"Reconfiguration of ATC Tower working positions as an adaptive strategy to achieve resilient performance"

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Abstract

Air traffic control (ATC) is a safety-critical activity in which practitioners must continuously navigate uncertainty, trade-offs, and operational variability. In such environments, resilience emerges not from strict adherence to procedures alone but from the adaptive strategies that air traffic controllers employ to sustain safe performance. One striking property of air traffic control is that controllers are the technology, they don't just watch the technology (Weick, 1987). This thesis examines the reconfiguration of working positions in the Gdańsk Tower as an adaptive strategy that enables ATC teams to manage complexity, redistribute workload, and preserve system stability in dynamic conditions. Using a qualitative case study approach, the research combines document analysis with semi-structured interviews grounded in the Critical Decision Method (CDM) and narrative storytelling.

The findings reveal that reconfiguration—through the merging or splitting of Aerodrome Control (ADC), Ground Control (GND) and Tower Assistant (AS TWR) positions—is the key strategy to maintain resilient performance. Controllers continuously assess complexity, workload drivers, and performance variability, drawing on anticipation, experience-based judgement, and tacit knowledge to make context-based decisions. Team dynamics, cultural norms, and trust strongly influence when and how

reconfiguration occurs, while informal coordination and improvisation frequently compensate for the limitations of work-as-prescribed (WAP). The analysis shows that work-as-done (WAD) sometimes diverges from formal procedures, reflecting the reality that resilient performance depends on ongoing negotiation between procedural structure and contextual demands.

The study concludes that reconfiguration is a manifestation of resilient performance rather than an isolated action. It is embedded in a joint cognitive system where individuals, technologies, and organisational expectations interact to manage the margins of air operation. Theoretically, the findings contribute to resilience engineering by illustrating how graceful extensibility and adaptive strategies are enacted in real-world ATC practice. Practically, the thesis highlights the need to incorporate reconfiguration into training, strengthen team-based learning mechanisms, and ensure that organisational narratives reflect the complexity of everyday work. Recommendations for future research include exploring adaptive strategies across units and examining how different pressures shape safety-critical decision-making.

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Contents

List of Figures and Tables

Abbreviations & Acronyms

ACC – Area Control Centre

ADC – Air/Aerodrome Controller

ANSP – Air Navigation Service Provider

APP – Approach Control

ARR – Arrivals

ASS - Assessor

AS TWR – Tower Assistant

ATIS – Automatic Terminal Information Service

ATC – Air Traffic Control

ATCO – Air Traffic Control Officer

ATFCM – Air Traffic Flow and Capacity Management

ATM – Air Traffic Management

ATOS – Airport Manoeuvring Area Surveillance System

ATS – Air Traffic Services

CDM- Critical Decision Making

CEO – Chief Executive Officer

CHMI – Collaboration Human Machine Interface

CO - Coordinator

CTR – Control Zone

DCL- Departure Clearance

DEP – Departures

DIR- Director

EC- Executive Controller

EFES – Electronic Flight Strips

EUROCONTROL – European Organisation for the Safety or Air Navigation

FDD – Flight Data Display

FIS – Flight Information Service

FMP – Flow Management Position

GDPR- General Data Protection Regulation

GND – Ground Controller

HFSS – Human Factors and System Safety

ICAO – International Civil Aviation Organisation

IFR – Instrument Flight Rules

JCS – Joint Cognitive System

LoA – Letter of Agreement

LPO – Lone Person Operations

LSE – Local Safety Expert

LVP – Low Visibility Procedures

MET – Meteorological

NDM – Naturalistic Decision Making

NOTAM – Notice To Airman

OJTI – On-the-job-training Instructor

OPS ROOM – Operations Room

PANSA- Polish Air Navigation Service Provider

PansaUTM – Operational Drone Traffic Management System

PC- Planning Controller

RE – Resilience Engineering

REST – Handover procedure: Restrictions, Equipment, Situation and Traffic

RWY - Runway

SC – Senior Controller

SDD – Situation Data Display

SIM – Simulator

SMS – Safety Management System

SOP – Standard Operating Procedure

SPO – Single Person Operations

TMA -Terminal Area around a group of airports

TRM – Team Resource Management

WAD – work-as-done

WADi – work-as-disclosed

WAI – work-as-imagined

WAP – work-as-prescribed

VCS – Voice Communication System

VFR – Visual Flights Rules

VMC – Visual Meteorological Conditions

Introduction

Broader Topic & Relevance

Air traffic control (ATC) teams operate in dynamic, uncertain contexts, where decisions are made under time pressure with uncertainty. ATC is a safety-critical element of Air Traffic Management (ATM) – the system that ensures the safe and efficient flow of aircraft. As air traffic increases in volume and complexity, it becomes crucial to understand how controllers safely negotiate boundaries of cognitive work by combining standardisation, interpretive work, and improvisation, thus supplying the resilience, reliability, and redundancy essential to the system (Vaughan, 2021).

One winter day, I was working the morning shift at the Tower, at the ground position when a heavy snowstorm hit the airport. Outside the window, visibility was nearly zero, and there were multiple aircraft queued for de-icing, pushback, and taxiing, with numerous airport services working across the manoeuvring area—clearing runway and taxiways, checking conditions, and assisting pilots.

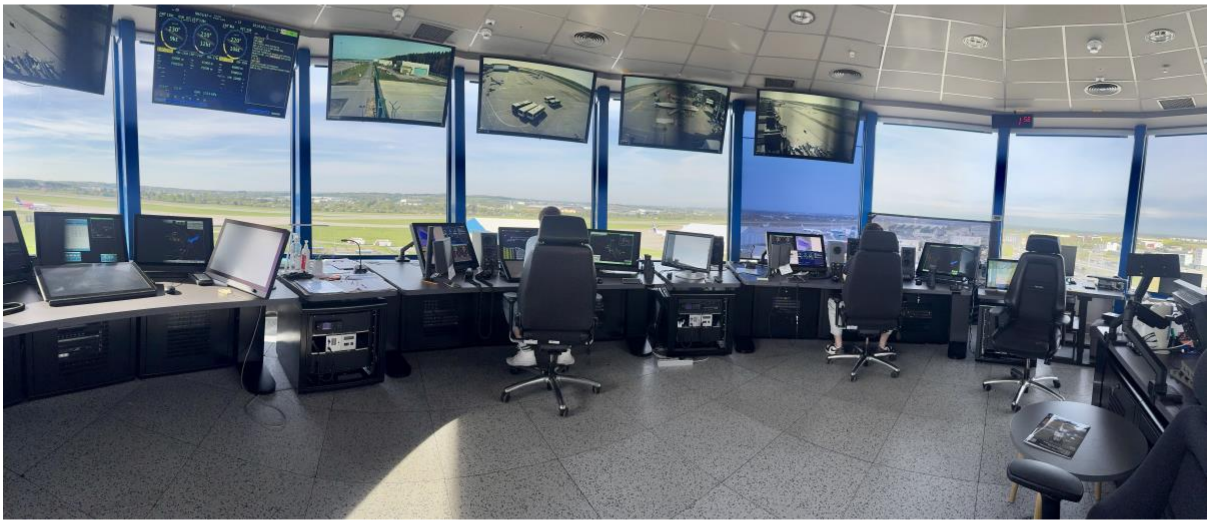
Then, the time came to close the ground position due to time-on-position limitations and staff shortages during COVID-19. However, it was almost impossible to do so. I stayed an extra 15-20 minutes to unload the traffic volume, ensuring a safe transfer to the Air Controller. Was this non-compliance, or was it an act of adaptation?

The analytical scope that has been selected for this research is the reconfiguration of working positions in Gdańsk Control Tower. This is representative of an adaptive strategy that involves dynamically adjusting roles, responsibilities, and coordination patterns among controllers by joining and splitting working positions to respond to operational demands, workload fluctuations, or emergent crises. Both failure to adapt and successful (even partially) adaptations are all key pieces of information in unravelling the complexities of everyday work in dynamic environments (Rankin, 2013).

Gdańsk Tower is part of the local air traffic service unit, which also includes Approach Control and Flight Information Service. Gdańsk Tower provides air traffic control, flight information and emergency services for all departures and arrivals to Gdańsk Lech Walesa airport, which operates 24/7. The airport is the third busiest in Poland in terms of traffic volume, with a total of 56,839 movements (departures and landings) and approximately 6.7 million passengers in 2024 (official data presented by Gdańsk Airport). Figure 1 presents my photograph taken in April 2025.

Figure 1

Gdańsk Tower Operating Room with three operating positions



The operational positions within the unit are Air/Aerodrome Controller (ADC) in the centre of the picture, Ground Controller (GND) on the right and Tower Assistant (AS TWR) on the left. A Senior Controller (SC) position is initially planned to be introduced next year (at the back of the operating room). ADC is mainly responsible for managing aircraft movements within the runway and the airspace around the aerodrome, ensuring the safety and separation of aircraft. GND's primary task is to safely and efficiently manage aircraft movement on the ground at an airport, including taxiways and apron areas. AS TWR is a supportive position for both ADC and GND. Their tasks include handling ground communication radio, managing flight data (including DCL – Departure Clearance – data messages exchange), and coordinating with adjacent air traffic service units.

Research within the field of Human Factors and System Safety (HFSS) has examined how practitioners in safety critical domains adapt to manage complexity and uncertainty. Exploring how controllers perceive, enact, and interpret reconfiguration offers a view of team dynamics, coordination, and shared mental models. The emphasis is on coordination in terms of a joint activity as an extended set of behaviours that are carried out by an ensemble of people who are coordinating with each other (Klein et al., 2005), which goes beyond ATC coordination as a purely operational task. Controllers' local improvisation consists of adjusting their work, decisions, and actions in response to the multiple intersecting sociotechnical system effects. Interpretive work is what controllers do that technology simply can't replace (Vaughan, 2021).

The focus of the research is on understanding work-as-done (WAD) from the perspective of practitioners, where performance variability and approximate adjustments in complex socio-technical systems make necessary, inevitable, useful, and the reason why everyday work is safe and efficient (Woltjer et al., 2015). Examining WAD requires comparing it with work-as-imagined (WAI) which, at a basic level, is the work that people imagine takes place, and it may overlook variability, contextual constraints, and adaptation in real settings. Often, the term is used to describe imagination of the work that others do (now or in the past or future). It may also, however, refer to the work that people imagine that they do (or did, or will do) (Shorrock, 2020a). By analysing the relationship between WAD and WAI, this study seeks to reveal how resilience in air traffic control emerges through practitioners' adaptive strategies that bridge the gap between formalised expectations and operational reality.

Work-as-prescribed (WAP) is the formalisation, specification and design of work. It is the work that people 'should do', especially according to policies, procedures, rules, and so on (Shorrock, 2020c). Moreover, documents construct social reality and version of events (Blaxter et al., 2010) – in this research they set a sense for reconfiguration and adaptation, however they cannot be taken at face value and need to be critically assessed for research purposes. (Blaxter et al., 2010).

Controllers are in and of a system of many boundaries. Their main task is to integrate interpretive work, improvise, and follow standardised rules to keep airplanes from colliding (Vaughan, 2021). Standard Operating Procedures (SOPs) and Letter of Agreements (LoAs) contextualise these strategies within formal organizational guidelines, and present WAP.

Hence my choice of research question:

How does the reconfiguration of tower working positions serve as an adaptive strategy to enhance resilient performance in Gdańsk Tower ATC teams?

Literature review

Air traffic control (ATC) is a safety critical activity where resilient performance contributes to sustaining and fulfilling the objective of Air Traffic Services (ATS) (ICAO, 2018). This literature review explores the key themes surrounding the resilience of air traffic controllers, focusing on definitions of resilience, ATM environment and adaptation.

Concept of resilience

It can be argued that in the context of ATC, resilient performance refers to the ability of the system to withstand, adapt to, and cope with surprises and subsequently recover to a stable system state, performance variability and challenges (Foster et al., 2019; Woltjer and Laursen, 2021, Hollnagel et al., 2022). To understand how failure sometimes happens it is necessary to first understand how people learn and adapt to create safety in a world fraught with gaps, hazards, trade-offs, and multiple goals (Hollnagel et al., 2006). This perspective is emphasized by the importance of adaptation in high-reliability organizations, including ATC (Weick et al., 1999).

Woods et al. (2013) presented the stress-strain model was presented as a framework for analysis to answer the key question – how does a system stretch to handle surprises. The framework specifies three forms of adaptive capacity: generate, mobilize and deploy to be called into action when events challenge boundaries (Woods et al., 2013). Extra adaptive capacity in terms of reconfiguration tower working positions include generating, mobilizing and deploying additional, although limited resources (operational personnel) to handle challenges and surprises.

Moreover, Woods (2015) defines resilience as graceful extensibility, which is relevant to ATC in everyday operations. This perspective positions resilience as the opposite of brittleness, or how to extend adaptive capacity in the face of surprise (Woods, 2015). Woods (2018) further developed the theory of graceful extensibility, introducing basic rules that govern adaptive systems. The theory explains the contrast between successful and unsuccessful cases of sustained adaptability for systems that serve human purposes (Woods, 2018).

ATM Environment

The foundation of this research is primarily informed by "Dead Reckoning", which offers an in-depth cogno-ethnographic, sociological, and historical analysis of an air traffic control environment (Vaughan, 2021). Vaughan's detailed examination elucidates the dynamics of daily ATC practice, encompassing the complex interplay of decision-making, organisational pressures, and interpersonal interactions. Her cogno-ethnographic approach provides critical insights into how controllers develop adaptive strategies in response to the high-stress environment. Through the analysis of specific case studies, including the events of September 11, Vaughan illustrates how controllers respond to crises, adapt to rapidly evolving situations, and learn from experience—highlighting the concepts of resilience and adaptive capacity within the system. Despite the richness of her analysis, it is important to acknowledge that Vaughan's study pertains primarily to the US context, which differs from the European environment that this research addresses.

Foster et al. (2021) presents a model of adaptation in order to understand the unexpected and unpredicted effects of change and uncovers the adaptation that has already existed within normal work. These findings reinforce the role of humans in coping with changing contexts, to appreciate the signals of risk and respond with following strategies and practices (Foster et al., 2021). The next level of adaptation happens when individuals work as a group to communicate, cooperate, and build consensus to resolve issues through teamwork (Foster et al., 2021). This is consistent with Woods (2015), who argues that resilience concerns the ability to recognise and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies and coordination. The human factors are reported to play a valuable role in examining adaptation and can aid in organising an exploration of adaptation throughout the organisational hierarchy, including at the team level (Foster et al., 2023).

A particularly comprehensive contribution is also provided by Foster (2025) in his doctoral thesis "Adaptation as a Source of Safety in Complex Sociotechnical Systems", which offers an extensive theoretical and empirical examination of adaptation in UK air traffic control. Grounded in resilience engineering, the thesis conceptualises adaptation as a core mechanism in everyday operations. The author develops a multi-factor model of adaptation that captures how individuals, teams, and organisations adjust performance in real time to manage uncertainty, competing goals, and system constraints, emphasising that such adaptations are often informal and "hidden in plain sight" during normal work (Foster, 2025).

Malakis et al. (2021) investigate the concept of leverage points—key events that catalyse the development of innovative solutions to operational challenges. The research emphasizes controllers' behaviours and the processes involved in establishing, evaluating, and refining operational courses of action (Malakis & Kontogiannis, 2021). Although their focus centres primarily on Approach Control (APP) in simulator settings, these insights are relevant to the current study's interest in controllers' adaptive behaviours during routine operations, particularly in understanding decision-making processes within Tower environment.

Another pertinent contribution is the body of work by Woltjer et al. (2013, 2015), which articulates resilience principles within the ATM context. The authors characterise resilience as the adaptive capacity of the ATM system to adjust its functioning proactively or reactively in the face of disturbances or change (Woltjer et al., 2013). Building on this foundation, Woltjer et al. (2015) further elaborate these principles through a focus on work-as-done, highlighting how everyday operational practices underpin system safety. These studies relate to the concept of reconfiguration and inform understanding of how operational positions and roles are adapted in response to dynamic conditions.

A Lund University Master's thesis extends this discourse by examining mechanisms of uncertainty management and recovery in sociotechnical systems following operational failures (Lowth, 2024). While focused on degraded states, the study highlights how safety emerges through practitioners' adaptive actions offering insights relevant to understanding resilience mechanisms also present in normal operations. The present research differs in focus by examining reconfiguration during everyday tower operations rather than solely during system breakdown.

Bie (2021) researched ATCOs' "choices" when "splitting" sectors in enroute ATC operations. Splitting is a term from the ATCOs natural language for reconfiguring operational positions - bandboxing and splitting. In Bie's research the object was reconfiguration in Area Control Centre (ACC). There are significant differences between reconfigurations in Towers and ACC operational contexts. As Bie explains, reconfiguration of en-route sectors is an essential facet of strategic and tactical strategies for managing capacity and demand across the European ATM network managed by the Network Manager. ACC sector teams are constituted as two person teams with specific functions and responsibilities that provide the control function on an ATC sector: Executive and Planning Controllers. These positions can be duplicated during sectors splitting. In contrast, tower reconfiguration redistributes different task sets among the available personnel (controllers and assistants) rather than multiplying identical roles.

However, the ATCOs professional identity is a dominant element in the "choice" to split sectors in tower positions as it is on ACC sectors. The reasons for this, as derived in Bie's (2021) research are "feel sharp", "knock rust", and "fun" in the Copenhagen context. These three notions sustain the confidence that ATCOs, both in Tower's and ACC's, hold that underpins competence.

Finally, a noteworthy case study investigates how controllers managed to compensate for the missing information and keep traffic flowing during a computer breakdown, although with reduced capacity, while the technical staff managed to restart the system. ATC work is often quiet and hardly invisible, this approach focuses on learning from situations where things go well and where "nothing" seems to happen (Hollnagel et al., 2022).

Adaptation

All publications mentioned above explore adaptive capacity in overlapping and complementary ways that still yields diverse interpretations. Adaptation is viewed as a key factor for safety in complex sociotechnical systems and is pertinent at all levels of the organizational hierarchy—individual, team, and organisation (Foster et al., 2020). Another study on team adaptation highlights the necessity for managing complexity in safety-critical sociotechnical systems and presents valuable taxonomy of adaptation strategies (Malakis & Kontogiannis, 2023).

An important aspect of adaptation is coordination as a joint activity principally between a human and a machine or other artefact and embracing teams, which is related to *common ground* – pertinent knowledge, beliefs and assumptions that are shared among involved parties (Klein et al., 2005). It is important in operations rooms (ops rooms), where common ground permits controllers to use abbreviated forms of communication and still be reasonably confident that potentially ambiguous messages and signals will be understood (Klein et al., 2005).

Moreover, coordination is a complex choreography that requires rapid, smooth, and synchronised efforts across multiple actors. It also incurs, often hidden, cognitive costs including the mental effort and load related to the additional work of enabling smooth synchronisation across multiparty groupings in high tempo scenarios (Maguire, 2020).

From another perspective, adaptation begins with problem detection, when practitioners recognise that their current approach to handling a situation is not progressing effectively (Malakis & Kontogiannis, 2023). The authors offer valuable insights into key elements such as decision-making, sense-making, the common operating picture, transfer of control, managing changes, and the planning-doing-checking cycle (Malakis & Kontogiannis, 2023). These concepts support a structured understanding of how controllers operate.

Further insights are provided by Rankin's research, where she explores how adaptive abilities can be identified and analysed within complex work environments across various domains. Her study presents a framework to analyse adaptive behaviour in everyday work where systems are working near the margins of safety (Rankin et al., 2014), a condition highly relevant to air traffic control.

For any adaptive systems, events present themselves as a context for adaptation. A resilient system is an adaptive system that protects its core goals (e.g., safety through separation of aircraft in ATC), sometimes by sacrificing and replacing other goals that are instrumental to the core goals (Lundberg & Johansson, 2015).

Lastly, Hindsight Issue 34, a publication by EUROCONTROL, discusses resilience and underscores the importance of multiple perspectives when handling surprises, noting that there is often tension among these viewpoints (Shorrock, 2022).

In summary, the literature consistently frames air traffic control as a complex sociotechnical system in which safety emerges from adaptive performance rather than strict procedural compliance alone. Across resilience engineering, and ATM-specific research, a shared emphasis is placed on performance variability, surprise, coordination, and adaptive capacity as defining features of everyday work. Presented studies collectively demonstrate that controllers continuously interpret, adjust, and coordinate their actions to manage uncertainty and operational trade-offs. While prior research has provided valuable conceptual models and empirical insights, there remains a space for focused research on team-level adaptation during normal tower operations. This gap provides the foundation for the present study, which seeks to examine how air traffic controller teams enact adaptive strategies to sustain resilient performance in everyday work.

Methodology

This chapter outlines the theoretical perspective and philosophical position, as well as the qualitative approach, methodology and research design adopted in this study.

Considering the research question's focus on adaptation and operational contexts, a case study methodology has been chosen, which is one of the most commonly used methodologies in social research (Priya, 2021). It was selected for the research, as it is concerned with collecting and analysing information in many forms, chiefly non-numeric (Blaxter et al., 2010), and understanding of how teams function under pressure and navigate uncertainty.

Yin defines case studies as an empirical inquiry which investigates a phenomenon in its real-life context. It is not purely a method of data collection, rather is a research strategy or design to study a social unit (Yin, 2009). Given the complexity and variability of operational air traffic control environments, a case study allows for a detailed examination of specific teams, their practices, and the contexts in which they operate. This methodology can capture the nuances of team dynamics, communication, and decision-making processes. It typically employs multiple sources of evidence, such as interviews, observations, and document analysis (Priya, 2021), which can lead to a rich understanding of the subject.

Yin puts forth that a case study can be descriptive, explanatory or exploratory (Yin, 2009). The explanatory type is useful for the research, as this study looks for factors to explain a particular phenomenon. The primary focus on such a case study is to explain "why" and "how" certain conditions come into being, that is, why certain sequence of events occur or do not occur (Priya, 2021).

The case study, which is reconfiguration of operational positions at Gdańsk Tower in this research, allows for an exploration of real-world scenarios, capturing the interrelated factors that influence decision-making. Previous studies highlight the effectiveness of case studies in understanding complex teamwork dynamics in high-risk professions (Flin et al., 2003; Foster et al., 2021).

Epistemology and theoretical perspective

For the research project investigating the adaptive strategy of air traffic controller teams and their navigation of uncertainty and complexity, constructionism as an epistemology and interpretivism as a theoretical perspective are appropriate.

Constructionism posits that knowledge is actively constructed rather than passively received, emphasizing the role of social contexts and interactions in shaping understanding. There is no objective truth waiting for us to discover it. Truth, or meaning, comes into existence in and out of our engagement with realities in our world. There is no meaning without the mind. Meaning is not discovered, but constructed (Crotty, 2020). Because of its focus on the real world, this perspective is well-suited for examining how air traffic controllers collectively adapt amidst the complexities of their work environment – but having in mind that different people may construct meaning in different ways, even in relation to the same event/occurrence. The truth cannot be easily categorised as either objective or subjective (Crotty, 2020). As a consequence, the meaning can differ depending on the controller's experience and their role in a team.

The philosophical stance impacts the chosen methodology and provides the context for the process involved and a basis for its logic and criteria. I chose interpretivism because it emerged in order to understand and explain human and social reality (Crotty, 2020), which is useful for this research. It focuses on the subjective experiences and meanings that individuals attribute to their roles and interactions. It advocates for understanding human behaviour from the participants' viewpoints rather than imposing external frameworks. This approach is essential for exploring the ways in which air traffic controllers perceive and respond to challenges, allowing for the analysis of their lived experiences and the social dynamics within teams.

Methods

The research combines qualitative data from semi-structured interviews, complemented by storytelling, and document analysis. The primary data will include narratives and insights from air traffic controllers about their adaptive strategies, performance challenges, reconfiguration practices, and storytelling on their natural work environment. Additionally, SOPs (Standard Operating Procedures) and LoA (Letter of Agreement) will provide contextual background on operational procedures and reconfiguration options.

Document analysis

For the purpose of the research, Standard Operating Procedures (SOPs) of Gdańsk Tower, Gdańsk Approach, Gdańsk FIS and Letter of Agreement (LoA) between Gdańsk Tower and Gdańsk Approach are analysed to provide procedural framework for the reconfiguration.

Critical Decision Method – a structured approach to eliciting knowledge and storytelling

Critical Decision Making (CDM) is a mean of eliciting knowledge for this research question will provide the flexibility needed to explore specific experiences and insights related to the reconfiguration of working positions and adaptive strategies, which are central to my research question. Allowing participants to elaborate on their roles, challenges, and strategies in a narrative format has yielded richer data. Especially where informants were able to share their stories.

CDM- Critical Decision Method was used, that is grounded in interviews with proficient decision makers and builds on critical incident techniques by using a set of cognitive probes to determine the bases for situation assessment and decision-making during nonroutine incidents (Klein et al., 1989). It is a retrospective cognitive task analysis interview technique and an approach to analysing the data.

The technique relies on participants recalling a particular memorable incident they have experienced in the course of their work. Participants are probed to identify the decisions that they made and how these decisions were made (Wong et al., 1997). This method is particularly useful in terms of the discussion on an event related to reconfiguration, however there are some challenges. Potential limitations are: biases for schemata activation, complexity in identifying the cognitive process, and dependence on participant recall and verbal reports, therefore it is important to understand operators' roles in decision-making, especially in the context of aviation where training procedures and SOPs offer a limited set of choices (Plant & Stanton, 2013). People interpret past events using their mental 'templates' (schemata), where much decision making is automatic or intuitive. This method relies on what participants can remember or describe.

The full CDM procedure comprises six sequential steps: preparation, incident selection, incident recall, incident retelling, timeline verification and decision point identification, along with progressive deepening (Hoffman et al., 1998). This serves as a comprehensive framework for interviews. While this full set of steps provides a robust foundation, it will be adapted to develop a tailored CDM protocol aligned with the research objectives.

The focus of the study is on the controllers of Gdańsk Tower. During the research, eight semi-structured interviews were conducted to gather data on how air traffic controllers employ reconfiguration as an adaptive strategy in their daily operations. Most interviews were conducted in person, with one interview taking place online. The participants were purposefully selected to ensure diversity within the sample (different roles and experience).

The group comprised three females and five males, with professional experience ranging from seven months to thirty-one years in air traffic control. All participants were affiliated with the Gdańsk Tower unit and represented a range of roles, including two former heads of the unit, the current head and deputy head, four on-the-job instructors (OJTI), three assessors (ASS), a PEER representative, an occurrence investigator, and a local safety expert (LSE). Interviews were conducted in July and August 2025 and the average duration of the interviews was 50 minutes.

While undertaking the interviews additional stories came out. Storytelling is an integral part of the controllers' environment, as they share their experiences during shifts, handovers, and refresher/TRM sessions. It provides a means to address risks—similar to the stories shared by technicians (Sanne, 2008), and to learn from incidents and everyday work, where they get things done. Moreover, storytelling may be an especially effective way to communicate ambiguous meanings (like "adaptation" or "resilience" for some controllers), because people expect stories to be elusive and they often accept that their initial interpretation may be incorrect or partial, and people often respond to a story by telling one of their own (Polletta et al., 2011).

The use of a focus group was considered; however, this approach was not pursued due to time and staffing constraints—particularly during the summer peak-traffic period—which would have limited the feasibility of assembling participants in a single location. Consequently, the method was excluded to avoid potential restrictions that could adversely affect the data collection process.

This combination of methods allows for an understanding of how controllers adapt in real operational settings in practical terms, which is essential given the complexity and variability inherent in air traffic management.

Transcription & Analysis technique

The analytical strategy for the research was inductive and involved qualitative thematic analysis supported by a comparative approach. Qualitative inquiry asks how the world looks through the eyes of the person(s) doing the work, and the research interprets the ways in which people make sense of their work experiences be examining the meanings and categories people use and construct in light of their own situations (Dekker & Nyce, 2004).

Analysis aimed to unpack informants' meanings and categories (Dekker & Nyce, 2004). Initially, all transcripts and gathered data were transcribed and interpreted inductively, identifying emergent themes. Thematic analysis, proposed by Braun and Clarke (2022), states recommended steps including: familiarizing with data, generating initial codes, searching for themes, defining and naming themes and producing the report of the analysis (Braun & Clarke, 2022).

The themes were mapped against organisational procedures outlined in documents to assess alignment or divergence. An analytical framework based on RE principles was utilised to guide the interpretation of both interviews data and documents analysis. Patterns related to adaptive strategies, coordination, and reconfiguration were synthesised to develop a conceptual understanding of operational resilience. The data analysis employed open and secondary coding techniques to systematically identify, refine, and develop emergent themes from the dataset. The analysis was iterative, allowing for refinement of themes as new insights emerge, ultimately enabling a rich interpretation of how adaptive work supports safety and efficiency in air traffic control.

The interviews were recorded using a mobile device, and the transcriptions were generated through specialised transcription software (clipto) before being carefully reviewed for accuracy and completeness.

Ethics and Limitations

The data collection process (interviews) was discussed with the CEO of PANSA and her approval for the research was received, enabling public presentation of the data that has been collected. Clear consent procedures for participants in interviews have been also included in a dedicated form (Appendix A).

Furthermore, it is explicitly stated that this research is distinct from my responsibilities related to my roles as the head of safety investigation and controller at the same tower, and that the data collected will not be utilised for any other purpose.

As I am professionally embedded in the same operational environment as the participants, this proximity might have influenced both the data collection and interpretation processes. Familiarity facilitated openness and shared understanding of operational language and context, but it also carried a risk of implicit assumptions, selective interpretation, or socially desirable responses. To mitigate these risks, the study followed a structured interview protocol, encouraged participants to elaborate on concrete events rather than general opinions, and grounded the analysis in transcribed data linked to theoretical framework rather than personal experience.

The following chapter presents the findings, examining the data and knowledge elicited through the study and organising them into the categories that emerged from the analysis.

Findings

Document analysis

This section examines the Standard Operating Procedures (SOPs) governing air traffic control at Gdańsk Tower (TWR), focusing on how the reconfiguration of working positions—that is, the capacity to dynamically modify role boundaries and task allocations—supports operational continuity, safety, and resilience.

The analysis draws upon associated procedural documents, including the Gdańsk Approach (APP) and Flight Information Service (FIS) SOPs, as well as the Letter of Agreement (LoA) between Gdańsk Tower and Gdańsk Approach. Collectively, these materials define the formal architecture through which operational flexibility and system resilience are achieved in practice. The research question—how reconfiguration of tower working positions contributes to system resilience—guides the interpretation of these procedures in relation to theoretical framework of adaptation and resilience.

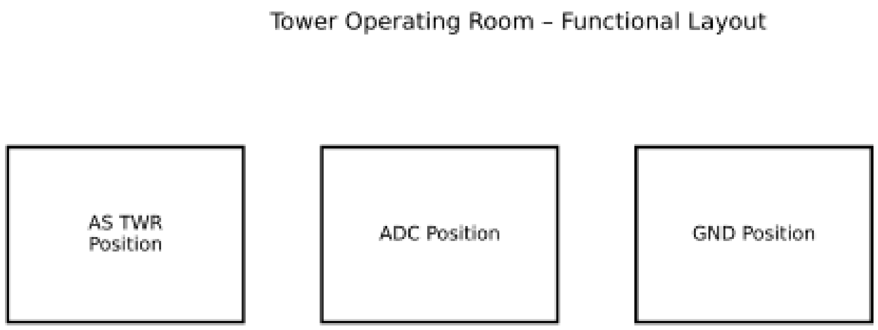
Gdańsk Tower SOP: Structure and functional relationships

The Gdańsk Tower unit is organised around three core positions:

- Aerodrome Controller (ADC) – responsible for managing air traffic within the Gdańsk Control Zone (CTR) and for supervisory oversight of tower operations.
- Ground Movement Controller (GND) – responsible for ground traffic management on the manoeuvring area.
- Tower Assistant (AS TWR) – providing operational support to ADC and GND through coordination and data management tasks.

Figure 2

Tower Operating Room scheme



These positions form elements of a sociotechnical system consequentially have interdependence internally as well as externally, in which control authority, information flow, and task allocation are distributed dynamically according to operational conditions. Prior to assuming duty, each practitioner reviews and confirms the latest operational changes via a dedicated information system, and position handover follows the REST protocol, ensuring the transfer of required information.

The ADC serves as the central coordinating role within the tower's control environment. Beyond providing aerodrome control services, the ADC holds decision authority for system reconfiguration—that is, for merging or separating working positions depending on traffic demand, personnel availability, and workload. The ADC operates through a suite of integrated digital systems—Surveillance System: ATOS, Electronic Flight Strips (EFES), Situation Data Display (SDD)/ Flight Data Display (FDD), Collaboration Human Machine interface (CHMI), Voice Communication System (VCS), and Operational Drone Traffic Management System: PansaUTM—that collectively support surveillance, coordination, and decision-making. These systems constitute the technological scaffolding that enables flexible reallocation of ATC functions.

Even when tasks are delegated to AS TWR (for example, coordinating with adjacent units or entering data into PansaUTM), the ADC retains supervisory accountability. This hierarchical flexibility ensures that authority and responsibility remain coherent even when structural configurations change.

The ADC also informs Flow Management Position (FMP) Warsaw of capacity variations resulting from reconfiguration, ensuring that local adaptability remains aligned with the broader Air Traffic Flow and Capacity Management (ATFCM) network managed by the Network Manager.

The GND position is responsible for managing the safe and efficient movement of aircraft and vehicles on the manoeuvring area (excluding runway), coordinating with both ADC and aerodrome services. The SOP defines GND as a modular function, capable of being integrated or separated from other positions. When combined with the AS TWR or ADC, GND's responsibilities (e.g., pushback approvals, taxi instructions, or coordination with vehicles) can be redistributed without disrupting control integrity. This modularity is a structural feature that facilitates operational continuity under varying conditions.

The AS TWR acts as a functional reserve, supporting communication, coordination, and administrative processes. While not authorised to make independent control decisions, the Assistant contributes to system buffering, absorbing workload from controllers (ADC and GND) during high-activity periods or role consolidation.

Tasks include updating flight plans, maintaining ATIS information, receiving and transmitting coordination messages, and—when authorised—managing surface movements or drone operations through PansaUTM. This redundancy provides elasticity within the system, allowing the redistribution of tasks during reconfiguration without loss of functionality.

The Gdańsk Tower SOP formally defines multiple operational configurations, enabling structured adaptability of the tower's control - as depicted in figures 3 to 6.

Figure 3

Fully Separate configuration: ADC, GND, and AS TWR

Figure 4

Partially Combined configuration: ADC, GND + AS TWR

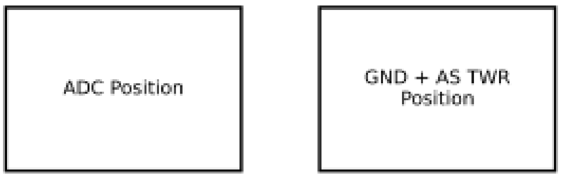


Figure 5

Alternate Partial configuration: ADC + GND, with a separate AS TWR

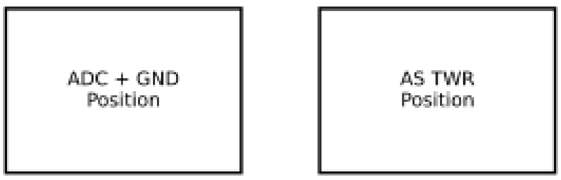
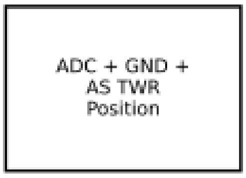


Figure 6

Fully Combined configuration: ADC + GND + AS TWR merged (SPO)



The default configuration—ADC with GND + AS TWR combined (Figure 5)—represents a balance between efficiency and oversight. The idea is to match available controllers with an operational demand. During periods of increased traffic volume or heightened coordination requirements with airport services, an additional AS TWR position may be opened and staffed by non-ATCO personnel (e.g., trainees). The ability to transition between configurations demonstrates predefined structural adaptability, a design feature that operationalises resilience-by-design (Rasmussen, 1997). These configurations form a scalable model of operation, ensuring the tower can match its capacity to the available resources without undermining safety or efficiency.

Single Person Operations (SPO) provisions constitute the most explicit operational manifestation of functional reconfiguration within the tower SOP. Under SPO flexible or fixed – Lone Person Operations (LPO) modes, a single controller—usually the ADC—assumes the full spectrum of tower responsibilities when traffic intensity or staffing levels fall below defined thresholds. While SPO is procedurally defined and formally sanctioned, its safe execution relies on the controller's ability to manage increased task coupling, prioritise competing demands, and continuously monitor the evolving operational situation. Whereas SPO is formally approved, it remains contentious due to the loss of cross-monitoring. The 'four-eyes principle', central to ATC operations, is not directly maintained under SPO, shifting potential error or system malfunction detection toward individual performance and technical mitigations. At Gdańsk Tower, this mode of operation is used only infrequently and is typically limited to night-time periods, when no or only minimal traffic is expected.

The decision to implement SPO is made locally by the ADC based on a tactical assessment of operational conditions, aligning with the principle of distributed decision authority. Supporting mechanisms include:

- Continuous availability of a duty person, ready to resume work if workload increases (excluding LPO mode).
- Contingency communication through a dedicated "PANIC BUTTON" on the VCS.
- System-level monitoring via Pandora, which detects inactivity and generates automatic alerts.

When necessary, operational capacity changes are communicated externally through NOTAMs or ATIS updates, maintaining transparency within the broader air traffic network.

From a resilience perspective, SPO represents a monitored form of functional contraction, allowing the system to preserve essential services while optimising for limited human resources. A key system element is the provision of panic button, which operates as a time-critical alert mechanism, enabling controllers to quickly signal the need for additional support when temporal pressure escalates. This controlled adaptation exemplifies the dynamic balancing between efficiency, workload, and safety that Rasmussen (1997 pp. 183-185) describes as central to managing system boundaries.

Gdańsk Approach and FIS SOPs: Coordination boundaries supporting reconfiguration

Although the focus of this research lies with tower operations, the APP and FIS SOPs provide a more appropriate granularity within the operational context for understanding coordination boundaries.

The Gdańsk Approach (APP) unit, composed of Senior, Executive, Director, and Coordinator positions, coordinates runway in use, sequencing, and airspace management with TWR. Senior Controller (SC) oversees the overall approach operation and manages workload distribution. Executive Controller (EC) provides tactical air traffic control by issuing clearances and instructions to aircraft in TMA. Director (DIR) plans and sequences arriving and departing traffic, anticipating conflicts and coordinating traffic flow, and Coordinator (CO) APP acts as the primary liaison.

Similarly, Gdańsk Flight Information Service (FIS) — located in the same control centre, and operating through East, West, and Assistant positions—facilitates seamless electronic transfer of aircraft between control zones using the TRANSFER function. These automated and standardised coordination procedures complement verbal exchanges and enhance the interoperability of reconfigured tower operations.

This design demonstrates that while internal structures within TWR are flexible, external interfaces remain stable, ensuring boundary robustness amid internal reconfigurations.

Letter of Agreement (LoA): procedural conditions for adaptive cooperation

The Letter of Agreement (LoA) between Gdańsk Tower and Gdańsk Approach defines the procedural and communicative framework for inter-unit cooperation. It establishes mutual autonomy—each unit operates independently under normal circumstances without verbal coordination, relying on electronic data exchange. In non-standard situations, or when operating in a degraded ATM system mode where electronic coordination is not feasible, coordination is conducted via telephone communication. From the viewpoint of reconfiguration, this arrangement minimises external dependency, allowing the tower to adapt internally (e.g., shifting to SPO mode) without disrupting the inter-unit coordination. The LoA therefore acts as a boundary-stabilising mechanism, providing a procedural "anchor" around which internal flexibility can occur safely by explicitly defining the functional, spatial, temporal, and responsibility interfaces between operational units. The LoA between Gdańsk Tower and FIS Gdańsk was introduced during the research period but is not presented here, as it had not yet been published at the time the interviews were conducted.

The Gdańsk Tower SOP embodies a model of adaptive reconfiguration, where flexibility is designed, authorised, and continuously monitored. The explicit provision for multiple structural configurations, SPO modes, and supervisory hierarchies operationalises resilience through procedural governance. This reflects the central premise of resilience engineering—that safety in complex socio-technical systems depends not solely on rule compliance but on the capacity to adapt dynamically to changing operational contexts (Hollnagel & Woods, 1983; Hollnagel et al, 2006).

Within this framework, structural reconfiguration (e.g., merging or separating positions) represents the system's capacity to modify its organisation without losing coherence; functional reorganisation (e.g., SPO operations) demonstrates the flexibility of human roles and task boundaries in response to workload; procedural safeguards (e.g., monitoring, escalation protocols, redundancy) act as buffers that stabilise adaptation.

Analysis

The reconfiguration mechanisms outlined in the Gdańsk Tower SOP can be theoretically framed within two complementary perspectives: Rasmussen's dynamic safety model (Rasmussen, 1997) and resilience engineering concepts (Hollnagel et al., 2006). According to Rasmussen (1997), socio-technical systems operate within a landscape bounded by three interacting constraints: acceptable performance, workload, and efficiency. Operators navigate within these boundaries, continuously adjusting their behaviour to sustain system performance. The tower's ability to transition between configurations and activate SPO modes exemplifies this dynamic migration, allowing the organisation to remain within acceptable performance boundaries despite external disturbances.

In parallel, resilience can be viewed as the capacity of a system to recognise, adapt to and absorb variations, changes, disturbances, and surprises (Woods and Hollnagel, 2006). The tower's reconfiguration procedures—underpinned by monitoring tools, distributed decision authority, and predefined contingency protocols—embody this adaptive cognition in organisational form.

Together, these frameworks situate the Gdańsk Tower SOP as a codified manifestation of resilience. The system's capacity to reconfigure—both structurally and functionally—represents an operationalised balance between rigidity and flexibility, ensuring that continuous operations are maintained under varying and uncertain conditions.

Interviews

The semi-structured interviews based on CDM were followed up by the general questions regarding reconfiguration. Appendix B provides the questions for the interviews.

Themes

During the data analysis (first order analysis), several themes appeared and have been identified. In exploring these themes relationships were found between them and they were grouped as follows:

- Complexity, workload, and performance variability
- Anticipation, decision making, and coordination
- The messy reality: work-as-done, work-as-prescribed, work-as-imagined, work-as-disclosed

- Teamwork and culture
- Training, tacit knowledge, and experience
- Adaptive strategies and capacity- beyond reconfiguration

The groups were analysed using second order analysis and the findings are presented below.

Complexity, workload, and performance variability factors that affect reconfiguration

Complexity: what makes the situation "complex"?

Complexity is a feature of the system, not of components inside it. It arises from the huge, multiplied webs of relationships and interactions that result from local actions, when components respond locally to information presented. (Dekker, 2012). Moreover complex systems are held together by local relationships only, components (controllers in the research) respond locally to information presented to them, and complexity arises from the huge, multiplied webs of relationships and interactions that result from these local actions (Dekker et al., 2011).

Most frequently cited complexity drivers identified in the data are summarised in Table 1.

Table 1

Most frequently cited complexity drivers in the collected data

Complexity driver	Illustrative examples from the data
runway/airport status and configuration	mixed runway in use (29/11) (Interviewees 1,2), runway inspection (Interviewee 1), bird debris on RWY (Interviewee 1), layout of the airport impacts capacity (Interviewee 1)
communications/technology constraints	frequency overload (Interviewee 3), radio failure (Interviewee 1), noise…communication barely readable (Interviewee 4), missed readback (Interviewee 1)
traffic volume and configuration	mixed traffic (DEP and ARR) (Interviewees 1,5,6,7), many VFR (5–8) with the same squawk (Interviewee 7), around 20 aircraft extra per hour

	(Interviewee 7), tight sequencing (Interviewee 1) , go around (Interviewees 1,2), high volume of voice communication (Interviewee 3), departing aircraft parked on the adjacent stands (Interviewee 2), taxiway incursion (Interviewee 2), VFR circuits (Interviewee 6), rescue flights (Interviewees 3,6), multiple conflicts in different areas (Interviewee 2)
coordination with external actors	snow removal (Interviewees 6,8), extended de-icing time (Interviewee 3,8), constant coordination and plans' change (Interviewee 2), extensive coordination with FIS and APP (Interviewees 2,5,7), confused pilots (Interviewee 5)
weather	thunderstorms (Interviewee 1), wind variability (Interviewee 2), storm cells (Interviewees 1,2), low visibility conditions (Interviewees 2,5)

Weather issues have a direct impact on safety and trade-offs. A set of fixed operating limits covers many potential hazardous situations – for example maximum allowable cross wind on a runway (Hayes, 2017). In the Gdańsk Tower environment, complexity is not represented by a single factor but a configuration of interacting elements: runway state/use and manoeuvring area layout; volatile demand composition (IFR/VFR mixes, bursts); and frequency load. As explained by interviewee 2, complexity often emerges when these elements co-vary (e.g., convective weather (storm cells/thunderstorms) → go-arounds + mixed runway use → high-frequency load + adaptive sequencing). Complexity is produced by interactions and interdependencies between environment, infrastructure, traffic, and communication, rather than by traffic count alone.

Controller's workload: what pushes cognitive/temporal load?

Prominent workload drivers identified in the data are summarised in Table 2.

Table 2

Prominent workload drivers identified in the collected data

Workload driver	Illustrative examples from the data
communication load	increased communication (Interviewees 2,3,6), all traffic on one frequency (Interviewee 3), an assistant was busy with a phone call (Interviewee 1), missed readback (Interviewee 1), too much for one person (Interviewee 3)
time pressure/peaks	45 min peak traffic volume (Interviewee 2), no space for considering the reconfiguration (Interviewee 2), pressure to depart aircraft from RWY 11, while arrivals were planned for RWY 29 (Interviewee 2), pressure to compress work on one frequency (Interviewee 3)
task load on GND controller	non-standard pushback (Interviewees 2,6), taxi via stands (Interviewee 2), increased number of clearances and re-clearances (Interviewee 2), multiple conflicts on taxiways (Interviewee 2)
cognitive tunnelling constraining information processing	lack of awareness of falling behind the traffic (Interviewee 1), go around and duty officer coordination at the same time (Interviewee 1)

Workload, understood as instantaneous workload (Smolensky & Stein, 1998), in the tower is dominated by variability, uncertainty and temporally dense micro-tasks (e.g., constant updating EFES) under aggressive time constraints leading to time pressure and the need for the ATCO to prioritise and reprioritise the sequencing of tasks. Even moderate traffic can yield a high workload if frequency saturation, phone coordination, or non-standard taxi flows compress controller time, and presents a need for unloading the position. The workload can be interpreted as an intervening variable between the totality of operating methods (including e.g., detecting of conflicts, verbal communication, division of tasks), which can be described and evaluated by a behavioural analysis of the operator, and the level demanded by the task, which can be evaluated by an analysis of the objective work situation and expressed in units suitable for task in question (Sperandio, 1978).

The findings from Gdańsk Tower are consistent with the other ATC complexity and controller workload study, which demonstrates that controller workload is not a direct function of traffic volume, but an emergent property arising from the interaction between communication demands, task coupling, and temporal pressure (Athenes et al., 2002). This study highlights that workload increases significantly when controllers are required to manage multiple concurrent tasks—such as radio communication, coordination, monitoring, and planning—within compressed timeframes, particularly under conditions of high communication density. This perspective mirrors the interview data, where controllers described high workload during moderate traffic when frequency congestion, missed readbacks, or simultaneous coordination calls absorbed cognitive resources.

Moreover, some informants reported that the workload associated with opening an additional position during periods of high traffic volume was nearly as high as that during continuous operations at peak traffic levels. The initial steps of reconfiguration further increased the workload, as passing the important information and coordination during a handover takes time and requires attention. The regulatory feedback between workload and operating methods is used by controllers to avoid the abrupt onset of overload conditions and to delay satiation (Sperandio, 1978).

Notably, interviewees describe moments when workload becomes so absorbing that it delays consideration of reconfiguration: "I was so engaged, there was almost no space for considering the reconfiguration"(Interviewee 2), "I didn't realise at that time that I was getting behind with the traffic, but the colleague who was sitting behind me, noticed it instantly" (Interviewee 1), revealing a risk of late or missed adaptations because of capacity exhaustion as disturbances/challenges cascade. The timing of the split is crucial and includes a subjective ATCO's decision based on their individual preferences when to split. Under such circumstances, components are stretched to their components limits and the system's overall control can collapse abruptly (Branlat & Woods, 2010).

Performance Variability: why do behaviours/outcomes vary?

Frequent variability factors identified in the data are summarised in Table 3.

Table 3

Frequent variability factors identified in the collected data

Variability factor	Illustrative examples from the data
demand variability	unexpected VFR traffic (Interviewee 7), go-around (Interviewees 1,2), intensive air traffic (Interviewees 5,6,7), around 20 aircraft extra per hour (Interviewee 7), extensive IFR and VFR traffic (Interviewees 6,8)
weather variability	VMC (interviewee 3), heavy snowfall (interviewee 8), storm cells (Interviewees 1,2), thunderstorms (Interviewees 1,2), low visibility conditions (Interviewees 2,5)
system/equipment	radio malfunctions (Interviewee 1), ATM system unification and redundancy issues (Interviewee 1), electronic flight strip system layouts differing by an operational role (Interviewee 3)
temporal variability	time-of-day (Interviewee 7), seasonal variations (Interviewees 5,6,8)
crew/operator	pilot's comprehension issues (Interviewee 5); non-standard or unclear phraseology (Interviewee 5); difficulties in understanding taxi instructions (Interviewee 5)
roles/positioning	role and position changes (all Interviewees); tower control room and controllers' working positions layout influencing team dynamics (interviewees 1,4)

fitness for duty	feeling unwell (Interviewees 3,7), sleep deprivation (Interviewee 3)

Variability is multi-source: exogenous (weather, seasons, demand surges, pilots' proficiency and experience) and endogenous (ATM systems/control room layout, tools' reliability, fitness for duty). This variability is the backdrop against which reconfiguration is both necessary and occasionally delayed.

Conclusions of second order analysis of this group

Complexity signals the potential need for reconfiguration. Runway/airport constraints, frequency saturation, and mixed IFR/VFR traffic produce coordination entropy. Controllers interpret these conditions as cues that attentional focus and temporal margins are eroding, which can lead to decisions to split positions—particularly the opening of a dedicated ground position—to reduce interference and concentrate cognitive effort. However, these same conditions do not always necessitate reconfiguration. Depending on traffic temporal structure, controller strategies, and available tools, complexity may remain absorbable without functional change, and reconfiguration may introduce additional coordination cost.

Workload determines the timing and urgency. When communication and task load spike, temporal bandwidth for strategic decisions narrows, risking delayed reconfiguration. Conversely, early split/opening tends to rebalance workload: "assistant unloads GND, a controller can focus on aircraft instead of assistant's tasks" (Interviewee 1), "split restores efficiency, time on frequency and rebalances priorities, main goal is to distribute workload among more personnel" (Interviewee 4), "a decision to split in advance helped, splitting during the traffic peak would not have helped that much and could have increased the complexity" (Interviewee 5), "it's worth opening GND just in case" (Interviewee 5).

Performance variability shapes which reconfiguration serves the traffic situation. Weather/season and demand bursts make the same nominal traffic behave differently. Thus, the unit prefers modular responses (open GND, separate AS tasks, temporarily reassign AS tasks to ADC) to fit the specific variability pattern with having their own capacity in mind: "If I feel unwell or sleep deprived, I always split" (Interviewee 3), "Sometimes when I have a bad day, I split cause it decreases the workload" (Interviewee 7).

Anticipation, decision making, and coordination: people in the process

Anticipation operates as an early-warning layer within the cognitive system

The predictability associated with the process under control and the environment is never perfect, therefore any work system needs to be able to adapt to a variety of perturbations. Anticipation corresponds to the belief that surprising events will occur and challenge the system's assumptions about the world (Weick & Sutcliffe, 2015). Controllers continuously project near-future states based on traffic evolution, weather, and system constraints. The strongest signal in the data concerns traffic prediction—anticipating peaks, mixed flows, or extra coordination demands: "expected VFR bundles" (Interviewees 5,7) "anticipating nonstandard pushbacks/departures" (Interviewees 2,6). These anticipatory actions shape when and how teams decide to reconfigure or redistribute tasks.

Experience-based intuition plays a central role in this process. Consistent with a view of intuition as rapid pattern recognition grounded in tacit knowledge and accumulated experience (Klein, 2011), controllers described "just knowing" when workload would increase, without deliberate analytical calculation: "you know from experience when traffic density will increase"(Interviewee 5). This form of intuition reflects the ability to quickly match the current situation to familiar patterns and detect subtle cues that signal emerging pressure. As plans and procedures are necessarily underspecified and cannot account for all contingencies (Branlat and Woods, 2010; Hollnagel, 2018), such intuitive expertise becomes critical. Building on this anticipatory capacity, controllers employ a range of adaptive strategies to manage situations where operations move close to safety margins. Rankin et al. conceptualise such strategies as everyday, often informal adaptations enacted at the sharp end under conditions of uncertainty and variability. These adaptations are highly context-sensitive and rely on subjective practitioner assessment, vigilance, and available resources (Rankin et al., 2011). This anticipatory expertise is socially transmitted through storytelling and example sharing during training, suggesting a cultural, not just individual, competence.

Weather-related anticipation (storms, wind variability, snow) influences runway configuration planning and expected frequency load. Interviews reveal that weather monitoring is not a separate task but rather an integrated part of cognitive scanning, where controllers continuously reinterpret MET information in light of their local operational knowledge.

Coordination-based anticipation also reoccurs in descriptions of pre-emptive communication: briefing other controllers, adjusting timing with APP and FIS, and preparing for potential configuration changes: "I was not very busy at the time, I could monitor expected traffic flow, so I called FIS in advance, when most aircraft were already in polish airspace and I got estimated time of arrival of the first one" (Interviewee 5), "We asked FIS to send five aircraft on the frequency, but for the next 15 minutes no more traffic could have been transferred" (Interviewee 7).

However, some controllers noted that the situation came as a surprise: "At the beginning, it didn't seem at first that the situation would escalate so quickly. We couldn't have anticipated a mistake in the taxi instructions or that the aircraft would perform a go-around" (Interviewee 2). Another (Interviewee 1) said, "Everything happened so quickly. The whole situation was unusual—somewhat unexpected." A third controller (Interviewee 7) remarked, "And I still don't know why we didn't see it coming—like that one time when about 100 VFRs suddenly showed up in Gdańsk."

Viewed through the scientific lens of fundamental surprise, which can be characterised as a breakdown of the prevailing interpretative framework, where accumulating information alone is insufficient because the surprise stems from flawed or unexamined assumptions rather than missing data (Lanir, 1986). This paragraph illustrates how controllers encountered events that fell outside their existing mental models and expectations of how a situation should unfold. A fundamental surprise is the event that challenges previous views, demands an explanation, and leads participants to question their basic assumptions. It is a dissonant state that calls for resolution and re-establishing a new equilibrium (Woods, 2010). The cases analysed in this research showed how controllers, through their reactive adaptation, handled surprises by rebalancing priorities, agreeing on reconfiguration, or delaying inbound traffic.

In summary, anticipation in the Gdańsk tower operates as a temporal buffer—tactical strategies that enable controllers to act before complexity peaks. By forecasting traffic patterns, weather impacts, and coordination demands, teams can reshape workload and reorganise resources ahead of time, embodying the idea that avoiding disruptions is often more effective than responding to them (Branlat & Woods, 2010). Yet the episode also reveals the limits of anticipation: certain events constituted fundamental surprises that fell outside extant models that did not represent the unfolding traffic situation and necessitated reactive adaptation. In these moments, controllers restored stability by reprioritising tasks, negotiating reconfigurations, and delaying inbound flows. Together, these patterns illustrate that resilience in practice relies on the interplay between both anticipatory and reactive strategies.

Decision Making: balancing structure and flexibility

The interview data show that decision-making in the Gdańsk Tower environment oscillates between formal procedural reference and experience-driven adaptation. Controllers rarely rely on written procedures alone; instead, they draw upon tacit knowledge and pattern recognition accumulated through years of practice e.g.,: "decisions are based on experience" (all Interviewees), "It always depends on how complex the situation becomes — that's what triggers the need to reconfigure."(Interviewee 3), "experience and tacit knowledge are more important than other procedures" (Interviewee 2)," I think experience is more important than any structured forms [capacity limits in SOP]" (Interviewee 8), "the problem is when half of the traffic volume departs and the other half arrives in the same time"(Interviewee 7), "even if the current traffic volume is lower than the prescribed one for splitting positions, I would still open GND, because the traffic can become much denser very quickly" (Interviewee 5), "the most important is controller's decision to split, even if the traffic is below capacity limits" (Interviewees 2,5), "I don't count the aircraft — I judge it by eye [whether to split positions]" (Interviewee 7). A resilience strategy may be a part of a procedure, instruction or checklist (blunt end), or a local adaptation or improvisation (sharp end) (Rankin et al., 2011). In some cases, several strategies are employed, originating both from procedures or trained skills and local adaptations.

Experience-based judgement was the dominant theme, appearing in many references to decisions made "based on own judgement" (Interviewees 1,2,3,5,7), "on-the-job practice" (Interviewees 1,2,4,6) or "tacit expertise" (Interviewees 1,3,5,7,8). This reflects a naturalistic decision-making (NDM) model rather than a purely analytical one, where NDM is an attempt to understand how people make decisions in real-world contexts that are meaningful and familiar to them (Lipshitz et al., 2001).

Risk and uncertainty management emerged through statements describing controllers' assessment of "when to split positions" (all Interviewees), "how long to maintain present configuration" [to work on positions without any changes] (Interviewees 3,4,6,7,8) or "when to intervene" [a suggestion for reconfiguration made by other ATCO] (Interviewees 1,2,6). Such decisions are typically taken under time pressure and partial information, where controllers weigh operational safety against efficiency pressures to achieve system and network goals (minimising delays and handling the expected traffic volume).

Collaborative decision making also featured prominently: available controllers often participate informally in moment-to-moment judgments: "decision to reconfigure based on the other ATCO's suggestion" (Interviewees 1,2,6) "we agreed that ATCO working as AS would help me and supervise my work as if he were an instructor/supervisor" (Interviewee 3), "I always ask if ADC will need to open GND" (Interviewee 5). A complex and uncertain decision-making environment increasingly requires the collaboration of participants, the exchange and interaction of knowledge among different actors can effectively promote and improve the decision-making process (Cai et al., 2023) . Decision processes align with the joint cognitive system (JCS) approach to cognitive systems engineering that acknowledges that cognition emerges as goal-oriented interactions between people and artefacts to produce work in a specific context, at the level of the work being conducted (Hollnagel & Woods, 2005).

Procedural references (e.g., adherence to training requirements or established configurations and capacity limits) were comparatively infrequent but served as anchors in uncertainty: "I wanted to observe a trainee in a more difficult situation, traffic prediction was for 12, but it did not include general aviation" (Interviewee 6), "it is very subjective, it matters what operations look like, what are the conditions"(Interviewee 3), "I rarely monitor the traffic volume graphs and total traffic count, I monitor the flight strips"(Interviewee 8). Controllers describe these as starting points—often overridden when real-time dynamics diverge from procedural assumptions: "complexity is more important than traffic count"(Interviewee 7), "we are not very strict with those capacity limits, they serve as a point of reference"(Interviewee 2), "every controller needs to analyse it [a need for reconfiguration] and make a decision based on complexity and their own experience"(Interviewee 3).

In short, decision-making in Gdańsk Tower exemplifies a contextually adaptive process—where procedure, professional judgment, and peer input dynamically trade off to sustain safe operations amid complexity and system/network goals.

Coordination is the social and procedural framework of tower operations

ATC coordination refers to the operational, real-time management of traffic and tasks among controllers and adjacent units, while JCS coordination concerns the broader joint cognitive system that includes humans, procedures, technologies, and organisational structures acting together to achieve safe and efficient operations. Coordination is therefore not only a social and procedural framework of tower operations, but also a system-level property emerging from interactions within this joint cognitive system.

Coordination can be defined as the implementation of the various mechanisms that allow team members to manage interdependencies between their roles and tasks, and conflicts between their goals (Branlat & Woods, 2010). The most frequent data concern timing and sequencing: "time required to brief the other ATCO" (Interviewees 1,6), "handover during splitting and joining positions" (Interviewees 1,3,6), and "temporary chaos during reconfiguration, some pilots preparing for departure remain on TWR frequency, even if information about GND opening is already in ATIS" (Interviewee 2). Interpersonal and team coordination emerged through explicit mentions of collaboration and peer support: "all involved personnel should share the same mental model" (Interviewee 4), "if there is good coordination everything is going smooth, if it is worse it has an impact on the performance" (Interviewee 4), "it is essential to communicate effectively with a controller, or assistant who is next to you" (Interviewee 4), "ideas sharing is crucial, as not to end up with team members have different ideas on traffic planning and management" (Interviewee 4). These excerpts demonstrate the presence of shared understanding and mutual performance monitoring. From a resilience engineering perspective this coordination incurs additional demands. To use the skills and experience of incoming personnel, they need to be briefed and understand tasks delegation according to a required sequencing of task. The choreography needed for smooth operation is effortful (Maguire, 2020).

This reflects that temporal coordination is a core vulnerability and skill; misaligned timing can escalate workload or reduce safety margins which represents the choreography of joint cognitive systems. Adaptive processes can threaten the maintenance of synchronisation between tasks e.g., when aircraft are on different frequencies while taxing and pushing back: "I started to get lost, we had four aircraft for taxi, two on TWR and two on GND frequencies" (Interviewee 8), "I started to loose situational awarenesses" (Interviewee 8), and can constitute sources of failures when interdependencies are not sufficiently managed through coordination processes (Branlat & Woods, 2010).

Coordination with FIS and APP appears as another major category: decisions about runway changes, departure and arrival sequencing, inbound/outbound VFR traffic, and mutual understanding of traffic flow. Interviews emphasize that coordination is bidirectional, requiring continuous negotiation—especially during configuration changes or unusual operations (e.g., mixed runway use, thunderstorms, low visibility procedures (LVP), de-icing, and airspace restrictions).

Finally, coordination with external actors (airport services, maintenance teams, pilots) introduces cross-boundary complexity. It ensures that distributed agents—controllers, pilots, and airport services—function as a joint cognitive unit. Most controllers responded that pilots were impacted by the configuration's changes, but did not consider APP controllers, FIS officers, and airport services as directly involved. The interactions between those actors often involve asynchronous communication, each actor working within their own operational timeline and differing priorities, underscoring the need for flexible coordination structures beyond the tower control room.

Conclusions of second order analysis of this group

In combination, these three cognitive themes represent a control loop for adaptive safety in Gdańsk Tower. Anticipation provides foresight—detecting cues of rising complexity or changing environmental conditions. Decision making translates those anticipatory cues into actionable strategies (e.g., deciding to open positions, reprioritise tasks, or maintain configuration). Coordination executes it as a function of practitioner's choices/strategies and stabilises these decisions through shared communication and temporal synchronization among actors. This triad forms the core of adaptive expertise/capacity and resilient performance in tower control. When anticipation weakens (e.g., during fundamental surprises) decision-making becomes more reactive, and reconfiguration tends to occur later, echoing the same systemic vulnerabilities seen in the earlier analysis of complexity and workload. Thus, these themes together illustrate how ATCO adaptation and team synchronization underpin operational resilience in the Gdańsk Tower environment.

The messy reality: how work-as-done, work-as-prescribed, work-as-imagined, work-as-disclosed intertwine

The interview data reveals that daily operations in the Gdańsk Tower are shaped by a continuous negotiation between formal structures and practical improvisation, and adaptation in the face of surprise, variability and uncertainty. Controllers work in an environment where procedures, expectations, and real situations rarely align perfectly, resulting in what can be described as a "messy reality"—a dynamic interplay between Work-as-Prescribed (WAP), Work-as-Imagined (WAI), Work-as-Done (WAD), and Work-as-Disclosed (WADi).

Work-as-Prescribed (WAP): the procedural ideal

Work-as-prescribed is the formalisation, specification, and design of work. It is the work that people 'should do', especially according to policies, procedures, rules, and so on (Shorrock, 2020c). Formal prescriptions define the expected mode of operation including available configurations, predefined capacity levels, and standardised task divisions. Controllers acknowledge the value of these rules as necessary reference points for consistency and safety. However, they also emphasize that the prescribed system often lags behind operational realities. For example, respondents noted that simulation training scenarios and local manuals often "lack reconfiguration options" (Interviewees 1,4,5) or "do not reflect the actual dynamics of tower operations (Interviewee 5)" The prescriptive framework, including capacity volumes in SOPs, works in stable conditions, yet daily work is inherently variable — influenced by weather, staffing fluctuations, and mixed traffic flows. Thus, while WAP provides a procedural scaffold, it is seldom followed literally. Instead, it is selectively applied, adjusted, or even bypassed when it constrains rather than supports operational performance (as seen in one case study, where working longer in a position was chosen over merging with another due to adverse weather conditions).

Work-as-Imagined (WAI): expectations and organisational narratives

Work-as-imagined is, at a basic level, the work that people imagine takes place, the imagined work reflects how managers, regulators, and sometimes even controllers themselves believe the system operates or should operate. Often, the term is used to describe imagination of the work that others do (now or in the past or future). It may also, however, refer to the work that people imagine that they do (or did, or will do) (Shorrock, 2020b).

In the Gdańsk Tower context, WAI is represented by assumptions around predictable traffic patterns, clear role divisions, and uniform controller competence. However, interviews revealed a discrepancy between these ideals and the lived experience. Participants mentioned "perceived pressure to handle higher traffic volumes" (Interviewees 6,7,8) or "the belief that asking for reconfiguration may be seen as weakness" (Interviewees 2,8). These statements point to cultural imaginaries—implicit beliefs about what constitutes "good performance"—which can discourage timely adaptation or open communication about limitations. From a practice-based perspective, competence is not a stable individual attribute, but an ongoing social accomplishment enacted and recognised within practice (Gherardi, 2009). In this way, WAI creates both a motivational framework and a social pressure that influences Work-as-Done, sometimes fostering unsafe perseverance or delayed reconfiguration decisions.

Work-as-Done (WAD): adaptation in real time

The actual conduct of work—WAD—is characterised by fluid adaptation, improvisation, and cooperative adjustment. Controllers routinely modify role boundaries through extending control authority, redistribute tasks, or simplify procedures to keep operations flowing. Examples from the interviews illustrate this vividly: "sending aircraft to GND frequency even if it is not formally open" (Interviewee 3) and "AS was on the call, so I grabbed the radio and talked to a duty officer" (Interviewee 1) demonstrate emergent coordination and adaptive strategies that go beyond formal allocation of duties. "All hands on board—even without full training"(Interviewee 3) or "There were many calls from FIS, I [GND] answered all the calls on coordination related to ADC traffic and did not ask the other controller how aircraft should enter/or be delayed" (Interviewee 6), "There was no time to ask how they want it" (Interviewee 6) reveal pragmatic trade-offs made to sustain system performance under pressure. It aligns with the observation that the system is designed to rapidly call in and benefit from additional types of expertise when anomalies arise (Patterson & Woods, 2001). WAD therefore represents the adaptive capacity of the system to adjust structure and behaviour dynamically when prescribed patterns no longer fit. These adaptations, while locally rational, may remain invisible or even contradict official rules, leading to further divergence between WAD and WAP.

Work-as-Disclosed (WADi): the narrated and visible work

Controllers often make sense of their activity retrospectively, through reports, debriefs, and informal storytelling. One controller reflected in hindsight: "I should have made a decision to split, because there could not have been more visible cues to do so" (Interviewee 2). The disclosed version of work tends to be sanitised and linearised compared to the messy, overlapping decisions of real-time performance. An example is mentioned by one of the informants: "There is one more factor [driving reconfiguration], but in my opinion, it is off the record and that is ambition" (Interviewee 2). It means that ambition, that is tied to personal expectations, may not always align with formal expectations

(WAI/WAP), where the capacity limits for reconfiguration are presented. It can also reinforce organisational blind spots by filtering out the improvisational aspects of daily work—the very elements that make the system resilient.

Conclusions of second order analysis of this group

In the Gdańsk Tower, these four "work realities" are not distinct layers but mutually shaping elements: WAP (rules) provides structure but cannot anticipate all variations. WAI (assumptions) shapes what controllers feel they should be able to do. WAD (practice) embodies how work actually gets done through adaptive expertise. WADi (disclosure) translates this messy practice back into a format legible to the organisation. The interplay among them forms dynamic feedback loops. As controllers repeatedly adapt in practice (WAD), they gradually reshape what the organization imagines as acceptable (WAI) and even influence the next iteration of prescriptions (WAP). Conversely, strong organisational narratives or audit expectations (WAI/WAP) constrain what can be openly disclosed (WADi) ("anxiety about how operational decisions will be assessed later"), perpetuating selective visibility of real work.

Teamwork and culture's impact on configuration

The analysis of interview data highlights that both teamwork and local culture play a decisive role in how reconfiguration is recognised, initiated, and executed within the Gdańsk Tower. While operational triggers such as traffic volume, workload, or weather complexity often prompt the need for change, the actual decision to reconfigure — and the smoothness of its implementation — depend heavily on interpersonal dynamics, trust, and shared norms within the team.
In this sense, teamwork and culture act as social enablers (or inhibitors) of adaptive capacity.

Teamwork: dynamics and mutual support

Controllers repeatedly described teamwork as the practical foundation of safe adaptation. The data show that successful performance requires constant information sharing, briefings, and implicit coordination between positions (ADC, GND, AS TWR). Statements such as "It is always nice to have somebody to support or challenge your tactical decision e.g., by saying easy – it will work out or no, do not push it" (Interviewee 8), "I do believe in the power of teamworking" (Interviewee 8), and "I do think this job relies on help, mutual support between ATCOs, pilots, and airport services make it safe"(Interviewee 3) illustrate how team members rely on each other for real-time monitoring and workload balancing. Moreover, three controllers (Interviewees 3,6,8) explicitly mentioned the four eyes principle as a safety barrier in the working environment.

This teamwork can be understood as a form of joint cognitive work, where control over the system is distributed between a human and a machine or other artefact and embracing teams. Reconfiguration decisions — such as opening a new position, shifting responsibilities, or managing frequency load — often emerge through collaborative sensemaking, rather than through top-down instruction. However, one controller (Interviewee 6) noted instances where top management predefined the configuration — setting SPO as the default setup with the option to add more people as needed — but this approach ultimately proved unrealistic.

Teamwork also manifests itself in adaptive role flexibility. During peaks or disruptions, controllers described "all hands-on board" (Interviewee 3) situations, in which inexperienced staff temporarily step in to assist colleagues, even outside their formal roles. The other example is: "After splitting the positions, the controller does not stop monitoring the traffic flow, to make sure he did not forget to pass all essential information during the handover" (Interviewee 1). Such informal support structures serve as a buffer against sudden increases in complexity, ensuring continuity of control.

However, teamwork effectiveness is not uniform. Several controllers emphasised that trust and shared experience determine how smoothly reconfiguration unfolds: "My decision not to split immediately was influenced by the fact that there was a very experienced controller at the AS position whom I trusted"(Interviewee 3), "If there was a less experienced person or the one who felt unwell, I would have split earlier" (Interviewee 3), "It feels different when AS position is taken by a non-licensed personnel, these are the operational details related to coordination"(Interviewee 4), "The person you work with matters" (Interviewees 3,7), "Some controllers feel good working together and have been doing it for many years" (Interviewee 6), . When these elements are weak — for instance, during trainee supervision or when incompatible team compositions occur — adaptation tends to be slower and more error-prone. This indicates that trust and interpersonal familiarity are critical enablers of fluid reconfiguration.

Cultural influences: values, norms, and perceived expectations

Beyond task coordination, the data reveals a cultural dimension shaping when and how reconfiguration occurs. The Gdańsk Tower exhibits a culture and local tribal norms that values competence — but it can also create subtle pressures that hinder early adaptation. Interviewees mentioned that "asking for reconfiguration may be considered a weakness" (Interviewees 2,8), or that "It leads to having "cowboy shifts", where controllers work less and mostly in combined positions" (Interviewee 6), Additional comments: "Another downside is something I do myself as well — we can end up challenging each other unnecessarily" (Interviewee 7), "If there is a team member, to whom you do not want to show that you are having a bad day, you take over a merged position not to show that the traffic is too high for you to handle"(Interviewee 7) suggest the presence of performance-oriented cultural norms where delaying the request for assistance or additional staffing is seen as a sign of endurance or mastery.

This echoes the broader phenomenon of "heroic controller culture," where maintaining control under high load is socially rewarded through recognition by fellow team members, even when operational efficiency or safety margins would benefit from earlier reconfiguration. This cultural impact is reflected in Carsten Bie's study of sector splitting and bandboxing in Copenhagen ACC, which shows how professional identity and informal norms encourage controllers to extend operational limits by "handling the traffic," thereby creating adaptive capacity but also delaying reconfiguration (Bie, 2021).

At the same time, the cultural narrative also includes learning-oriented elements. Statements like "you learn that if traffic peaks up, you ask for help" (Interviewee 5) and "real-life experience shapes the right timing for splitting" (Interviewee 2) reflect a gradual internalisation of adaptive practices reinforced within the group through mentorship and example sharing. The data show that these cultural lessons are largely transmitted informally — through on-the-job training, storytelling, and observation — tacit knowledge. Bie also demonstrates that the timing of splits is learned primarily through storytelling, mentoring, and lived experience rather than formal procedures, embedding sector reconfiguration as tribal knowledge that supports resilient performance (Bie, 2021).

Thus, culture operates both as a constraint (when norms discourage help-seeking) and as a resource (when collective learning and shared experience promote adaptation).

Conclusions of second order analysis of this group

The local Gdańsk operational team culture shapes: initiation of reconfiguration – who feels authorised to propose opening or closing positions; timing – how long the team waits before acting; communication dynamics – whether concerns are voiced early or withheld to avoid social friction. As

Sanne (2008) shows, such practices are sustained through informal storytelling that privileges local competence, vigilance, and responsibility, while simultaneously constraining the articulation of concerns that might challenge team norm.

Some controllers and teams tend to reconfigure pre-emptively, preventing overload and maintaining smooth operations: "Even when traffic is still manageable, I check with ADC about opening GND, pointing out that it could soon become dense" (Interviewee 5), "I don't like working alone (…) working on split positions is safer" (Interviewee 8). In contrast, when social barriers or hierarchical assumptions dominate, reconfiguration becomes reactive, often following visible performance degradation. Controllers noted that "trainees need to earn trust" (Interviewees 6,7) revealing how perceived competence and interpersonal confidence influence not only workload distribution but also the credibility of adaptation proposals. These actions reflect a form of local, tribal adaptation, in which decisions are not only operationally driven but also socially attuned to individual ATCO experience, competence, and controlling style. This indicates that cultural perceptions of expertise strongly shape who is heard and when within the team.

Training, tacit knowledge, and experience – building ATCOs' skills

The analysis of interview data reveals that the development of ATCOs' competence in the Gdańsk Tower is shaped by a dual learning pathway: formalised procedural training and the gradual accumulation of tacit, experience-based knowledge. While initial and recurrent training provide foundational technical proficiency, the interviews underscore that real operational expertise emerges through lived experience, mentorship, and social learning within the team environment: "It [competence] comes from years of experience and new situations" (Interviewee 7).

Formal training: structure without full realism

Controllers generally acknowledged the value of simulation and on-the-job training (OJT) as necessary components of professional preparation. However, several interviewees emphasised limitations in how these formal mechanisms capture the dynamics of real tower work. It aligns with the view that competence is often shaped through everyday performance adjustments, informal workarounds, and adaptive decision-making that emerge only in live operations and are difficult to replicate fully in simulated or structured training environments (Petri, 2015). Statements such as "simulation lacks reconfiguration options" (1,4,5), "no previous training on reconfiguration neither on simulator nor during on-the-job training" [own judgement and experience to decide whether to split positions] (interviewees 2,7) and "SIM prepares for high traffic volume but not for configuration variability" (Interviewee 1,5,8) highlight a common perception: formal training replicates procedures but not the adaptive demands of everyday operations.

This suggests that current instructional design tends to emphasize Work-as-Prescribed (WAP)—with fixed configurations—while providing limited adaptation options to the messy reality of operational variability and uncertainty. The result is a training–reality gap, where controllers must learn to manage complexity largely after certification, during real-time operations under supervision or peer guidance.

On-the-job training (OJT): learning through guided adaptation

OJT emerged from the interviews as the core mechanism for transforming procedural competence into operational expertise. Controllers repeatedly referenced how real learning occurs "in the tower," where instructors, assessors, and peers model decision-making and situational adaptation. For example, participants described "storytelling and real-life examples are more important than procedures" (Interviewee 2) and "reconfiguration should be a part of OJT, not a theoretical training" (Interviewee 4). These remarks reflect that the didactic value of OJT lies in social transmission—trainees learn not only what to do, but how experienced colleagues think, prioritise, and interpret uncertainty.

This apprenticeship model aligns with the Situated Learning Theory (SLT) (Lave & Wenger, 1991). SLT explains the process and development of learning when individuals can participate in a community of practice. In such a community, new learners reach the level of the expert as they have more opportunities to practice within the context of learning. In this light, learning is unintentional (Lave & Wenger, 1991). Through repeated exposure, observation, and reflection, trainees internalise the rules of thumb and practical judgment that enable effective reconfiguration and decision-making under pressure.

Tacit knowledge: the invisible foundation of adaptation

Tacit knowledge refers to knowledge that cannot be written down, either because of its characteristics or because it is embodied (Vaughan, 2021). The experience-based understanding that is difficult to verbalise emerged as a dominant theme in the data. Controllers referred to "decisions based on tacit knowledge, practice and experience" (all 8 Interviewees) and "you learn that if traffic peaks up, you ask for help"(Interviewee 5), "if there is a younger controller, who is more careful, he will look for support from older colleagues" (Interviewee 5), "I like to open three positions, if there is a trainee/assistant and sits on the sofa, to get them involved" (Interviewee 7). These examples demonstrate that much of what sustains resilient performance in the tower is not formally taught but absorbed through participation, observation, and repetition. Tacit knowledge includes the ability to sense when complexity is about to rise (anticipatory cue recognition), judge when to initiate or delay reconfiguration, understand the unspoken rhythms of coordination between ADC, GND, and AS TWR, and prioritise tasks fluidly under high communication load. This knowledge develops incrementally through experiential calibration: controllers learn to "feel" when the operation is reaching a cognitive threshold, even before metrics indicate overload: "It was my decision to initiate the split at that moment, when I realised—while handling everything—that I was reaching my limits." (Interviewee 7). Such skill is central to resilient performance, allowing timely adaptation within procedural boundaries.

Experience as a cognitive resource

The interviews included participants with experience ranging from seven months to thirty-one years, offering insight into how expertise evolves over time. Experienced controllers described pattern-based reasoning, in which situations are recognised as variations of familiar scenarios: "The decision was made on my previous experience, that if there was a big group of VFRs coming from Germany, they usually caused trouble" (Interviewee 5), "My previous experience told me that I could handle working longer in a position"(Interviewee 8). Novices, by contrast, rely more on rules and explicit checklists. One of the examples comes from the case study, where a very experienced controller made an administrative decision to call in additional personnel when the team was overloaded with work without getting the Head's authorisation first. A younger controller might have been struggling to make that autonomous decision.

Over time, repeated exposure builds mental repertoires—internalised templates that guide rapid decision-making without conscious deliberation. This mirrors findings in naturalistic decision-making research (Klein et al., 1989), where expertise consists not merely of knowledge accumulation, but of refined situation assessment and recognition-primed action. More experienced controllers play a vital role as cultural carriers of experience. Through informal mentoring, anecdotes, and feedback, they pass on contextual knowledge that cannot be codified. Statements like "real-life experience shapes the right timing for splitting" illustrate how experience evolves into a collective memory embedded in team routines.

Conclusions of second order analysis of this group

Learning in The Gdańsk Tower is based on mentorship, peer evaluation, and social trust. While the environment values competence and independence, it also recognises that skill maturity is achieved through guided autonomy in a team setting rather than isolated learning. Several controllers mentioned that "trainees need to earn trust" (Interviewees 6,7) before being granted more responsibility. This reflects a progressive exposure model, where autonomy is increased as confidence and experience grow, influencing reconfiguration decisions; specifically, who one works with matters, as pairing with a more experienced controller may reduce the perceived need to reconfigure or delay such decisions.

Adaptive capacity and strategies – beyond the reconfiguration

Adaptive capacity is the potential for adjusting patterns of activities to handle future changes in the kinds of events, opportunities, and disruptions experienced, therefore adaptive capacities exist before changes and disruptions call upon capacities (Woods, 2018).

While reconfiguration of working positions represents the most visible form of adaptation in the Gdańsk Tower, the interviews reveal that controllers employ a wide range of informal, cognitive, and operational strategies, which are presented below, to sustain performance and safety in dynamic conditions. Operators fill the gaps by adapting to the real conditions of operations and their dynamics (Cook & Rasmussen, 2005). These strategies can be viewed as local resilience strategies enacted at the sharp end, often combining monitoring, responding, and anticipating to manage everyday risks while operating close to the safety margin (Rankin et al., 2011). Operating in the background of everyday work, they enable the system to remain flexible even when staffing, space, or procedural limits constrain formal reconfiguration.

Controllers' narratives indicate that adaptation is not an exception but a constant property of tower operations — navigating trade-offs, coordination shortcuts, and improvisations that bridge the gap between idealised procedures and real operational demands.

Dynamic task redistribution and support

A recurring strategy in the data involves fluid redistribution of tasks within the team. Even when the configuration remains fixed, controllers spontaneously share workload through short-term interventions such as "taking over (FM) radio from AS, as he was busy on the phone call" (Interviewee 1) "sending aircraft to GND frequency even if it is not formally open" [where an ATCO working on AS position will respond]" (Interviewee 3), "supervision from another ATCO" [monitoring the work of ADC by other controllers]" (Interviewees 2,3) or "ADC supporting GND when overloaded" [by executing coordination with airport services and answering the phone calls] (Interviewees 3,6). These actions demonstrate an adaptive coupling between positions, where roles are temporarily blurred to maintain overall system stability. This practice is enabled by mutual familiarity and trust: controllers anticipate each other's limits and intervene seamlessly without formal handovers. Such fluid task sharing functions as a buffer against transient peaks of complexity, preventing overload long before official reconfiguration becomes necessary.

Prioritisation and dynamic sequencing

Controllers frequently described micro-level adjustments in traffic sequencing and prioritisation as everyday strategies for coping with operational pressure. Examples include "delaying departures or inbound VFRs" (Interviewees 5,6,7) "rebalancing priorities" (Interviewees 1,2,3,4,6,7)" temporarily ceasing non-critical operations" (Interviewees 2,3) or "picking up the phone and saying -will call you back" (Interviewee 3). These small, tactical modifications help to regulate system demand to match capacity. Controllers optimise locally within broader operational constraints. This strategy highlights the team's temporal intelligence: the ability to slow down or pause certain activities to maintain control e.g., prioritising IFR arrivals over VFR training flights.

Improvisation under constraints

When unexpected conditions disrupt the normal flow — such as sudden traffic peaks or extensive coordination periods — controllers resort to improvisation guided by common ground rather than strict procedures. Interviewees described situations where "all hands-on deck" (Interviewee 3) or "instead of going home, I took over communication with airport services" (Interviewee 7) actions compensated for incomplete training or unclear roles. Such improvisation is typically bounded by professional norms: it is rule-informed, not rule-free. Improvisation in this context serves as a local innovation process, enabling the team to re-stabilise performance when standard resources or configurations are temporarily unavailable.

Emotional regulation, fitness for duty, and composure as adaptive strategies

Although rarely explicit, several interview comments suggested emotional and cognitive control as a subtle adaptive strategy. Assessing own level of fitness for duty :"I don't like working on night shifts, so working on combined positions can help me focus" (Interviewee 7), "It's a bit like when you sometimes feel the urge to go to the gym or for a run — when your muscles almost itch because you need to do something. I get that feeling too, especially after a holiday; my brain almost itches to start working hard again [on merged positions]" (interviewee 7), maintaining composure, humour: "the team is more engaged and happy, when there is more stuff" (Interviewee 6), or informal reassurance within the team: "having another person next to me, increases my sense of safety"(Interviewee 8) during high-stress moments serves as psychological stabilisation, preventing escalation of stress and preserving decision quality. Such interpersonal micro-interventions are part of the affective dimension of resilience, which is the capacity to remain calm, focused, and communicative under volatility.

This research has demonstrated that the reconfiguration of ATC tower working positions serves as an essential adaptive strategy, enabling air traffic controllers to maintain safe and effective operations amid fluctuating demands and uncertainty. Drawing on qualitative data from the Gdańsk Tower, the study revealed that reconfiguration is a complex process, deeply embedded in everyday work. It is triggered by rising complexity and workload, shaped by tacit expertise and teamwork, and governed by an interplay between formal procedures (WAP) and adaptive judgment (WAD). The analysis confirms what Hollnagel et al. (2022) described, that resilience in ATC is not derived from strict compliance but from the system's capacity to adjust dynamically, balancing procedural rigidity with human adaptation, expertise and competence. Controllers act as adaptive agents who continually negotiate between the prescribed and the possible, converting uncertainty into operational stability through experience, coordination, and anticipatory sensemaking.

The findings show that reconfiguration of tower working positions is a routine yet highly context-sensitive adaptive practice through which controllers manage complexity, workload, variability, and uncertainty. Decisions to split, merge, or maintain configurations are shaped less by formal thresholds and more by experienced-based judgement, anticipation, and coordination within the team. While procedures provide an essential structural framework, everyday resilient performance emerges from locally negotiated adaptations, coordination, and common ground among controllers.

Discussion

The present study explores how the reconfiguration of ATC tower working positions functions as an adaptive strategy that supports resilient performance in a complex socio-technical system, showing that controllers routinely merge and split ADC, GND, and AS TWR positions in response to workload peaks, complexity, performance variability, and staffing constraints to maintain operations and safety margins. The findings from the Gdańsk Tower case study reveal that reconfiguration represents both a structural and cognitive adaptation mechanism, embedded in everyday operational work and shaped by the dynamic interplay between complexity, workload, coordination, experience, and culture.

Reconfiguration as a manifestation of resilience

The knowledge elicited demonstrates that reconfiguration embodies resilience principles of anticipation, monitoring, responding, and learning (Hollnagel, 2015) by controllers predicting emerging workload and complexity, monitoring traffic and coordination demands, responding through merging or splitting of ADC, GND, and AS TWR positions, and refining future reconfiguration decisions based on experience, team feedback, and prior operational outcomes.

Controllers continually monitor evolving operational complexity, anticipate workload thresholds, respond through dynamic reallocation of roles and functions, and learn through experience and storytelling. This reflects the principle of graceful extensibility (Woods, 2015)—the system's capacity to stretch its operational boundaries without compromising functionality. Reconfiguration enables the ATC system to sustain performance under variable demand, the findings are consistent with Bie's (2021) research showing that sector splitting and bandboxing are central mechanisms through which controllers create adaptive buffers and maintain system stability in the face of uncertainty.

Complexity and workload as adaptive triggers

The results confirm that complexity is perceived not as a single factor but as a configuration of interacting variables—traffic mix, runway configuration, environmental conditions, and coordination demand. This supports Dekker's (2012 p. 128) and Branlat & Woods' (2010) arguments that complexity arises from couplings among system elements rather than from individual components.

Workload emerges as the primary operational signal that triggers or delays adaptation. High communication density, frequency overload, or task congestion often precipitate reconfiguration decisions, as controllers seek to preserve buffers to manage unexpected events such as abnormal or emergency situations. When these buffers are eroded and cognitive resources are saturated, decision-making shifts from proactive to reactive, delaying adaptation and potentially compromising safety margins. This aligns with the "brittleness" described by Woods (2015), where systems fail not because of component failure but due to depleted adaptive capacity. Conversely, early or anticipatory reconfiguration was associated with restored cognitive balance, confirming that timing and foresight are key determinants of resilient performance.

Cognitive and collaborative adaptation

Decision-making within the Gdańsk Tower reflects a naturalistic, experience-based model (Lipshitz et al., 2001; Klein et al., 1989), where formal procedures serve as reference points but not as strict determinants of action. Controllers rely on tacit knowledge, experience, pattern recognition, and collaborative judgment to tailor procedural prescriptions to situational demands. This hybrid of procedures and flexibility exemplifies resilience-in-action—balancing SOPs' standardisation and improvisation to sustain safety. Anticipation, decision-making, and coordination form an interdependent loop. From a NDM perspective, anticipation supports pattern recognition and early sensemaking, enabling experienced practitioners to translate emerging cues into timely action rather than deliberative choice (Lipshitz et al., 2001), decision-making translates those cues into adaptive strategies, and coordination operationalises these strategies through shared understanding and synchronised action. Breakdowns in any of these elements lead to reactive rather than proactive adaptation. These findings support Branlat & Woods' (2010) framework of cognitive resilience, where adaptability is sustained through perception, prediction, and distributed control.

Negotiating work-as-imagined and work-as-done

The study reinforces the relevance of Resilience Engineering perspectives (Hollnagel, 2014), showing that safe outcomes in ATC result from successful adjustments rather than strict compliance. The coexistence of Work-as-Prescribed (WAP), Work-as-Imagined (WAI), Work-as-Done (WAD), and Work-as-Disclosed (WADi) demonstrates that organisational systems operate through multiple, sometimes conflicting realities. Controllers' improvisations—extending shifts, redistributing tasks, or merging positions beyond prescribed limits—illustrate the creative negotiation between rules and reality.

However, these adaptive acts often remain invisible at the organisational level, as Work-as-Disclosed tends to emphasize compliance over adaptation. It is often based on what people want and are prepared to say considering what is expected and understandable to the audience, and promote a particular view or impression of work (Shorrock, 2016). This gap reinforces the need for organisations to institutionalise learning from success—to recognise and integrate WAD into procedural and training frameworks, thereby closing the loop between everyday performance and formal regulation.

The social foundations of adaptation

Teamwork and social norms emerged as pivotal mediators of reconfiguration. The ability to adapt depends on common ground and trust within the team. When interpersonal confidence is high, reconfiguration occurs earlier and more smoothly. When trust is low or hierarchy dominates, adaptation may be delayed. This finding resonates with the concept of collective mindfulness—where teams remain sensitive to weak signals and flexible to reframe assumptions under stress.

Cultural and professional expectations—particularly the valorisation of individual endurance and "heroic" performance—sometimes inhibit timely adaptation, as controllers may hesitate to request reconfiguration for fear of appearing less competent. Conversely, informal mentoring and storytelling were found to promote reflective learning and normalise adaptive behaviour, demonstrating that culture can act as both a constraint and a resource for resilience.

Tacit knowledge and learning as resilience enablers

Formal training provides procedural foundations but often falls short in preparing controllers for real-world adaptation. The interviews highlight that tacit knowledge, acquired through experience and guided participation, is the real substrate of resilient performance. Through mentorship, on-the-job training, and storytelling, controllers internalise how to "read" complex situations and calibrate their actions accordingly. This aligns with Lave & Wenger's (1991) Situated Learning Theory and Vaughan's (2021) ethnographic observations, which suggest that interpretive work and local improvisation are irreplaceable human contributions to system safety. To strengthen resilience, organisations should therefore bridge formal and experiential learning—integrating examples of adaptive work into training curricula, encouraging reflection-on-action, and legitimising adaptive judgment as a professional competence rather than a deviation from the norm.

Beyond reconfiguration: everyday adaptive strategies

Finally, reconfiguration represents only one manifestation of adaptation within a broader ecosystem of micro-adjustments. Controllers employ a wide repertoire of strategies—dynamic task redistribution, temporal prioritisation, communication management, and fitness self-assessment—that collectively sustain operational stability. These findings confirm that adaptation in ATC is continuous and distributed, not episodic. Resilience emerges from the accumulation of these small, situated adjustments rather than from isolated structural changes.

In summary, the Gdańsk Tower case demonstrates that resilient performance results from the integration of technical flexibility (reconfigurable structures), cognitive adaptability (anticipation, decision-making, coordination), and social dynamics (teamwork, trust, and culture). Recognising, supporting, and learning from these everyday adaptations is essential for sustaining safety and efficiency in complex, high-stakes systems.

Conclusions

Theoretical implications

The findings build on the literature on Resilience Engineering by demonstrating how adaptation occurs not only through response but also through anticipation and sensemaking. The study operationalises Woods' (2015) notion of graceful extensibility, demonstrating how human cognition and coordination enact this principle in real-time. Moreover, the integration of Work-as-Prescribed, Work-as-Done, Work-as-Imagined, and Work-as-Disclosed provides a nuanced understanding of how organisational systems construct, conceal, or learn from everyday adaptation. This contributes to resilience theory by emphasizing the importance of recognising informal work as a legitimate and necessary dimension of system performance.

Further implications

For operational management, the study highlights several implications:

a) Bridge the gap between work-as-done and work-as-prescribed by updating procedures based on lived experience,

b) Design for flexibility: ensure that operational structures and technologies support dynamic reconfiguration and distributed decision authority,

c) Preserve margins for manoeuvre, where operationally feasible, by maintaining redundancy in staffing and ATM systems to preserve adaptive capacity.

Recommendations for supporting resilient performance

Based on the findings of this study, the following recommendations are proposed:

a) Recognise adaptation as a critical element of sustaining resilience, rather than as deviation, through experience sharing, training and occurrence investigations' processes,

b) Strengthen organisational learning by supporting reflection and storytelling as legitimate mechanisms for transferring operational knowledge and sustaining adaptive expertise,

c) Encourage psychological safety and mutual trust to promote early communication about workload and adaptive needs by addressing cultural norms that may discourage requests for support.

Limitations and future research

While the findings are grounded in rich empirical data, the research is limited to a single ATC unit (Gdańsk Tower) and reflects the perspectives of a specific organisational culture. Further research could employ comparative analysis across different towers or national contexts to examine how local norms, traffic complexity, or organisational hierarchies influence adaptive behaviour. Longitudinal studies could also track how resilience evolves over time, particularly following procedural or technological changes.

Final reflections

The study demonstrates that adaptation in air traffic control is not an exception to the rule—it is the rule and confirms others research – including Hayes (2017), Bie (2021), Hollnagel et al (2022), Malakis (2023), Lowth (2024), and Foster (2025). Controllers continuously balance stability and flexibility, structure and improvisation, compliance and creativity. Reconfiguration, as explored here, represents the tangible manifestation of this balancing act—a microcosm of resilience at work. Recognising and supporting these adaptive practices is therefore central to ensuring that air traffic control remains both safe and sustainable in an increasingly complex aviation system.

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Appendix A

Informed consent and information sheet for informants

Project: Adaptive strategies of Gdańsk Tower

Researcher: Dominika Zabratańska, master's student, Human Factors & System Safety, Lund University;

Supervisor: Dr Anthony Smoker, Lund University; email: anthony.smoker@tfhs.lu.se;

Purpose of the study:

The focus of this research is on adaptive strategies related to reconfiguration of working positions of Gdańsk Tower, and in particular your personal experience of it, based on an event. The purpose is to understand how controllers adapt during specific circumstances, such as workload fluctuations, emergent crises, and dynamic weather conditions.

Process:

You are invited to participate in an interview lasting approximately 60 – 90 minutes, where you will be asked questions to prompt the sharing of your experience of reconfiguration, based on one particular case of your choice.

You may be asked to complete an extension interview in approximately two months to clarify points from your original interview or discuss items that have been identified during this research.

These interviews will be recorded to ensure accurate capture of the experience you share, while notes may be taken during the interviews for further discussions and clarifications. A copy of your interview transcript will be made available for confirmation and accuracy of the content.

Results of this study will be made available upon the master thesis's publication on the email address provided on the consent form.

Confidentiality:

This research is distinct from my responsibilities related to controller's and safety role within PANSA, and the collected data will not be utilized for any other purpose. Identities of all participants will remain anonymous and will be kept confidential from all other parties than the researcher. Transcribed segments form the interviews may be used in the research providing the anonymity. Any material gathered during this process will be stored on the researcher's password protected computer in an anonymised form and will be deleted upon approval of the final thesis.

Your right to withdrawal:

Your participation is voluntary, and you can decline participation by rejecting this interview invitation. If you do accept to participate, you have the right to withdraw your participation at any time during the interview. You also have the right not to answer any specific questions during the interview. If so, let the author know and we will skip to the next question.

GDPR consent statement:

I hereby give my informed consent to participate in this research study. I understand that my personal data will be collected, processed, and stored in accordance with the General Data Protection Regulation (GDPR) and relevant data protection laws.

I acknowledge that the purpose of data collection is for research analysis related to this study, and my data will be kept confidential and anonymized where possible. I understand that my data may be used in publications or presentations related to this research, with all identifying information removed.

Print out, sign the form, and send back to the author's email (see above).

Date:____

Name:____

Email:____

Signature:____

Appendix B

Questions for the interviews

Interviews followed the CDM framework (Klein et al., 1989), additional questions were used for eliciting knowledge:

1. Can you describe any instances where you or your team reconfigured working positions during a shift? What prompted these changes? What was the purpose of the reconfiguration?
2. Under what operational conditions do you typically find it necessary to reconfigure working positions?
3. How do you perceive the benefits and challenges of reconfiguring working positions?
4. In your experience, how does reconfiguration impact your team's ability to maintain safe and efficient operations?
5. What strategies or practices do you consider effective when reconfiguring roles in response to operational demands? What is the split of bandbox trying to achieve?
6. Can you share any specific examples where reconfiguration either successfully enhanced operational performance or posed difficulties?
7. How do team members communicate and coordinate during reconfiguration of roles?
8. What training or support do you believe is necessary to improve reconfiguration practices in your environment?