated to manage air traffic flow for a controlled shutdown or even a complete airport closure, if necessary. TWR-E is not capable of maintaining a normal operating capacity due to the lack of visibility.

Table 4.1
Current operational towers

Towers ***Period active***	***Image of TWR***
TWR-C (Tower-centre) **1991-present**	 **(LVNL, n.d.)**
TWR-W (Tower-West) **2003-present**	 **(Schiphol, 2021)**
TWR-E (Tower-Emergency) **1967-1992 (active)** 1992-present (Emergency)	 **(De Kruijf, 2021)**

4.2.2 Workload division in and between towers

At AAS, the workload for air traffic management is carefully divided between the two operational control towers: TWR-C and TWR-W. This division ensures efficient and coordinated handling of air traffic, particularly in the vicinity of the Polderbaan runway.

The responsibilities of ground controllers (GCs) are divided into distinct areas, as illustrated in Figure 4.2.1. During operational hours, TWR-W is staffed with one runway controller (RC) and one GC to handle air traffic in the West area of responsibility and on the Polderbaan.

The GC-West (GC-W) manages the gray-colored area in Figure 4.2.1, extending from the Polderbaan to the GC-Centrum (GC-C) area of responsibility. All departing traffic from this area is guided by GC-W to a holding point on runway 36L. There, it is handed over to RC-W for clearance to take off. After landing and leaving the Polderbaan, pilots independently switch from the RC-W frequency to the GC-W frequency. GC-W then guides the traffic to the GC-C area of responsibility.

During the night hours, when TWR-W is not staffed, the Polderbaan can still be utilized. However, this is only possible due to reduced volume of air traffic. In this scenario, a camera setup with live feeds from TWR-W surroundings and Polderbaan RWY is projected. Traffic is handled by standard procedures with radar support, maintaining a minimum separation of 4 nautical miles compared to the standard 2.5 nautical mile separation. (LVNL, 2022

TWR-C ATCOs are supported by the camera images due to limited visibility. Figure 4.2.2 shows the setup used in TWR-C during nighttime operations. This outdated setup may eventually be replaced with a completely new remote tower position within TWR-C. The use of a camera setup and procedural handling during nighttime operations demonstrates the airport's adaptability in maintaining runway utilization while upholding safety standards. The use of a camera setup and procedural handling during nighttime operations demonstrates the airport's adaptability in maintaining runway utilization while upholding safety standards.

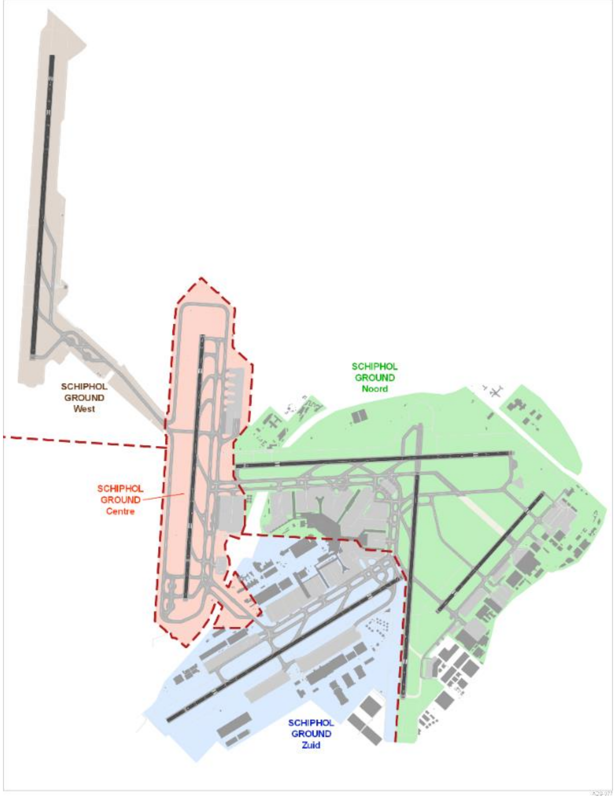


Figure 4.2
Ground Control areas of responsibility
(LVNL, n.d.)

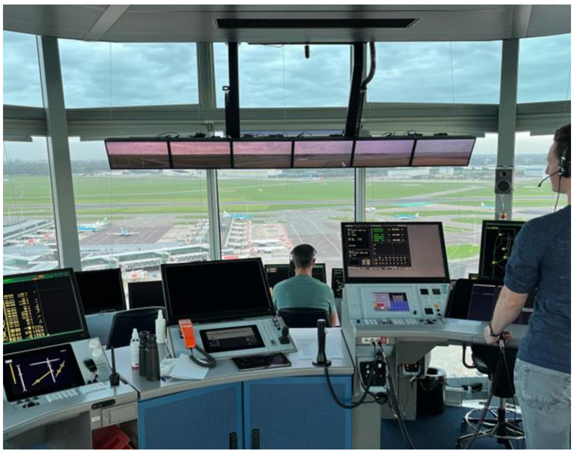


Figure 4.3
TWR-C drop down screens of Polderbaan

4.2.3 Importance of the Polderbaan runway

The Polderbaan is often prioritized for runway use due to its favourable noise profile compared to other runways at AAS. This prioritization stems from the airport's efforts to minimize noise pollution for surrounding inhabitants. The Polderbaan runways role is further enhanced by the airport's runway configuration strategy, particularly during peak traffic periods. AAS employs a "2+1" and "1+2" configuration, where two runways are used for take-offs and one for landings during peak departure times, and vice versa during peak landing times. In both configurations, the Polderbaan is always active, highlighting its crucial position in managing air traffic flow.

Government regulations, such as the MER (“Milieueffectrapportage”), also play a role in the Polderbaan importance. This report outlines the regulations and guidelines governing runway prioritization, with the Polderbaan identified as the preferred runway due to its lower noise impact. These regulations impose noise limits on the airport's overall operations, promoting the use of the Polderbaan. Noise flightpath figures, such as Figure 8.1 in appendix A, illustrate the overall noise pollution impact of different runways at AAS. The Polderbaan runways flight path clearly shows minimal noise disturbance over densely populated areas compared to other runways. (Ministerie van Infrastructuur en Waterstaat, 2022)

Given the Polderbaan runways critical role and the challenges associated with its separate location, LVNL has a significant interest in developing innovative solutions for its operation. This is evident in the creation of TWR-W as a dedicated control tower and the ongoing research into remote tower solutions for the Polderbaan runway. By investing in such innovations, LVNL aims to further optimize air traffic management, enhance safety, and ensure the continued efficient utilization of the Polderbaan runway.

4.2.4 Current operational complexities

Even though the airport has taken a number of steps to streamline operations, several operational complexities still exist, particularly in regard to the Polderbaan runway and the TWR-W operations.

The Yerkes-Dodson Law illustrated in Figure 4.2.4, shows a psychological concept, which suggests an inverted U-shaped relationship between stress and performance. While moderate stress can enhance focus and productivity, excessive stress can lead to performance deterioration and increase the risk of errors (Level of Arousal, 2022). The Yerkes-Dodson Law also highlights the risks associated with under-arousal, the situation where ATCOs experience too little stress or challenge. In these situations, boredom can set in, leading to decrease in alertness and potential attention slips. Different ATCOs located at TWR-W experience this level of arousal in certain scenarios when the Polderbaan has limited movements.

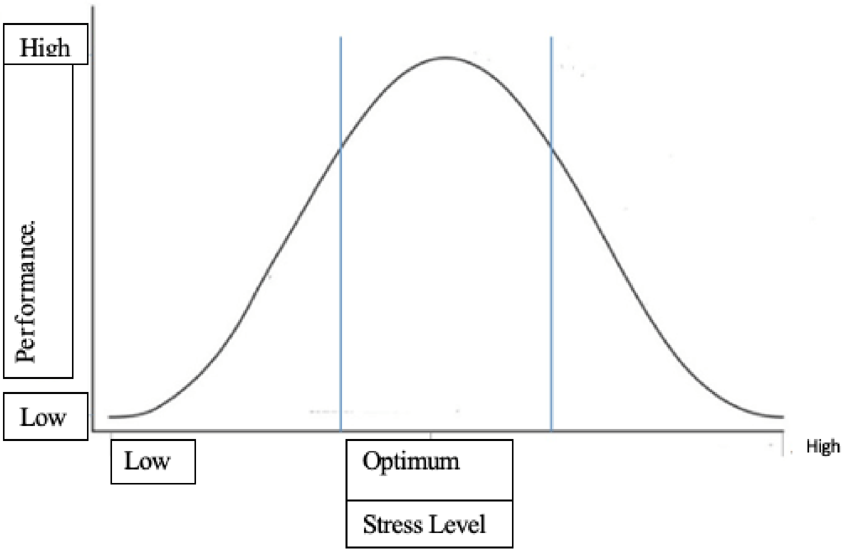


Figure 4.4
Graph compares stress level with performance
(Retitling Stress: A Look at the Yerkes-Dodson Law – Dartmouth Undergraduate Journal of Science, 2021)

The current staffing situation at TWR-W raises concerns regarding workload balance and the utilization of overqualified personnel. Despite the simpler operations at TWR-W compared to the main control tower centrum, it occurs that overqualified ATCOs are employed for this role, this is brought to attention by the ATCOs themselves. This mismatch between skill level and task complexity could potentially lead to underutilization of ATCOs expertise and create a sense of dissatisfaction due to unchallenged work.

The separation of TWR-W from TWR-C introduces coordination challenges that may hinder operational efficiency. In contrast, a centralized tower operation would allow for more seamless coordination and information sharing between controllers, particularly during critical situations. In the event of an emergency or incursion, such as a go-around over a crossing runway, the decentralized tower structure necessitates explicit radio communication between TWR-W and TWR-C. This reliance on radio communication could introduce delays and increase the risk of miscommunication, potentially harming safety.

Finally the physical separation of TWR-W from the main airport terminal poses an additional challenge in terms of ATCO travel time. The extra time spent commuting to and from TWR-W reduces the effective working time of ATCOs, further straining the resource allocation and potentially impacting operational efficiency. These do not directly effect the operations negatively, however they do cause additional inconvenience to the staff.

4.3 Background assessment

The construction of the Polderbaan in 2002 presented unique challenges for air traffic management at AAS. The remote location of the runway required a separate control tower, TWR-W, to ensure effective and safe air traffic control could be provided. Due to regulatory constraints and technological limitations at the time, it was not feasible to operate the entire tower function from a single centralized tower.

The current operational situation at TWR-W highlights several complexities that impact the efficiency and safety. The decentralized tower structure, while initially necessary, introduces coordination challenges and potential communication delays, particularly during critical situations. Additionally, the underutilization of overqualified ATCOs and ATCOs in general raises concerns about workload balance and utilization of staff.

The findings of this chapter provide a solid foundation for exploring potential solutions to address the operational complexities surrounding TWR-W. The transition to a remote tower operations setup at TWR-C offers a promising approach to streamline current operations, enhance coordination, and optimize ATCO utilization. Chapter 4 has established a clear understanding of the historical context, initial requirements, and current operational challenges of TWR-W. These insights will serve as a basis for the coming chapters, which will delve into the feasibility and potential benefits of implementing an RTO setup at TWR-C, creating a more efficient, coordinated, and safer ATM system at AAS.

5. Remote Tower Operations assessment

The following chapter explores the various scenarios identified by LVNL for combining the current tower operations at Amsterdam Airport Schiphol. Each scenario will be clearly outlined, along with its origin and how these came about. Additionally the chapter will compare the preferred scenario to more traditional RTO & multiple-RTO, highlighting their respective trade-offs.

To ensure a comprehensive evaluation, the chapter will explore various aspects beyond the proposed scenarios. Stakeholder perspectives are discussed in Section 5.2, including those of ATCOs, a system expert and a safety expert. The perspectives are used to understand their concerns and expectations regarding a RTO implementation at LVNL. Furthermore, a deep dive into the technical requirements and additional features regarding RTO implementations is discussed, both in terms of general RTO and the specific LVNL scenario. This analysis will acknowledge the potential trade-offs and implementation challenges.

The chapter is concluded in section 5.4, which discusses the change of operation criteria, these are crucial for determining the feasibility of the transition.

5.1 Evaluation of RTO scenarios for LVNL

This section evaluates several Remote Tower Operations (RTO) scenarios identified to address staffing challenges at LVNL. While a preferred scenario has been established, all scenarios are presented for a comprehensive understanding of the decision-making process. The scenarios explored represent an iterative process. The initial scenario (Scenario 1), while not a feasible long-term solution, provided valuable insights that informed the development of the more promising Scenarios 2 and 3.

Scenario one: The first recognized scenario is to operate according to the night procedures using the overhead displays -as mentioned in subsection 4.2.2- during day time. This form of remotely operating TWR-west traffic is not considered to be a feasible solution, due to the insufficient camera support currently available. A trial was conducted by Bos et al. (2022), to operate air traffic at the Polderbaan according to the night procedures in the break-time of TWR-W controllers. Initially, it was decided that when TWR-W had a break, 18R/36L would not be used and another runway would be used. However, this is not in line with LVNL's obligation to stick to the runway preference as much as possible, hence the reason for the trial. The trial means that the air traffic controller is supported by the camera system of the Polderbaan, and that the capacity during the break period is 30/30 (take-offs/landings). A significant reduction compared to the regular capacity of 37 to 40 take-offs per hour for RWY 36L and 34 to 38 landings per hour for RWY 18R. While the trial ensured runway preference and maintained continuity of operations, it revealed several limitations that make it unsuitable as a long-term solution.

The trial has demonstrated the limitations of relying only on the existing overhead displays for handling Polderbaan traffic from TWR-C. Workload spikes due to unforeseen events, decreased situational awareness due to the poor camera quality, and difficult shifts between TWR-W and TWR-C operations all raise concerns about long-term sustainability. Additionally, the trial also introduced planning complexities and generated delays.

While the trial in its current form is not feasible, it has highlighted the potential of a well-developed remote tower solution. The need for improved camera quality, ergonomics, and a dedicated system for handling TWR-West traffic remotely has become evident. Building on these insights, further scenarios have been identified, prompting advancements in camera technology and user-friendliness.

Scenario two: This scenario proposes establishing a dedicated remote tower unit within Tower-C (but not on the 12e operational floor) or elsewhere in Schiphol-Oost, the head office of LVNL at Schiphol. This approach aims to address the limitations of the first scenario while maintaining the benefits of centralized operations.

While the second scenario offers potential benefits in terms of workspace, and digital contingency, the drawbacks related to coordination, situational awareness, and personnel flexibility raise concerns about its overall feasibility. The remote setup could introduce communication challenges and potentially compromise safety due to reduced situational awareness. Subsection 5.2.2 delves into the specific advantages and disadvantages of this specific scenario. The second scenario presents a more promising alternative for remotely handling TWR-W operations, but recurring challenges from the current situation require a different solution like explained in scenario three.

Scenario three: This third scenario proposes modifying one or two existing tower positions on the operational 12th floor of TWR-C to accommodate remote TWR-W operations. This approach aims to leverage the benefits of face-to-face coordination and situational awareness while minimizing the drawbacks of the previous scenarios.

LVNL is currently conduction a research parallel to this research into the feasibility of a one-tower concept for AAS's air traffic management. This concept envisions consolidating all air traffic control operations under a single tower, eliminating the current two-tower system. By centralizing operations, LVNL aims to enhance communication, coordination, and efficiency, leading to optimized service delivery. The one-tower concept aligns with LVNL's long-term vision for tower operations at Schiphol. The temporary nature of TWR-West, established as a temporary solution, has always been acknowledged within this vision. The research into a one-tower concept represents a strategic step towards a more permanent and streamlined air traffic management structure at AAS.

Given its potential to address the limitations of the previous scenarios while offering significant advantages, Scenario three emerges as the preferred solution for remote TWR-West operations. The following sections will delve deeper into the specifics of Scenario three, analysing its advantages and disadvantages in detail, outlining recommendations, and ultimately compare it to the more traditional forms of RTO.

5.2 Stakeholder perspectives on RTO implementation

This subsection delves into the insights gathered through semi-structured interviews with the various stakeholders involved in the potential implementation of RTO for the TWR-W operation at LVNL. For these interviews the focus was laid on combining specific topics with open-ended questions to explore stakeholders' perspectives on RTO and LVNL's preferred scenario (Scenario 3).

The analysis starts off by examining the perspective of a system expert relevant to the current RTO technology in subsection 5.2.1. The interview with this individual, having a crucial role in developing LVNL's concept version, focused on the specifications of the existing system, potential areas for improvement and any existing bottlenecks or limitations. This initial exploration provided a crucial foundation for understanding the current technological advancements made for TWR-W.

Following the system expert's input, subsection 5.2.2 examines the perspectives of two ATCOs directly involved in the research: one Runway Controller and one Ground Controller. These interviews specifically examined their views on Scenario 3, the preferred RTO solution. The ATCOs' insights proved to be particularly valuable, offering crucial information for the final decision-making process regarding this operational change.

Finally, subsection 5.2.3 examines the perspective of a safety expert interviewed to gain insights into the criteria for evaluating operational changes, particularly those about safety. Additionally, this section will discuss a standard safety criteria framework used to assess the safety implications of any ATM change of operation. Furthermore, a more in-depth analysis of the criteria most relevant to the preferred scenario (Scenario 3) is provided.

5.2.1 System experts perspective

The interview with the system expert from the Systems & infrastructure department (S&I), highlighted multiple considerations regarding the transition to remotely operating TWR-W. The first acknowledgement is that the assumption is made that the same procedures will be followed when transitioning from conventional TWR-W operations to a remote scenario. This means that OTW traffic handling will be a one-on-one takeover, no limitations have been found in various tests done with the concept version.

The opportunity was taken to view and test the 'PoC' (Proof of Concept) setup, a concept version of the preferred scenario. This PoC setup is shown in Figure 5.1 and is currently installed in TWR-C, which is the preferred option for operational implementation.

Figure 5.1
'Proof of Concept' set up in TWR-C.

One of the advantages of the concept over conventional TWR-W is the use of new features. The current concept version uses overlaid information, which involves labels projected onto the visual representation of the external view as shown in Figure 5.1. The letter A indicates tracking overhead labels which are able to provide flight information, this will be applicable to all traffic that can be tracked with radar technology. A significant factor is that VFR (visual flight rules) traffic can also be tracked, which is often more difficult to manage due to its somewhat unpredictable presence and the need for extra attention. Other general information related to meteorological aspects is displayed in the top shown by the letter B. Additionally specific visibility and wind conditions at the respected head of the runway are displayed with the letter C.

Different colour labels can also be used to distinguish between arriving and departing traffic. These innovations are extra functionalities made available through RTO. A distinguished function called PTZ, pan, tilt & zoom, is also available in the concept version. This function currently operates with digital zoom but if definite transition will come, this PTZ function will have a standalone camera having a much higher resolution, resulting in better quality. The effect of these features is that air traffic controllers have less 'look down time' and thus have a better and more efficient overview of traffic.

With the RTO solution described in scenario 3, there will be system limitations that are not present in the current operations. This is particularly the case for the delay that exists on the live projection of camera feeds used in the system. This delay is 1.2 seconds in the concept version and is expected to be 0.7 seconds in the final operational setting. This delay is caused by synchronizing the different cameras and cannot be further reduced within the current systems. EASA Guidance Material states that the recommended maximum video latency should not be greater than 1 second (European Union Aviation Safety Agency, 2019). By looking at these guidelines, we can see that the expected value would be considered appropriate for handling air traffic safely.

In practice, the capacity for the number of take-offs and landings should not deviate from the current TWR-W capacity. However, this was not the case in the current night procedures. This is mainly due to the poorer system support used during night operations. With the current concept, it is expected that traffic can be handled at the same capacity during

In addition to the video latency that arises from using a remote tower position for TWR-West operations, there is also a new issue related to the continuity of operations. In addition to the system-supported radar, communication, and electronic flight strips systems, which will continue to be used in the same way, the new camera systems will need to be equipped with additional continuity protocols.

So far, there are no plans to duplicate camera feeds to build in a contingency. However, this is definitely the intention as soon as decisive decisions are made to implement the change of operations. In the current phase, the screens can be used universally and multiple cameras can be displayed on a single screen if a screen fails. If there is a system failure, the preferred scenario, which involves placing a remote position in TWR-C, will still provide a limited view of the airport. This would not be the case if a remote setup outside TWR-C were to be used. Subsection 5.2.3, from the safety expert's perspective, also discusses the overall continuity that would come into play in the event of a TWR-C failure rather than a specific remote position failure.

5.2.2 Air traffic controllers perspectives

The interviews with ATCOs revealed positive feedback on the PoC showcasing the preferred scenario. The new approach on managing air traffic was experienced well and concluded that the additional features, such as the overhead display labels and PTZ cameras to be extremely beneficial. “These new features give air traffic control a whole new look” commented one ATCO. Both ATCOs had the opportunity to test the concept version and provide input on further development, adjustments and including the content and positioning of labels. They have participated in simulation tests, confirming that the new approach of providing air traffic control remotely to the Polderbaan runway is considered workable.

Further testing is needed to determine whether departing and arriving traffic can be handled just as efficiently form TWR-C, ensuring that the capacity for take-offs of 37 to 40 and landings of 34 to 38 remain consistent. Simulation tests done by the ATCOs with the PoC have indicated that this is feasible under normal conditions, however these simulations were conducted in a controlled remote environment. This will not be the case when ATCOs responsible for operating the Polderbaan runway are situated in the operational floor in TWR-C, both ATCOs acknowledged.

Given these increased amount of ATCOs in TWR-C measures can be implemented to restrict the number of visitors. This could involve reducing room for visitors and enforcing group size limits. Additionally, more care should be taken when scheduling on-the-job training. New considerations should be given to the number of individuals simultaneously present in TWR-C

5.2.3 Safety expert's perspective

The interview with the safety expert from the Operational Risk Management (ORM) department revealed some very important aspects related to safety criteria. The expert currently does not expect any negative impact on safety aspects with using RTO during normal operations. However, non-nominal situations are a key aspect to be investigated in in order to determine the overall operational safety. Overall, the situational awareness seemed acceptable for the change of operations, but the PoC setup needs to confirm this further due to potential limitations in non-nominal situations. A definite improvement is expected in terms of situational awareness of the total operations, due to the facts that ATCOs will be located together in TWR-C.

The expert highlighted on the general criteria when looking at such changes in providing air traffic management. These changes come with specific requirements and quality criteria that need to be met. These quality criteria can be quantified in some cases, but in this instance, a qualitative approach is necessary. An example of such a safety criterion is ensuring the safety level of the ATM system remains at least the same after the change as it was before.

The particular focus is on non-nominal situations where the new system could introduce complexities. The expert also considers the future scenario with one combined ground- and runway control west ATCO. This aspect wasn't included in this study as it would be part of further optimization steps for the RTO concept. Even though these safety criteria apply here, they are also effective in the initial transition step.

These are general safety criteria applicable to changes that are difficult to quantify. The safety criteria defined within LVNL's safety criteria framework all align with the following safety acceptance levels:

I. Unacceptable
II. Tolerable
III. Acceptable
IV. Negligible

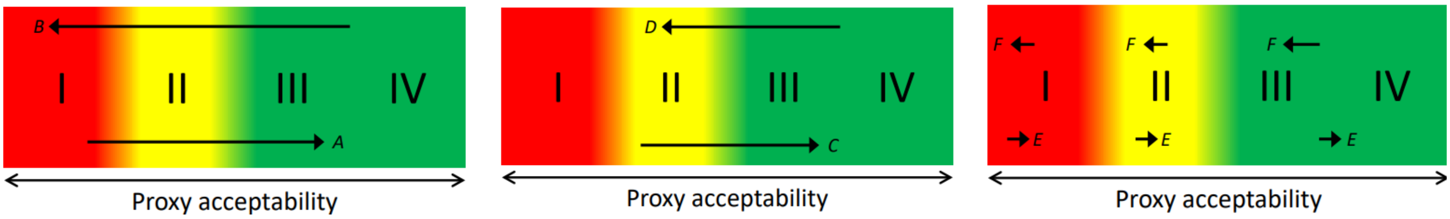
The safety level of the ATM system or a change to it can be assessed using so called proxy criteria, they assess potential safety hazards indirectly through risk, using the same four safety acceptance levels.

Proxies are indicators of safety risk that aren't expressed in terms of probability and severity of potential hazards. They are essentially derivatives or substitutes for safety risk, hence the name. Examples of proxies include controller workload, situation awareness, head-down time, and the extent to which operational staff is in control of the traffic situation. Proxies related to controller capabilities can be particularly useful in making the safety perception of controllers more objective, translating those often subjective feelings into something more concrete. Proxies are especially helpful when the proposed ATM system change influences dozens or even hundreds of different hazards. Table 5.1 clearly shows how the effects of these proxies are distributed across the three categories: large, medium, and small.

Table 5.1

Examples of the application of proxy classes

LARGE	MEDIUM	SMALL
Positive effect The effect can improve the proxy, going from an unacceptable level to an acceptable level (example: arrow A).	**Positive effect** The effect can improve the proxy such that a tolerable level becomes acceptable (example: arrow C).	**Positive effect** The effect can improve the proxy but the acceptability remains the same (example: arrow E).
Negative effect The effect can deteriorate the proxy going from an acceptable level to an unacceptable level (example: arrow B)	**Negative effect** The effect can deteriorate the proxy such that a tolerable level becomes unacceptable (example: arrow D).	**Negative effect** The effect can deteriorate the proxy but the acceptability remains the same (example: arrow F).



(Air Traffic Control the Netherlands, 2019)

The assessment looks at various situations and occurrences that could arise during both nominal and non-nominal operations. Currently, the focus isn't on the risks associated with nominal operations but rather those that could occur during non-nominal situations. It's believed that the biggest risks will arise during emergencies, where the limitations of the system might lead to less effective handling compared to the current situation. If specific situations have such a negative impact that the associated proxy becomes "intolerable," it's unlikely the implementation will proceed in the same way.

The expert mentioned that there are currently several potential options regarding the continuity of the TWR-West operation if it were to be conducted from TWR-C. In the event that the new remote TWR-W position in TWR-C fails in its entirety the following contingency options are acknowledged:

- **Option 1:** No TWR-W contingency positions, implying no Polderbaan traffic operations.
- **Option 2:** Create TWR-W* position(s) in TWR-E, with a limitation to 1+1 runway use.
- **Option 3:** Return to physical operations from TWR-W solely for the Polderbaan and manoeuvring area-West.
- **Option 4:** Facilitate TWR-W operations from a future Remote Tower Centre (or another setup).

Options two and 4 both require investments in new controller working positions including connections to the cameras needed for the TWR-W operations. While options one and three do not require additional investments, option three does necessitates maintaining the existing systems in TWR-W to be able to ensure that systems can be brought online directly if necessary.

5.3 RTO Specifications, Trade-offs and Considerations

The previous section already covered some insights into the benefits and challenges of the specific scenarios for LVNL. This section starts off with covering the more traditional RTO and multiple RTO considerations in 5.3.1. This is to further identify other applicable trade-offs in the specific scenarios for LVNL. The concept of RTO, as well as multiple RTO, is discussed in more detail to elaborate on their respective specifications. In subsection 5.3.2 the identified trade-offs for the specific scenarios are summarized and compared to the general trade-offs of more traditional multiple- and remote tower operations.

5.3.1 General RTO considerations and specifications

This subsections delves into the considerations and trade-offs connected to the traditional RTO variants, with the distinction between single-RTO and multiple-RTO. Additionally the specifications associated with these RTO forms are explained which allows for a comparison with the possible scenarios for handling TWR-west remotely. The trade-offs which have been recognized are collected through thorough desk research, SESAR JOINT UNDERTAKING & Irish Aviation Authority (2015) provided valuable results from tests done in Ireland with Cork and Shannon airport. Josefsson et al. (2018), was utilized in defining and further elaborate on the different trade-offs.

Standardized features for RTO
EASA has provided guidance material on remote aerodrome traffic services, in which the following basic features required for any remote tower position are declared:

- ***Visual representation*****:** Replacing the OTW view with a real-time representation of the airfield achieved through the use of cameras.
- ***Binocular function*****:** A controllable PTZ (pan, tilt & zoom) camera which acts as a replacement for the essential binoculars.

Keeping the basic features in mind, EASA also set up additional features to be able to enhance the situational awareness and effectiveness of RTO. The following features could be implemented when remotely operating more complex aerodromes:

- ***Additional camera angels*****:** Usage of extra camera angels on so called ‘hot spots’, often more complex areas like run- and taxiway crossings.
- ***Infrared or other optical sensors/cameras*****:** These can be utilized to improve visibility in low-light conditions, ensuring ATCOs can maintain visual contact with aerodrome users.
- ***PTZ-tracking*****:** Offering the option for PTZ cameras that have automatic tracking capabilities, offering a reduced the workload on ATCOs.
- ***Object tracking*****:** The use of specific tools to be able to track object on the airfield. This could involve identification labels for aircraft or ground personnel, either implemented through radar or visual tracking systems.
- ***Overlaid information*****:** Displaying relevant information on the visual representation can result in a lower look down time, increasing the situational awareness. These may include:
  - Outlining or marking of runways and taxiways.
  - Compass directions.
  - Relevant meteorological information including wind speed and direction.
  - Aeronautical information (e.g. NOTAM and SNOWTAM) containing critical information for aircrew regarding potential hazards.

- ***ATS surveillance*:** Utilization of air and/or ground radar systems in addition to the visual representation.

(European Union Aviation Safety Agency, 2019)

Next the key considerations for determining the required features is discussed, when switching from providing ATS from an OTW view to a remote position. The operational trade-offs are discussed separately in the paragraphs covering Single-RTO and Multiple-RTO.

Traffic volume, density and **complexity** are the main characteristics that effect the features needed to be able to transition to a RTO. With a big emphasis on the mix of aircraft as well, so the configuration of IFR (instrument flight rules), VFR (visual flight rules) and aircraft types. The higher the complexity of volume and density, the more supporting features a ATCO might need to be able to provide the same capacity as he would from a conventional ATC tower. Characteristics of the **aerodrome layout** play a crucial role in determining the required amount of cameras.

Single remote tower specifications & trade-offs

In this part, the consideration of providing ATS from a single remote position is done. Fürstenau et al. (2009) explores the concept of a Remote Tower Center (RTC) as an intermediate step towards a future "Virtual Airport Tower" without a physical tower building.

Single-RTO is envisioned to be workable for various types and sizes of airports, however the implementation can differ in several was as seen in possible features. Regardless of the specific variation, the common aspect is that ATS are provided to an aerodrome without direct visual observation from a traditional tower but rather through the use of technology. This transition from OTW view to a single remote position is illustrated in Figure 5.3.1.

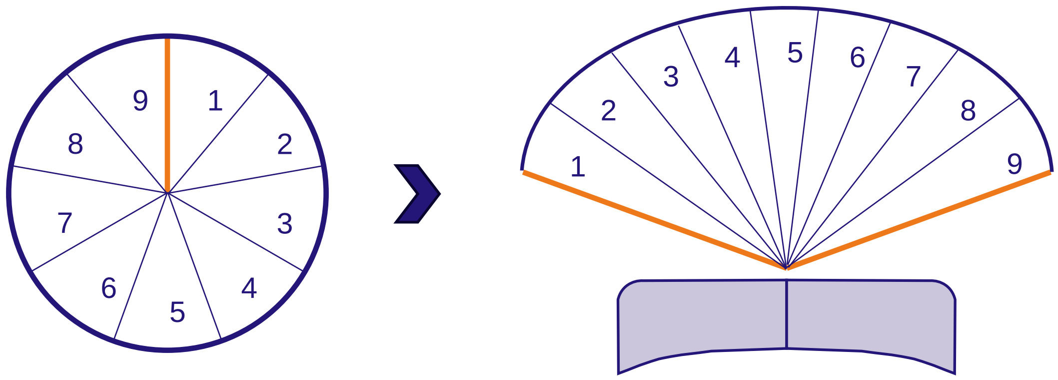


Figure 5.2
Transition of OTW view to single-RTO setup

Single-RTO offers potential benefits in terms of flexibility, cost-efficiency, and ATCO support. However these are paired with challenges related to service limitations, workload management, technological dependence and the introduction of video latency. On the following page a summarization of the main trade-offs related to single-RTO is made. Fürstenau et al. (2009)

Advantages:

- Air traffic control can be provided more flexibly, which can be more cost-efficient if well-organized. This also applies to the efficient use of personnel.
- Air traffic controllers can be supported in many different ways by means of the extra features, which are experienced as very effective by ATCOs.
- Tests (source: (SESAR JOINT UNDERTAKING & Irish Aviation Authority, 2015)) show that with single-RTO, safety is at least as safe as conventional tower air traffic control.

Disadvantages:

- Tests show that it is not always possible to provide the same service as with the conventional control tower. This is mainly the case when ATCOs have to deal with a more complex mix of traffic, a higher number of more unpredictable and difficult to recognize VFR traffic.
- It is very difficult to quantify the workload of air traffic controllers, but this is not a new problem and also occurs in the conventional control tower.
- Technological dependence, there is a new heavy dependence on the technology of the visual presentation and system redundancy. This introduces potential vulnerability when technical problems occur.

Having discussed the trade-offs for single-RTO, including the specifications. The next part will be concluding the specifications and trade-offs applicable to multiple-RTO.

Multiple remote tower specifications & trade-offs

Multiple remote tower is an extension of the Single-RTO concept, where a single remote tower position manages ATS for multiple airports simultaneously. This approach introduces several different considerations in equipment use, however the significant differences lie in the advantages and disadvantages. As these result from the significant complexity of managing air traffic across multiple aerodromes. The execution of multiple-RTO typically utilizes the same remote tower position as in single-RTO. However, to accommodate multiple airports, the visual presentation is divided either horizontally or vertically and even both in case of operating with over two airports. This is illustrated in Figures 5.2 and 5.3.

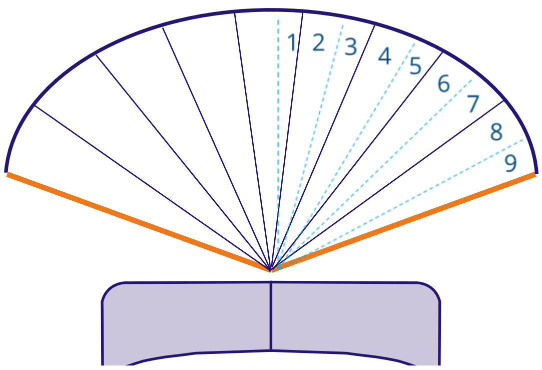


Figure 5.4
Multiple-RTO setup

Figure 5.3
NARSIM Multiple-RTO setup, displaying three airports
(Netherlands Aerospace Centre, 2021)

When utilizing multiple-RTO, it is common to be operating with two or more remote positions to be able to shift traffic volume based on workload. Figure 5.4 illustrates this principle in which an airport, represented by a control tower, can be distributed to a different remote position based on the current ATCO workload. By effectively coordinating these allocations, a significant distinction can be made between single-RTO and conventional tower control in terms of personnel cost savings.

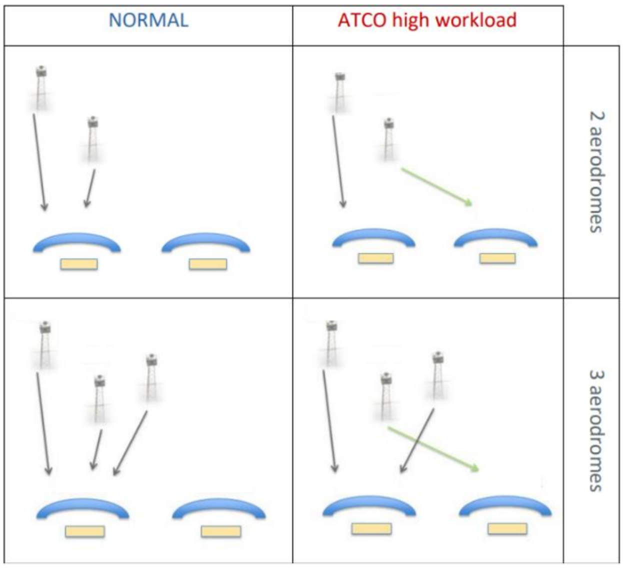


Figure 5.5
Interchangeability of workload between multiple-RTO positions

The advantages and disadvantages discussed for single-RTO are also applicable to multiple-RTO. However there are some additional trade-offs specific to multiple-RTO:

Advantages:

- Increased efficiency and personnel cost savings. Multiple-RTO allows for workload distribution across multiple remote positions. If operated well this results in greater personnel efficiency and cost savings compared to single-RTO.

Disadvantages:

- Complexity of workload management. Multiple-RTO introduces the challenge of allocating traffic load and being able to switch between airports across remote positions.
- Increased demands on communication and collaboration is also required, in order to maintain smooth workload management and coordinated handovers.
- Increased training is needed, ATCOs will need additional training to handle the complexity of

While multiple-RTO offers potential for great improvements in personnel efficiency, it also introduces new challenges related to workload management, communication and training needs for ATCOs (Hagl et al., 2019). These additional trade-offs need to be considered when evaluating the appropriateness of multiple-RTO.

5.3.2 Scenario specific considerations and specifications

In this subsection a summarization is made on the key specifications and trade-offs associated with LVNL's preferred scenario. It utilizes a two main screen setup for the PoC to display the external view, the so called visual representation. The PoC has the following specifications:

The two screens can display the following three systems:

- Remote Tower Camera System Polderbaan (visual representations)
- TWRSYS (a standard system used in the current situation)
- CCIS (a standard system used in the current situation)

The RTO camera system of the Polderbaan provides a panoramic view of the Polderbaan runway with a horizontal field of view. Ensuring excellent visibility of at least the following areas:

- Runway 18R/36L and Taxiway V (manoeuvring area of the Polderbaan runway)
- Airspace above Runway 18R/36L

Users will be able to zoom into the panoramic view to see relevant parts of the overall area in more detail. The system also provides configurable presets in addition to the manual zoom. Users have the possibility to utilize a PTZ camera highlighting a specific area, replacing the physical binoculars. The PTZ image is displayed in a picture in picture, this means a separate movable window inside the visual representation.

As discussed and shown in subsection 5.2.1, additional information windows are available for users inside the visual representation. Being able to display the following:

- Time
- Meteorological information:
    - QNH values, regarding air pressure which is used by pilots to determine altitude.
    - Current visibility in meters.
    - Wind direction and speed.
    - Runway visible range

Different images can be displayed as overlays on the visual representation, such as:

- Outlines of runways and taxi ways
- Radar labels:
    - Inbound/outbound/local/VFR flights.
    - Assigned gate

Analyzing trade-offs connected to the preferred scenario is essential for comparing it to the traditional RTO approaches. These trade-offs resulted from various simulation tests, interview insights, and the specifications of the current PoC. The trad-offs are separated in advantages and disadvantages in the same way as single-RTO and multiple-RTO are discussed.

Advantages:

Enhanced Flexibility and Cost-Efficiency.
Remote operations allow for more flexible use of ATCOs, potentially leading to personnel savings through better resource allocation. This can be particularly beneficial for TWR-W's lower traffic volume compared to the main control tower.

- Improved ATC Support. The new visual presentation can provide features like overlaid information and offer use of PTZ cameras. ATCOs indicate this being very beneficial for better traffic monitoring and increasing situational awareness.

- Maintained Safety Levels. Tests suggest that with a well-designed RTO solution, safety can be equivalent to or even exceed conventional tower operations during regular operations.

Disadvantages:

- Test Potential Service Limitations. Compared to the conventional control tower, the RTO setup might face limitations in handling complex traffic mixes, especially involving unpredictable VFR flights.

- Workload Management Challenges. While workload is difficult to quantify, the transition might require adjustments to ensure ATCs are not overloaded, especially during peak hours or unforeseen situations.

- Increased Technological Dependence. The RTO setup relies heavily on advanced camera systems and
overall system uptime. Redundancy measures are crucial to be able to mitigate the risks associated with technical failures.

- Video Latency. Even with upgraded camera systems, a slight video delay is unavoidable. This can be a concern in terms of safety. The synchronization necessitates this slight latency.

- Reduced Interaction with Local Traffic. The physical separation of controllers might have a

By acknowledging the trade-offs, Section 5.4 will provide the comparison of LVNL's preferred scenario against the traditional RTO methods, in this way suitable recommendations can be identified.

5.4 One Tower concept

This final content section delves into the details of LVNL's preferred scenario for remotely operating TWR-W at TWR-C. A comparison is done on the traditional RTO forms with LVNL's one tower concept, highlighting the shared aspects that inform the recommendations. Additionally in Subsection 5.4.2, the change of operation criteria are established, these are crucial for determining the feasibility of the transition.

5.4.1 Single- & Multiple-RTO comparison

This subsection compares aspects of single- & multiple-RTO with those of LVNL's desired one tower concept. The goal is to identify potential operational complexities and significant differences between the various approaches.

While most advantages achieved with traditional RTO approaches are also applicable for LVNL's preferred scenario, traditional RTO forms generally have different disadvantages. One key difference lies in the technological dependence, single- & multiple-RTO both rely entirely on technology, whereas LVNL's scenario allows for providing OTW air traffic control with some limitations in visibility but a very essential aspect in case of system disruption.

Workload management also differs. In multiple-RTO, the workload can be distributed across several remote tower positions. LVNL, on the other hand, can consider sharing workload with other ATCOs present in TWR-C. There is a great benefit in terms of an higher situational awareness due to their physical location. This is one mayor disadvantage of switching between airports in a multiple-RTO concept.

5.4.2 Change of operations criteria

With the proposed change in providing ATS, it is crucial to establish specific criteria to effectively measure the positive and potential negative impact of the change on operational performance. LVNL has identified some key principles that emphasize that any solution implemented regarding a change of ATS, should not negatively impart operational **safety**. At a minimum, safety levels must remain at a consistent rate as current standards, if possible the safety should be enhanced.

To ensure this, the general safety criteria and proxy classes should be utilised to maximum extend, as these provide measurable quantitative aspects. These criteria and proxy provide a framework for evaluating controller workload, situational awareness, heads-down-time and also the extend to which ATCOs can maintain control of certain traffic situations. This is especially essential when comparing to the current standard operations to ensure the change of operations not negatively affect the overall operations.

The second key principle identified is **efficiency**, with the goal of maintaining the current capacity of handling 108 inbound movements per hour during peak periods and 112 outbound movements per hour. The initial tests and simulations suggest that this is feasible under normal conditions. However, further testing is required in the final location of the remote tower position in TWR-C to confirm this. Nevertheless, no negative impact on efficiency is anticipated. This is because the same operational tasks will be performed from TWR-C, with the same performance indicator expectations as for operations from TWR-W.

The final principle is **environmental** impact, the proposed change should not lead to increased environmental burden. This aspect however is easy to ensure, as the same operational tasks will be performed from TWR-C, with the same performance indicator expectations as for operations from TWR-W.

An additional principle specific to the RTO solution for LVNL is in terms of personnel requirements, these should be considered, ensuring that roster coverage can be maintained by reducing the operational personnel load compared to the current situation. This is also one of the key motivations of implementing this change, if the effect result in negative ATCO utilization the change will not be continued.

6. Discussion

This research explored the potential for a Remote Tower solution (RTO) solution to simplify and improve Amsterdam Airport Schiphol's (AAS) air traffic control operations. With particular focus on the Polderbaan operation, which concludes runway 36L/18R and the Polderbaan manoeuvring area, currently managed by Tower-West (TWR-W). In this chapter the interpretation of the key finding in relation to supportive literature is done, concluding with answering the sub-questions.

Sub-question 1: '*What are the current operational practices and challenges within the ATC tower operations at the Polderbaan Runway?'*

To address this first sub-question, Chapter 4 delved into the initial requirements of TWR-W, to further elaborate on the current operational challenges the duel-tower operations entails. The current ATC tower operations at the Polderbaan Runway involve two distinct towers: TWR-C (the central main tower) and TWR-W (the tower specifically dedicated to managing Polderbaan operations). This dual-tower setup was implemented during the construction of the Polderbaan runway to address the limitations of TWR-C in terms of Distance-related limitations. TWR-C's location was not ideal for providing effective air traffic control (ATC) for the Polderbaan runway due to its distance from the runway.as well as Line of sight obstructions. Physical obstructions, such as buildings and other airport infrastructure, hindered TWR-C's view of the Polderbaan runway.

Despite the initial effectiveness of the dual-tower system, the current situation presents several challenges in terms of Inefficient personnel deployment. Managing two separate towers requires a larger workforce, leading to higher personnel costs and potentially straining staffing resources. Uneven workload distribution also occurs. The workload distribution between TWR-C and TWR-W is not always balanced, especially during peak traffic periods. This can lead to increased stress for controllers and potentially compromise safety. Communication and overall situational awareness is negatively impacted. Communication and lack of situational awareness between controllers in TWR-C and TWR-W can introduce delays, potentially affecting the efficiency or even safety of ATC operations.

The challenges identified in the current dual-tower system align with findings from other studies on ATC operations. Fürstenau et al. (2009) discussed the challenges of workload management in traditional ATC environments, highlighting the potential for uneven workload distribution and increased stress for controllers.

Sub-question 2: '*What insights and best practices from existing literature on Remote Tower Operations (RTO) can be collected to support LVNL's transition to a simplified tower concept?'*

Sub-question two dives into the existing RTO literature to identify valuable insights and best practices that can support LVNL's transition toward a simplified tower concept at the Polderbaan runway. The recognition of RTO is briefly discussed in Section 2.1 Defitions, however the deeper elaboration is provided Chapter 5. Remote Tower Operations Assessment. By exploring this literature, crucial information to support LVNL's decision-making process and potentially support a more effective RTO implementation. The literature highlights significant advancements in RTO technology, including high-definition camera systems, advanced display technology, and even the potential for augmented reality (AR) features (Teutsch et al., 2022). These advancements can provide controllers with a centralized, panoramic view of the Polderbaan airspace, eliminating the need for constant refocusing between the distant runway and physical displays at TWR-W. This can significantly reduce workload and improve situational awareness for controllers managing Polderbaan operations.

While the traditional forms of RTO offer promising benefits, safety remains are paramount. The literature, such as research by Hagl et al. (2019), emphasizes the importance of considering human-machine interface design and fatigue management protocols in multi-RTO environments. These insights can inform LVNL's planning and implementation strategy to ensure a safe transition to RTO at Polderbaan.

Sub-question 3: '*What are the operational, specifications, complexities and requirements of implementing a partial Remote Tower Operations (RTO) models, regarding the specific LVNL scenarios?'*

With the third sub-question, a deeper dive is provided into the specific complexities and requirements of implementing a RTO scenario for the Polderbaan runway was conducted. The acknowledged scenarios are described in Section 5.1, resulting in a preference for scenario three. This scenario utilizes a remote control setup located in the operational floor of TWR-C, to handle Polderbaan activities remotely. Section 5.2 includes a broad stakeholder perspective on the implementation of RTO for LVNL, following this Section 5.3 discussed the operational specifications, potential challenges, and crucial considerations for LVNL to navigate a successful RTO implementation.

The preferred scenario requires installation of high-definition cameras with pan-tilt-zoom capabilities at strategic locations around the Polderbaan runway to provide controllers at TWR-C with a clear and comprehensive view of the airspace. Implementing advanced display technology at TWR-C to create a centralized visualization system that integrates live camera feeds, radar data, and other relevant information for controllers.

The centralized operation is aimed to cope with the current operational complexities as identified with sub-question one, however implementing a RTO scenario at AAS presents certain complexities. The user interface should be carefully designed, ensuring user friendliness preventing information overload for controllers transitioning from a traditional tower environment to an RTO setup. Within the current concept, robust backup systems and procedures should be in provided to ensure uninterrupted and safe ATC operations in the event of an RTO system failure.

Sub-question4: '*What solutions are available for simplifying TWR operations at the Polderbaan Runway, and how effective are these solutions in addressing the identified challenges and enhancing operational efficiency?'*

The final sub-question focuses on further establishing the solutions for simplifying tower operations at the Polderbaan runway. To analyse the effectiveness of the preferred solution, concluding a partial RTO model specific to LVNL's needs, addressing the identified challenges and enhancing operational efficiency is required. Tackling the present challenges like inefficient personnel deployment. This research suggest that the preferred solution will reduce workforce, provide a better balanced workload and enhancing the situational awareness. The effectiveness of RTO in reducing workload and improving efficiency aligns with findings from SESAR JOINT UNDERTAKING & Irish Aviation Authority (2015).

While the principle of improved workload cannot be quantitatively measured, there are still observations to be made on the areas to be gained with RTO implementation. As Pinska et al. (2006) stated: "In the tower environment of large airports, the constant refocusing between the distant view and displays contributes to workload and increases head-down time." These aspects are minimized with the adoption of an RTO concept. Unlike traditional RTO, LVNL can retain centralized control of the main runway complex at TWR-C while simplifying operations for the geographically isolated Polderbaan runway.

In conclusion, this discussion section has explored the potential of a partial RTO model for the Polderbaan runway at AAS. By examining operational challenges, RTO best practices, and solution effectiveness, we gained a strong understanding of RTO's feasibility and potential benefits. The next chapter (Chapter 6) will provide a comprehensive conclusion, summarizing the key findings and addressing the main research question.

7. Conclusion

This research has explored the potential of Remote Tower Operations (RTO) to streamline and enhance air traffic control (ATC) management at Amsterdam Airport Schiphol (AAS), particularly for the Polderbaan runway. With LVNL's preferred scenario in mind, the analysis carefully examined the specifications and requirements for this operational shift.

Ensuring Safety, Efficiency, and Environmental Neutrality
The paramount principle throughout this investigation was ensuring that the transition has no detrimental impact on safety, efficiency, or the environment. The goal is to establish an operation that is not only as safe as the current one but also equally efficient, capable of handling the same maximum number of take-offs and landings.

Stakeholder analysis revealed no anticipated negative impacts on safety and efficiency based on available simulations and tests conducted with the concept version. However, these evaluations were conducted in an environment different from the proposed TWR-C setting and with normal conditions, necessitating further testing of the combined operation's workload. In terms of environmental impact, no significant deviations from current operations are expected. The same operational tasks will be performed from TWR-C, adhering to the same performance indicator expectations as for operations from TWR-W.

Quantifying Safety and Efficiency
To guarantee that efficiency and safety remain paramount even in non-nominal situations, the research employed safety criteria and proxies identified in collaboration with the safety expert. These safety proxies are crucial for quantifying these assessments of potential safety hazards as much as possible. The qualitative measures were utilized to evaluate controller workload, situation awareness, head-down time, and the extent to which operational staff maintains control of the traffic situation. Proxies related to controller capabilities were particularly valuable in making the safety perception of controllers more objective, translating subjective feelings into concrete data.

A comparative analysis of traditional RTO variants and LVNL's preferred scenario highlighted distinctive advantages. Notably, in the event of a complete remote tower system outage, LVNL's preferred scenario offers superior continuity. This stems from the ability to being able to provide out-the-window air traffic control from TWR-C, even though this is with limited visibility, it expels a complete operational shutdown.

This comprehensive conclusion serves as the definitive response to the primary research question established as the key issue to be addressed in this study:

What are the key complexities and workload division aspects within
the air traffic control (ATC) ground/tower operations, and how could LVNL simplify and improve their
operations through multiple- and remote tower operation aspects?

Based on the findings recommendations have been carefully selected in Chapter 8 Recommendations following this conclusion.

8. Recommendations

Drawing upon the insights gained from this research, this chapter presents a comprehensive set of recommendations for LVNL, providing both short-term and long-term considerations. These recommendations are tailored to address the specific needs and challenges faced by LVNL. They are aimed to guide the organization towards a successful implementation of Remote Tower Operations (RTO) at Amsterdam Airport Schiphol (AAS).

The recommendations are ordered in a short- to long-term sequence, providing the most relevant short-term considerations first.

First recommendation is to **conduct comprehensive simulations.** To bridge the knowledge gap regarding non-nominal situations, prioritize the execution of detailed simulations utilizing the concept version of the preferred RTO scenario. These simulations should closely replicate the operational environment anticipated in Toren-Centre (TWR-C), with a particular focus on non-nominal scenarios.

It is recommended to take full **leverage of the determined safety criteria and proxies**. To ensure objective and measurable assessments, make extensive use of safety proxies during simulations and subsequent evaluations. By comparing safety proxy data against nominal conditions, a clear understanding of safety performance under non-nominal situations can be established.

If simulations and evaluations demonstrate the effectiveness and safety of RTO under non-nominal conditions, consider **expanding the functionalities** of the remote tower system. The current concept version offers several features that can be leveraged to minimize controller workload, particularly in environments with diverse and high-volume traffic.

Moving on to a longer-term recommendation. Implement robust **backup and redundancy systems** within the RTO infrastructure to minimize downtime in case of partial failures. This may include backup servers, communication networks, and visualization displays. This should of course only be realised if and when the final decision is made to implement RTO for the Polderbaan runway.

Maybe one of the most important considerations to think about with every step within the process of implementation is, to keep continuously monitor and evaluate the performance of the RTO system against established metrics. Especially regarding the initial requirements of lowering the roster occupancy, if it is found that there is no progress or even regression in this area, then the considerations of RTO implementation should be reconsidered. Use of data-driven insights should be used to identify areas for improvement and make adjustments as needed.

The literature on RTO implementation consistently emphasizes the importance of careful planning, phased implementation, comprehensive training, and continuous evaluation. These recommendations align with best practices in the aviation industry for introducing new technologies and operational changes.

9. Reflection

This research on Remote Tower Operations has been quite a ride, I am pleased of what I've done, but I've also picked up some important lessons along the way.

One of the things I'm most happy about is getting a good handle on the different RTO options available. The understanding of pros and cons of each approach compared to the current two-tower setup, felt like a continuous puzzle. But in the end gave me a solid foundation to analyze LVNL's preferred scenario of using RTO from Tower-Centre.

Early on, I realized the importance of managing my reference materials better. It wasn't just about finding relevant sources, but also keeping track of them and how they would fit into the overall research picture. Looking back, it is an important lesson learned to utilize improved literature management.

There were some moments where I got stuck on specific issues. One of the biggest things I learned was not to avoid getting stuck for too long on certain topics early on. Sometimes, stepping away and focusing on other parts of the research gave me a new perspective. It allowed me to make progress on other areas that might even helped me solve the initial problem.

This research also made me realize the importance of efficient content and version management. Developing a suitable system for organizing my findings would have allowed me to build the different chapters of the report more smoothly.

Overall, this research has been a valuable learning experience. I've developed a more systematic approach to research, and discovered helpful tools for managing my workflow. These newly acquired skills will definitely be utilized in my future challenges.

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Appendix A: Figure 9.1 – Noise pollution map

Figure 9.1 shows the noise pollution map of all runways combined. Demonstrated in red are the direct noise pollution results from the Polderbaan runway, it is clearly visible how the main pollution area lies in between densely populated areas, ultimately limiting the nuisance.

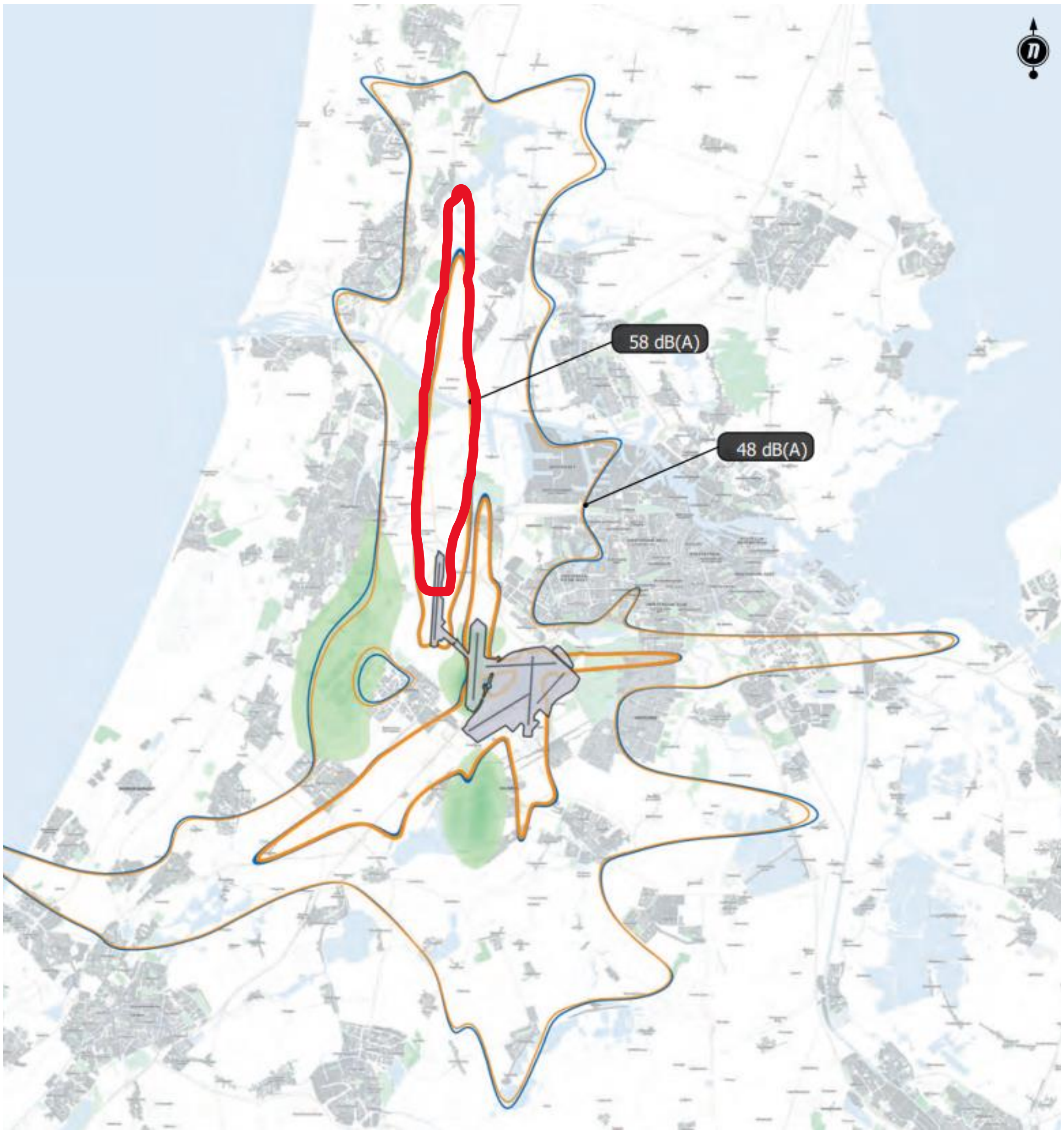

Figure 9.1

Noise pollution map

(Ministerie van Infrastructuur en Waterstaat, 2022)

Appendix B: Interview Topics and Questions

To gather in-depth insights relevant for this research, semi-structured interviews with open-ended questions were conducted with different representatives of LVNL that play crucial roles in devolving the remote tower concept for the TWR-W operations. The key findings resulted from these interviews are summarized and discussed per stakeholder in subsection 5.2.

Role and perspective of S&I department in transitioning from two towers to one

Key topics: Assessing and identifying risks, establishing minimum requirements, evaluating capacity and performance and defining continuity minima, all in terms of technological advancements.

Questions for S&I representative:

- What are ongoing limitations and risks associated with the current TWR-W operations?
- What are newly introduced limitations and risks that arise from the proposed change of operations?
- Are there any specific minimum requirements for this particular change of operations?
- What are the general minimum requirements for such an operational change?
- Are there any clear capacity results from the trials conducted with the current ‘PoC’?
- What continuity requirements are set respectively for the ‘PoC’ phase and potential operational implementation?

Role and perspective of ATCOs in transitioning from two towers to one

Key topics: assessing ease of use, user interface opinions, evaluation of innovations, system workability and evaluating capacity and performance, aimed to acknowledge the ATCOs experience and perspectives.

Conversations with ATCOs did not require additional questions to be set up prior to the interviews. These key topics were thoroughly discussed covering relevant topics and discussion resulted in follow-up questions regarding certain situations.

Role and perspective of ORM department in transitioning from two towers to one

Key topics: assessing and identifying risks, requirements and compliance, coordination and performance evaluation and separation standards, all in the concept of assessing safety.

Questions for ORM representative:

- What specific guidelines, risk analyses or models are used for such a change of operations?
- What specific safety requirements must be met before and after the potential implementation of RTO for TWR-W?

- What safety standard and regulations apply to a change of operations of this nature?
- Have there been any analyses to assess whether the conditions have improved of decreased since the implementation of TWR-W in 2003?
- What safety criteria might be used to measure the effectiveness of the change of operations?
- Are the same separation standards (e.g. 2.5nm or 4nm at night) applied with testing and assessing safety risks?