When the Black Swan looms

Operationalising resilience in airports

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Operationalising resilience in airports

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There have been as many plagues in the world as there have been wars, yet plagues and wars always find people equally unprepared.

- The Plague by Camus (1947/2002, p. 30) -

Contents

Summary

From the 2020s onwards, our society has dealt with many high-impact crises, such as the COVID-19 pandemic, the Suez Canal obstruction, and the Russo-Ukrainian war. These crises exposed multiple fragilities in our transportation system, supply chains and national security. In reaction to these crises, the interest in operationalising resilience by translating resilience aspiration to actionable interventions (e.g. training, products and strategies) peaked within multiple organisations. In this context, the Delft University of Technology in collaboration with the Royal Schiphol Group, the operator of Amsterdam Airport Schiphol, initiated a PhD research project to investigate how to operationalise resilience. Key to this project was its action research approach, through which I, as the PhD researcher, closely collaborated with the Innovation Hub and Operational Resilience team of the Royal Schiphol Group. This fruitful exchange between academia and practice resulted in five studies, each presented as a separate chapter, contributing a key piece to the puzzle of operationalising resilience.

In Chapter 2, I aimed to understand how high-impact crises disrupt and fragilise organisations. Using the COVID-19 pandemic and Amsterdam Airport Schiphol as a case study, I conducted interviews whereby 16 experts from across the airport system shared their lessons learned. These experts originated from the airport operator, airlines, public health agencies and government officials. Thematic analysis revealed three key experiences: (1) the pandemic was considered unimaginable beforehand, leading to a limited readiness; (2) the aviation sector found itself constantly on the back foot, struggling to implement interventions while undergoing reorganisation; and (3) during the pandemic complex relational dynamics emerged between stakeholders, particularly between aviation, government and public health actors. Furthermore, the analysis surfaced four lessons learned, suggesting that airports should: (1) adopt a systemic approach, (2) strengthen sensemaking capabilities against surprising crises or Black Swans, (3) foster informal relationships among stakeholders, and (4) further examine the role of organisational interventions such as crisis management teams.

In Chapter 3, I investigated the conceptual meaning of resilience through an academic lens. Resilience became an omnipresent buzzword in response to the COVID-19 pandemic and the Russo-Ukrainian war. However, resilience's exact meaning remained vague, and the concept was related to other terminology, such as antifragility and bouncing back. Subsequently, I conducted a scoping review that

utilised a resilience-as-an-outcome lens. Based on this scoping review, I proposed a categorisation which dissects resilience into four aspects: (1) fragility, (2) robustness, (3) adaptation and (4) transformation. This categorisation aims to provide a structure to conceptualise resilience, which is expected to support its operationalisation.

In Chapter 4, building upon the findings of Chapter 2, I explored how resilience-as-a-process is operationalised in practice. I observed six training sessions of Amsterdam Airport Schiphol's operational crisis management team involving 54 managers. Through thematic analysis, I identified three resilience capabilities: (1) proficiently navigating the rules of play, which refers to the effective use of protocols, procedures, and leadership styles; (2) metacognition, a reflective decision-making approach enabling other known resilience capabilities such as shared situational awareness and the anticipation of future developments; and (3) directionality, a capability whereby a team establishes and reflects upon a shared goal during a crisis. Furthermore, I identified doubt as a critical disruptor of the decision-making process. Finally, the training methodology, related to red teaming, proved to be an effective approach for evaluating and enhancing resilience capabilities, and can therefore be considered an asset in the operationalisation of resilience.

In Chapter 5, building on the need for a systemic approach (Chapter 2), improved sensemaking capabilities (Chapter 2) and the proposed categorisation of resilience (Chapter 3), I developed a wargaming resilience blueprint. This blueprint enables decision-makers within complex organisations to wargame Black Swans and, in doing so, operationalise resilience. This chapter presents the iterative design process based on four playtesting workshops with 52 researchers and practitioners from crisis management, aviation, healthcare, and serious gaming.

In Chapter 6, I validated the wargaming resilience blueprint by investigating what 57 decision-makers from the aviation, crisis management, and defence sectors learned through its application in support of operationalising resilience. A thematic analysis revealed that the blueprint supported decision-makers (1) to develop a shared understanding of their organisation within its overarching complex system; (2) to imagine the impact of type-B (unknown knowns) and type-C (ignored knowns) Black Swans on their organisation; and (3) to operationalise resilience-as-an-outcome and develop a deeper understanding of it. Furthermore, conducting wargames may enhance resilience capabilities, namely shared situational awareness, the management of keystone fragilities, anticipating future developments, and sensemaking.

To conclude, this dissertation comprehensively explores how resilience can be operationalised in airports. By drawing on lessons from pandemic experiences, proposing a categorisation of resilience, observing resilience in practice, developing and validating a wargaming blueprint, the research offers both academic insights and practical tools for operationalising resilience. The findings are highly relevant for decision-makers across crisis management, policymaking, and business to improve their organisation's resilience before the next Black Swan comes.

And it will come.

Samenvatting

Sinds 2020 heeft onze samenleving verschillende grootschalige crises doorgemaakt, waaronder de COVID-19-pandemie, de blokkade van het Suezkanaal en de Russisch-Oekraïense oorlog. Deze crises brachten meerdere kwetsbaarheden aan het licht in onze transportsystemen, logistieke ketens en nationale veiligheid. Als reactie op deze crises groeide de interesse in het operationaliseren van resilience[1], oftewel het vertalen van resilience-ambities naar concrete interventies (zoals trainingen, producten en strategieën), binnen meerdere organisaties. In deze context initieerde de Technische Universiteit Delft in samenwerking met de Royal Schiphol Group, de exploitant van de luchthaven Schiphol, een promotieonderzoek naar de operationalisering van resilience. Het onderzoek hanteerde een action research-aanpak waarbij ik als promovendus nauw samenwerkte met de Innovation Hub en het Operational Resilience team van de Royal Schiphol Group. Deze vruchtbare uitwisseling tussen wetenschap en praktijk resulteerde in vijf studies, elk gepresenteerd als een apart hoofdstuk, die een essentieel deel van de puzzel rondom het operationaliseren van resilience leveren.

In Hoofdstuk 2 verken ik hoe hoge impact crises organisaties ontwrichten en kwetsbaar maken. Met de COVID-19-pandemie en luchthaven Schiphol als case study, voerde ik interviews met 16 experts uit het luchthavensysteem, waarin ze hun geleerde lessen deelden. Deze experts representeerden de luchthavenexploitant, luchtvaartmaatschappijen, publieke gezondheidsinstanties en overheidsfunctionarissen. Een thematische analyse onthulde drie belangrijke ervaringen: (1) de pandemie werd vooraf als onvoorstelbaar beschouwd, wat leidde tot beperkte paraatheid; (2) de luchtvaartsector bevond zich voortdurend in een reactieve positie, met enerzijds moeilijkheden bij het implementeren van interventies en anderzijds voortdurende reorganisaties; en (3) tijdens de pandemie ontstonden complexe relaties tussen stakeholders, met name tussen luchtvaart, overheid en publieke gezondheid.

1 In deze samenvatting gebruik ik bewust de Engelse term resilience. De Nederlandse taal heeft geen directe vertaling voor resilience. Vaak worden termen als weerbaarheid of veerkracht gebruikt als synoniem. Dit onderzoek beschouwt resilience als een combinatie van zowel weerbaarheid en veerkracht maar ook andere aspecten zoals adaptatie en transformatie.

Daarnaast werden er vier lessen uit getrokken die suggereren dat luchthavens: (1) een systemische benadering moeten hanteren; (2) sensemaking-capaciteiten (*duiding-capaciteiten)* moeten versterken om verrassende crises of Black Swans het hoofd te bieden; (3) informele relaties tussen stakeholders moeten verbeteren; en (4) de rol van organisatorische interventies zoals crisismanagement teams nader moeten onderzoeken.

In Hoofdstuk 3 onderzocht ik de conceptuele betekenis van resilience door een academische lens. Resilience werd een alomtegenwoordig modewoord in reactie op de COVID-19-pandemie en de Russisch-Oekraïense oorlog. De exacte betekenis bleef echter vaag en het concept werd gerelateerd aan andere termen zoals antifragiliteit en terugveren. Vervolgens voerde ik een verkennend literatuuronderzoek uit, waarbij ik een resilience-als-een-uitkomst-perspectief hanteerde. Op basis van deze review stelde ik een categorisering voor die resilience opdeelt in vier aspecten: (1) fragiliteit, (2) robuustheid, (3) adaptatie en (4) transformatie. Deze categorisering biedt structuur om resilience te conceptualiseren, wat naar verwachting de operationalisering ervan ondersteunt.

In Hoofdstuk 4 bouwde ik voort op de bevindingen van Hoofdstuk 2 en onderzocht ik hoe resilience-als-een-proces in de praktijk wordt geoperationaliseerd. Ik observeerde zes trainingen van het operationele crisismanagement team van de luchthaven Schiphol, met in totaal 54 managers. Door middel van een thematische analyse identificeerde ik drie resilience-capaciteiten: (1) bekwaam de spelregels navigeren, wat verwijst naar het effectief gebruik van protocollen, procedures en leiderschapsstijlen; (2) metacognitie, een reflectieve besluitvormingsaanpak die andere bekende resilience-capaciteiten mogelijk maakt, zoals gedeeld situationeel bewustzijn en het anticiperen op toekomstige ontwikkelingen; en (3) directionality (*richtinggeving)*, het vermogen van een team om een gezamenlijk doel te formuleren en hierop te reflecteren tijdens een crisis. Daarnaast identificeerde ik twijfel als een kritieke, verstorende factor in het besluitvormingsproces. Tot slot bleek de gebruikte trainingsmethodologie, gerelateerd aan red teaming (*een simulatie met tegenspel*), een effectieve manier om resilience-capaciteiten te evalueren en te versterken, en levert zo een waardevolle bijdrage aan het operationaliseren van resilience.

In Hoofdstuk 5, voortbouwend op de noodzaak van een systemische benadering (Hoofdstuk 2), verbeterde sensemaking-capaciteiten (Hoofdstuk 2) en de voorgestelde categorisering van resilience (Hoofdstuk 3), ontwikkelde ik een wargaming resilience

blueprint (*strategische simulatie blauwdruk)*. Deze blauwdruk stelt besluitvormers binnen complexe organisaties in staat om Black Swans te wargamen (*strategisch simuleren)* en daarmee resilience te operationaliseren. Dit hoofdstuk presenteert het iteratieve ontwerpproces, gebaseerd op vier ontwikkeling-workshops met 52 onderzoekers en professionals uit crisismanagement, luchtvaart, gezondheidszorg en serious gaming.

In Hoofdstuk 6 valideerde ik de wargaming resilience blueprint door te onderzoeken wat 57 besluitvormers uit de luchtvaart-, crisismanagement- en defensiesector leerden van de toepassing ervan ter ondersteuning van het operationaliseren van resilience. Uit een thematische analyse bleek dat de blauwdruk besluitvormers ondersteunde bij het: (1) ontwikkelen van een gedeeld begrip van hun organisatie en het overkoepelende complexe systeem; (2) het voorstelbaar maken van de impact van type-B (onbewuste maar bekende) en type-C (bekende maar genegeerde) Black Swans in relatie tot hun organisatie; en (3) operationaliseren van resilience-als-een-uitkomst en het verdiepen van hun begrip ervan. Daarnaast kan het uitvoeren van wargames bijdragen tot het versterken van resilience-capaciteiten, zoals gedeeld situationeel bewustzijn, het managen van kritieke fragiliteiten, het anticiperen op toekomstige ontwikkelingen en sensemaking.

Tot slot verkent dit proefschrift hoe resilience geoperationaliseerd kan worden op luchthavens. Door te bouwen op de geleerde lessen van de pandemie, een categorisering van resilience voor te stellen, resilience in de praktijk te observeren, een wargaming resilience blueprint te ontwikkelen en te valideren, biedt het onderzoek zowel academische inzichten als praktische instrumenten voor het operationaliseren van resilience. De bevindingen zijn relevant voor besluitvormers in crisismanagement, beleidsvorming en het bedrijfsleven om de resilience van hun organisatie te verbeteren vóór de volgende Black Swan komt.

En die zal komen.

1 INTRODUCTION

1. Introduction

1.1 It all started with a pandemic

In December 2019, a novel virus, SARS-CoV-2, emerged in Wuhan, China. Although a prominent news bulletin in Belgian media, I considered the unfolding epidemic as a local issue rather than a looming pandemic ready to take over the globe. Gradually, the virus spread, and cases of COVID-19 started to arrive in Europe at the end of January 2020. Still, I considered it a local issue. Around mid-March 2020, gears shifted significantly as the Belgian Federal government suddenly imposed a lockdown. Nevertheless, the ruling sentiment was "it will all be over in a few weeks"[2]. But then weeks turned into months and months into years. This consistent surprise would stick with me.

The pandemic had far-reaching impacts on all layers of society, but somehow, my paths crossed with an industry fighting for its survival, the aviation industry. As viruses spread through the movement of people, governments started to impose severe flight restrictions in March 2020, bringing aviation to a de facto standstill and pushing the industry into an existential crisis unseen since the outbreak of World War 2 (IATA, 2020). In reaction, the Delft University of Technology and the Innovation Hub of the Royal Schiphol Group drafted a PhD proposal originally titled Resilient Multimodal Transport Hubs in a Pandemic-Aware Society.

When I came across this PhD vacancy in September 2020, I was immediately intrigued. My professional background in urban logistics and robotics at bpost, the Belgian postal operator, combined with an academic background in strategic design at the University of Antwerp; medisign at the Institute for Tropical Medicine Antwerp, where I developed a patented fingerstick blood self-collection device (Nieuwborg & Goethijn, 2022); and aerospace at KU Leuven and the Belgian Nuclear Research Institute, gave me a unique interdisciplinary perspective. Furthermore, this PhD vacancy allowed me to integrate my prior experiences across logistics, healthcare, and aerospace into a cohesive research trajectory. Following a successful application, I was awarded the position which began in December 2020.

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2 As a history enthusiast, it reminds me of the "over by Christmas" sentiment present during the start of World War 1.

In relation to the COVID-19 pandemic, September 2020 was just after the first wave in the Netherlands. COVID-19 seemed to be out of sight and almost out of mind. Nevertheless, a second wave was looming, reaching its peak in December 2020. Starting in the midst of the pandemic, I held an unconventional position where I was tasked with investigating a phenomenon as it was unfolding. Subsequently, literature around pandemics, aviation and resilience exploded exponentially, making it extremely difficult to see the forest for the trees. To increase the difficulty even further, when starting my PhD, working from home was a legal obligation, making me unable to visit Delft and Schiphol, thus creating geographic, cultural[3] and contextual distance. It took me about nine months to set foot on both sites and meet my promotors physically. Gradually, the COVID-19 restrictions disappeared, and in December 2021, I moved to the Netherlands, then commencing the full PhD experience.

1.2 Research background

The COVID-19 pandemic triggered the most severe crisis in aviation history, surpassing any challenge faced since the outbreak of the Second World War (IATA, 2020). Beginning in December 2019, the SARS-Cov-2 virus quickly spread worldwide and became a global pandemic by March 2020 (WHO, 2020). In response, governments worldwide imposed strict travel restrictions, bringing aviation to a quasi-standstill. This standstill entailed an air traffic decrease of 94% in April 2020 compared to 2019 (IATA, 2020), resulting in major financial losses. To illustrate, in 2020, airlines and European airports lost respectively 372 billion USD (ICAO, 2022) and 37 billion USD in revenue (ATAG, 2020).

Although the aviation industry gradually recovered, the crisis underscored the urgent need for organisational resilience (Arora et al., 2021; Hanne et al., 2022; ICAO, 2020; Linden, 2021; Terry, 2020), hereafter referred to simply as resilience. The Royal Schiphol Group recognised this need and therefore initiated this PhD research. However, as Hermelin et al. (2020) note, knowledge on operationalising resilience, or translating resilience aspirations to actionable interventions (e.g.

3 Although Belgium and the Netherlands are neighbouring countries with an overlapping culture and share the Dutch language, things occasionally get lost in cultural translation. Furthermore, to address a common misconception, Dutch is the official language of Belgium, not Flemish. Colloquially, Flemish is considered an overarching term encompassing all regional dialects.

training, products, and strategies), remains scarce within aviation and other domains. As discussed in Chapters 3, 4 and 6, a key barrier to the operationalisation of resilience lies in its conceptual ambiguity. In general, this dissertation adopts the view of resilience suggested by Linnenluecke (2017), framing it as a desirable trait for dealing with adversity. Furthermore, resilience is considered both an outcome, or an organisational state after facing a disruption, and a process, referring to the capabilities that enable resilient outcomes (Ketelaars et al., 2024). In this dissertation, resilience-as-a-process and resilience capabilities are used interchangeably.

The nature of adversity considered in this research evolved over time. Initially, the focus was on the COVID-19 pandemic, but it later expanded to include broader public health disruptions. As addressed in Chapter 2, this perspective was ultimately extended to the broader notion of Black Swans or surprising and high-impact events that are only retrospectively predictable through hindsight (Taleb, 2007).

1.3 Research aim

Based on the research background, the aim of this dissertation was formulated as the following main research question (MRQ): *How can resilience be operationalised in airports to prepare for and respond to looming Black Swans?*

1.4 Research approach

This dissertation came to fruition through an action research approach. As defined by Greenwood and Levin (2007), action research is a research strategy and reform practice that is used in the field, consists of multiple research techniques and is aimed at creating change and generating data for scientific knowledge. The methodology is highly collaborative and focuses on mutual learning between stakeholders. Conducting action research implies a cyclical approach consisting of (1) constructing or uncovering issues, (2) planning action to respond to those issues, (3) taking action, and (4) evaluating action (Coghlan, 2019).

In my research, I conducted action research in close collaboration with the Innovation Hub, from December 2020 until December 2022, and Operational Resilience team, from January 2023 until December 2024, of Amsterdam Airport Schiphol of the Royal Schiphol Group. This collaboration offered firsthand insights into an airport system's operational and strategic challenges when dealing with a pandemic and other Black Swans. Furthermore, it enabled the creation of a fruitful exchange between academia and practice. The following research overview section will elaborate on how this action research approach influenced each chapter.

Besides an action research approach, I predominantly maintained a complexity science and systemic design lens. Although consistent definitions are scarce, complexity theory is interested in the behaviour of complex systems (Patton, 2015; Sevaldson, 2021). As defined by Snowden and Boone (2007), such systems consist of many dynamically interacting elements that can self-organise, producing emergent properties whereby the whole becomes greater than the sum of its parts. Furthermore, the elements interact non-linearly, whereby minor changes can have disproportionate consequences. An airport is a prime example of such a complex system. Systemic design fuses complexity theory and the broader systems thinking field with design thinking practices (Bijl-Brouwer & Malcolm, 2020). Foundational in complexity theory and a major inspiration for Chapter 3 is the Cynefin framework (Snowden & Boone, 2007). This framework functions as a decision-making support for dealing with complexity.

1.5 Research overview

To address the MRQ, I conducted five studies, each presented in a corresponding chapter of this dissertation. In the following subsection, I explain the rationale behind each chapter. The last paragraph of each section presents the corresponding studies, the sub-research questions (SRQ) and the methodologies used. For the quick reader, Table 1.1 summarises each chapter, SRQs, and method.

Table 1.1 Overview dissertation

Chapter	SRQ	Method
1. General Introduction		
2. Pandemic meets airport	What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic?	Interview study
3.The resilience Tower of Babel	What aspects does resilience consist of?	Scoping review
4. Resilience in the wild	What resilience capabilities do airport crisis management teams use?	Observational study
5. Wargaming looming Black Swans – the design	How to design a minimum viable seminar-style wargame that supports decision-makers in achieving systemic resilience in the face of looming Black Swans?	Playtesting
6. Wargaming looming Black Swans – the validation	What do decision-makers in complex systems learn from wargaming Black Swans to operationalise resilience?	Observational study
7. General Discussion		

1.5.1 Chapter 2: pandemic meets airport

Starting the PhD in the aviation industry during an ongoing pandemic, I was immediately thrown into the deep end. In collaboration with the Innovation Hub, I explored many product and service interventions, including digital health passports, shelter pods, rapid diagnostics and heat cameras. However, as quickly became apparent and reaffirmed by my own research, these interventions often got caught up by time due to new knowledge, such as new variants of COVID-19, or a shifting context, such as new policies or legislation, making them irrelevant. Subsequently, I noticed that, as designers tend to do, I needed to zoom out to explore the underlying issues hampering the deployment of these interventions on an airport system level.

Back then, multiple aviation scholars (Arora et al., 2021; Linden, 2021; Sun et al., 2021)affecting millions of aviation users and stakeholders. As the aviation sector has faced disease outbreaks and extreme events before—albeit not at the same scale—and will, in all likelihood, face them again, we provide an assessment in this study that a highlighted the importance of a systemic approach for dealing with public health disruptions. However, an airport system lens was rarely used to investigate the underlying issues that the COVID-19 pandemic spawned. Scholars predominantly

focused on operational interventions, such as exploring stress factors affecting aviation workers (Paisan & Wan-Chik, 2023) and highlighting the importance of contactless technologies and interoperability through Internet of Things applications (Sun et al., 2021). Others addressed organisational aspects, such as new airport revenue models (Choi, 2021; Colak et al., 2023) and strategies for coping with crises (de Wit, 2022; Linden, 2021).

Subsequently, I conducted an interview study investigating the complex interplay between aviation stakeholders (e.g. the airport operator and airlines) and non-aviation stakeholders (e.g. security services, government ministries, and public health agencies), collectively referred to as the airport system. The aim was to uncover the underlying issues hampering the operationalisation of resilience by capturing firsthand accounts from 16 experts across the airport system. Subsequently, SRQ1 was: *What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic?*

1.5.2 Chapter 3: the resilience Tower of Babel

In reaction to the COVID-19 pandemic, the interest in becoming "resilient" skyrocketed within the aviation industry (Eurocontrol, 2022; ICAO, 2020; Terry, 2020). However, I noticed that there was no consensus on what resilience as a concept means. Although originally collected in the context of Chapter 6, I illustrate this point using an excerpt of a questionnaire asking decision-makers from the aviation and defence sector about their definition of resilience.

> *Q: What is resilience?*
> *A1: Be predictable (robust) to meet your agreed service level; A2: The ability to absorb setbacks and recover quickly; A3: Adaptability in unforeseen circumstances; A4: The ability to navigate a disruption that ultimately changes your business model and strategy for better*
> *- pre-questionnaire responses, from Nieuwborg et al. (2024)*

One quickly notices multiple different conceptualisations: being predictable, robust, absorption, recovery, adaptability, etc. This phenomenon also occurred during the COVID-19 pandemic. I gained a new definition from each expert, whether from aviation, public health, or other stakeholders. Furthermore, another trending concept emerged, antifragility, whereby one gains from disruptions (Taleb, 2012). Although

these interpretations somewhat overlap, they can differ fundamentally, leading to a Babylonian confusion[4] whereby people start talking past each other. If an organisation wants to operationalise resilience, should it aspire to a more robust, adaptative, or antifragile approach?

Looking into academic literature revealed a similar issue: resilience has increasingly meandered into an elusive buzzword (Hillmann & Guenther, 2021; Linnenluecke, 2017). To address this ambiguity and establish a coherent frame of reference for subsequent studies, I conducted a scoping review investigating the many conceptualisations of resilience. Subsequently, SRQ2 posed the question: *What aspects does resilience consist of?* To provide some scope, I limited myself to a resilience-as-an-outcome lens. The following chapter delves deeper into resilience-as-a-process.

1.5.3 Chapter 4: resilience in the wild

The findings of Chapter 2 highlighted the importance of crisis management teams (CMT), or multidisciplinary teams within an organisation designated to handle crises (Coombs, 2015). The chapter attributed the CMT's importance to its multidisciplinary nature and collective capability to conduct sensemaking during a crisis. However, these findings remained at a high level and thus were difficult to translate into actionable interventions to build resilience. Building on the work of Williams et al. (2017) and through my own embedded research at Amsterdam Airport Schiphol, I hypothesised that CMTs implicitly operationalise various resilience capabilities throughout their decision-making processes. Much of this knowledge, however, is tacit, held by experienced crisis managers, but rarely formalised or documented. Meanwhile, academic research on the resilience capabilities of airport CMTs is virtually non-existent, with only limited empirical studies available in related sectors, such as Gomes et al. (2014) on nuclear facilities and Tveiten et al. (2012) on the oil and gas industry.

4 I am referring to the biblical parable of the Tower of Babel, which explains the existence of different languages. In this parable, humanity speaks a common language and aims to build a tower, the Tower of Babel, to reach heaven. Displeased with their ambition, God introduces multiple languages, making mutual understanding impossible, and scatters humanity across the earth, leaving the tower unfinished.

To uncover this tacit knowledge while answering the call for more empirical research within the resilience field (Linnenluecke, 2017), I conducted a study observing how 54 managers of the Commissie van Overleg, Amsterdam Airport Schiphol's operational CMT, operationalise resilience "in the wild". The corresponding SRQ3 was: *What resilience capabilities do airport CMTs use?*

1.5.4 Chapter 5: wargaming looming Black Swans – the design

Then, I set out to create an intervention enabling the operationalisation of resilience. Nevertheless, finding the right intervention was difficult. As mentioned earlier, our initial focus was predominantly on products and or services (e.g. digital health passports, shelter pods, and heat cameras). However, as both the findings of Chapter 2 and my lived experience showed, these interventions often became obsolete by the time they were implemented. Moreover, there was a risk that these interventions would only fixate on the prior and recently experienced crisis, in this case, the COVID-19 pandemic, rather than preparing organisations for other looming Black Swans.

The insights from Chapter 2 provided a new intervention direction, highlighting the need to strengthen sensemaking capabilities and suggesting the potential of wargaming as a tool for operationalising resilience. Wargaming, a subset of serious gaming, can be defined as the simulation of decision-making in a synthetic environment involving elements of competition or conflict (Perla, 2022). Scholars have suggested that wargaming may serve as a valuable method for simulating the dynamics of complex systems (Brightman, 2021; Development, Concepts and Doctrine Centre, 2017) and exploring the implications of Black Swan events (Perla, 2022; Perla & McGrady, 2011). I hypothesised that such simulations could provide critical insights into an organisation's resilience, or lack thereof, thereby supporting its operationalisation.

To test this hypothesis, I designed and validated a "wargaming resilience blueprint". This chapter focuses on the blueprint's development, which was shaped through four sessions in collaboration with 52 researchers and practitioners in the fields of design, crisis management, healthcare and serious gaming. Subsequently, SRQ4 posed the question: *How to design a minimum viable seminar-style wargame that supports decision-makers in achieving systemic resilience in the face of looming Black Swans?*

1.5.5 Chapter 6: wargaming looming Black Swans – the validation

Building upon the findings of the prior chapter, I sought to validate the wargaming resilience blueprint's effectiveness in enabling the operationalisation of resilience. This validation was done by assessing its impact through observing four wargaming sessions with 57 decision-makers from aviation, defence and other sectors. The corresponding SRQ5 was formulated as: *What do decision-makers in complex systems learn from wargaming Black Swans to operationalise resilience?*

1.5.6 Chapter 7: general discussion

Finally, this dissertation concludes with a general discussion that reviews the key findings and addresses the research questions. This chapter then outlines the implications and limitations of the dissertation while concluding with suggestions for future research.

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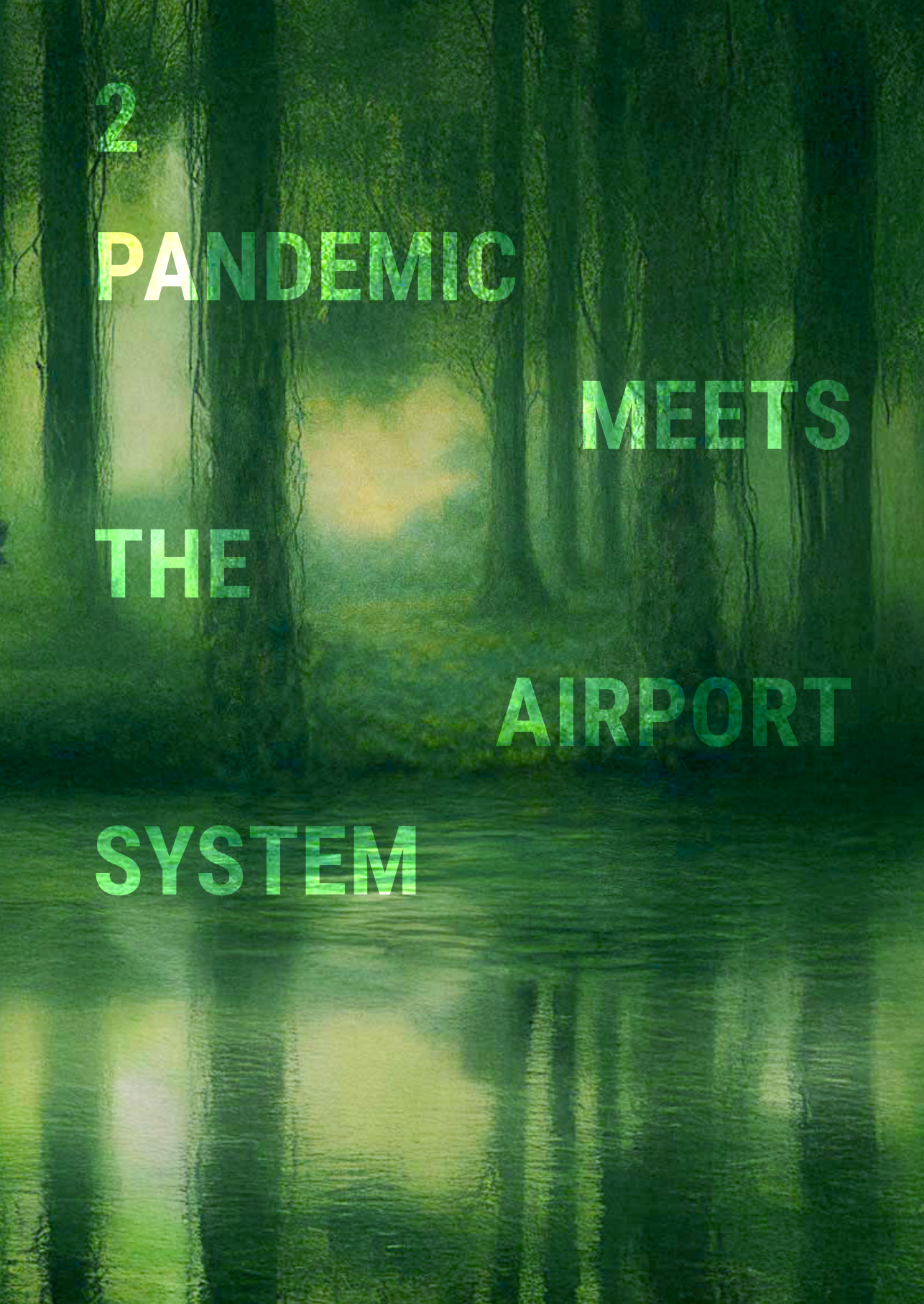
2
PANDEMIC
MEETS
THE
AIRPORT
SYSTEM

2. Pandemic meets the airport system

In this chapter, an interview study was carried out to investigate the complex interplay between aviation stakeholders (e.g. the airport operator and airlines) and non-aviation stakeholders (e.g. security services, government ministries, and public health agencies) during the COVID-19 pandemic. The aim was to uncover the issues hampering the operationalisation of resilience. The corresponding SRQ1 was: *What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic?*

Thematic analysis revealed three key experiences and four lessons learned. The key experiences indicate that: (1) the pandemic was considered unimaginable beforehand, leading to a limited readiness; (2) the aviation sector found itself constantly on the back foot, struggling to implement interventions while undergoing reorganisation; and (3) during the pandemic complex relational dynamics emerged between stakeholders, particularly between aviation, government and public health actors. The lessons learned suggest that airports should: (1) adopt a systemic approach, (2) strengthen sensemaking capabilities against surprising crises or Black Swans, (3) foster informal relationships among stakeholders, and (4) further examine the role of organisational interventions such as crisis management teams.

The results of this chapter construct an essential context while highlighting barriers and enablers for operationalising resilience. First, the chapter kickstarted a shift from pandemics towards the broader concept of Black Swans. Furthermore, lessons learned one and two planted the seeds for the wargaming resilience blueprint addressed in Chapters 5 and 6. Finally, lesson learned four formed the raison d'être for Chapter 4, whereby the workings of crisis management teams were further investigated.

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Abstract

The COVID-19 pandemic proved to be an existential public health and economic crisis for the airport system. An interview study was conducted using Amsterdam Airport Schiphol as a use case to prepare for future public health disruptions. The study aimed to uncover key experiences and lessons learned by an airport system during the COVID-19 pandemic by interviewing 16 experts from airport operators, airlines, public health agencies, security services, and the government. After thematic analysis, four themes emerged. The first theme addressed the limited readiness of the airport system; the COVID-19 pandemic seemed unimaginable regardless of prior experiences with infectious diseases or weak signals. The second theme depicts an airport system running behind the facts, one that had difficulties implementing operational interventions and had to deal with extensive reorganisations. The third theme illustrated the complex relational dynamics within the airport system, such as the hesitancy of public health stakeholders towards aviation stakeholders and the government utilising a top-down approach. Finally, theme four provides lessons learned for the future whereby actively fostering a systemic approach, sensemaking capabilities, and informal relations are recommended. Current constructions like Crisis Management Teams and the Airport Operations Centre support these learnings. Further reflection and operationalisation of the study's findings are critical to proactively supporting the airport system's transition from a potential pandemic liability to a strategic asset in mitigating public health disruptions.

2.1 Introduction

The COVID-19 pandemic triggered an unforeseen existential crisis for the aviation industry, the greatest since the outbreak of the Second World War (IATA, 2020). As COVID-19 spread across the globe, travel restrictions were imposed, and travel demand diminished. Subsequently, the aviation industry reached a de facto standstill, as total air traffic decreased by 94% in April 2020 compared to 2019 (IATA, 2020). In 2020, airlines lost approximately 372 billion USD in revenue while passenger numbers were reduced by 60% (ICAO, 2022). Meanwhile, airport revenue in the European region declined by 56.7%, translating to a loss of 37 billion USD in revenue (ATAG, 2020). Currently, the industry is bouncing back as global passenger traffic is expected to reach pre-COVID levels in 2024 (ACI, 2023)

The aviation industry played a crucial role in the spread of COVID-19 across the globe (Arora et al., 2021; Coelho et al., 2020; Sokadjo & Atchadé, 2020; Sun et al., 2022; Zhang et al., 2020), as travel is a vital facilitator of disease spread. Precedents for the spread of diseases through air transportation are extensive and include MERS (Gardner et al., 2016), Ebola (Bogoch et al., 2015), and H1N1 (Khan et al., 2009). Ozonoff and Pepper (2005) note that air travel is one of the most critical "interconnections" from a public health standpoint. Kuo and Chiu (2021) reaffirm this by stating that the spread of COVID-19 strongly correlates to air connectivity instead of geographic distance. For example, France was affected by COVID-19 before the Philippines, as it had greater connections with China.

Within the aviation industry, by consolidating converging and diverging passenger flows, airports form the central nodes of the air transportation network. The combination of high crowd densities and throughputs in an enclosed space facilitates prime conditions for transmitting infectious diseases (Browne et al., 2016). According to Nicolaides et al. (2012), airports are especially influential if they are dominated by long-range travel, have strong connections to other airport hubs, and have a strong west-east connection. Ribeiro et al. (2020) suggest that imposing strict entrance controls or locking down highly connected airports could significantly slow transmission rates. In other words, airports play an orchestrating role concerning the aviation-related spread of infectious diseases.

In the wake of the COVID-19 pandemic, a wealth of novel research emerged on airports and their role in public health disruptions. When looking into the state-of-the-art, publications can be broadly categorised around operational or organisational aspects. Regarding the operational aspects, research is conducted into airport employees' experiences, passengers' experiences, airport operations, and novel technologies. Based on a literature review, Paisan and Wan-Chik (2023) uncovered nine stress factors (e.g. workload, team conflicts and the pandemic itself) affecting aviation workers. Meanwhile, Tuchen et al. (2023) conducted a web-based survey amongst four airports: Amsterdam Airport Schiphol, Singapore Changi Airport, Taipei Taoyuan Airport, and Zurich Airport. Their main findings centred around the importance of protecting the workforce in terms of job security and against infectious diseases. Shifting towards the passengers, Ma et al. (2022) researched the impact of the airport's physical environment on the perceived safety, satisfaction and travel intentions through surveys. Their results underpin the importance of a clean airport as it improves the passenger experience. Regarding airport operations, Okulicz &

Rutkowska (2021) concluded, based on operational data of Chopin Airport, that there is a lack of appropriate procedures to deal with a complete suspension of air traffic. Subsequently, they propose using more real-time data exchange through Airport Collaborative Decision-Making (A-CDM) systems. Concerning technology, Štimac et al. (2021) investigated the future terminal design and emphasised the need to implement contactless technologies, health checkpoints, and redesign in-terminal passenger flows. Sun et al. (2021) reaffirm the importance of contactless technologies while advocating for more interoperable systems amongst aviation stakeholders through Internet of Things (IoT) applications.

Regarding the organisational aspects, research is conducted on airport revenue models, strategies, and policy. Choi (2021) and Colak et al. (2023) focus on airport revenue models. Choi (2021) proposes to repurpose the increased dwell time of passengers, a by-product of health verifications during a pandemic, to boost passenger spending by aligning operational procedures with a commercial revenue perspective. Meanwhile, Colak et al. (2023) conducted an interview study on airport business models concerning the COVID-19 pandemic. They highlight the importance of diversification of revenue streams, cost minimisation, enhanced digitalisation and sustainability focus. Moving towards airport strategies, Linden (2021) investigated how aviation managers could better prepare for uncertain crises. He makes recommendations for short- and long-term planning based on literature and praxis. The recommendations include not exaggerating short-term development, developing a common strategy language, managing uncertainty proactively, making long-term plans by fostering a multidisciplinary dialogue and making the board a co-creation team. In addition, de Wit (2022) researched how airport strategic planners should cope with high-impact and uncertain events and advocated using judgement-based approaches such as scenario building and simulations through serious gaming. Finally, looking at a policy level, Arora et al. (2021) assessed the effects of the COVID-19 pandemic and response mechanisms while proposing a more coordinated global response framework.

Reflecting on previous publications, multiple authors (Arora et al., 2021; Linden, 2021; Sun et al., 2021) highlight the importance of a systemic or multi-stakeholder approach, usually put forward as a lesson learned for future crises. However, the systemic approach is rarely used as a research lens to investigate airports during the COVID-19 pandemic. Current research seems to focus more on specific operational or organisational aspects rather than the airport system as a whole. Holistically

capturing the rich and complex interplay of aviation stakeholders (i.e. the airport operator and airlines) and non-aviation stakeholders (i.e. security services, ministries, and public health agencies) through first-hand accounts seems crucial for practitioners and researchers as they portray the on-the-ground operational and organisational realities while creating preparedness for airports in the face of future public health disruptions. Subsequently, this study aims to use a systemic approach to investigate learnings and key experiences through primary data collection, with the main research question being: What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic? For this study, the airport system is defined as the combination of aviation and non-aviation stakeholders, as both played a crucial role throughout the COVID-19 pandemic.

2.2 Methods

Semi-structured interviews held in a conversational style were used to capture the key experiences and lessons learned by an airport system during the COVID-19 pandemic. This method enabled capturing rich qualitative data (e.g., thoughts, intentions, and ways of organising) from multiple perspectives of a past event (Patton, 2015). Experts were recruited throughout the airport system to gain systemic insights while allowing for different perspectives. The resulting interviews were thematically analysed using Braun and Clarke's (2006) six-phase approach.

2.2.1 Case study, participants & recruitment

This study was conducted in collaboration with the Royal Schiphol Group, a Dutch airport operator managing Amsterdam Airport Schiphol (AMS). AMS was chosen as the use case for this study due to this collaboration and because it fits Nicolaides et al. (2012) profile of critical airports during a public health crisis. To illustrate, AMS is dominated by long-range travel; before COVID-19, AMS was the second largest European airport with an annual total of 71.1 million passengers while being a major transfer hub, as in 2021, 43.7% of its passengers used AMS as a layover (Royal Schiphol Group, 2022). Second, in 2022, AMS was Europe's most connected airport, ranked third globally (ACI, 2022). Third, AMS maintains strong connections to Asia and North America, with 6.6% and 10.7% of the passenger volumes travelling between these regions in 2019 (Royal Schiphol Group, 2020).

In preparation for expert recruitment, key stakeholders involved in AMS's system during the COVID-19 pandemic were identified by exploratively interviewing four airport operator employees and co-creating a stakeholder map (Figure 2.1). The resulting map included aviation stakeholders, such as the airport operator and airlines, and non-aviation stakeholders, such as public health services and ministries.

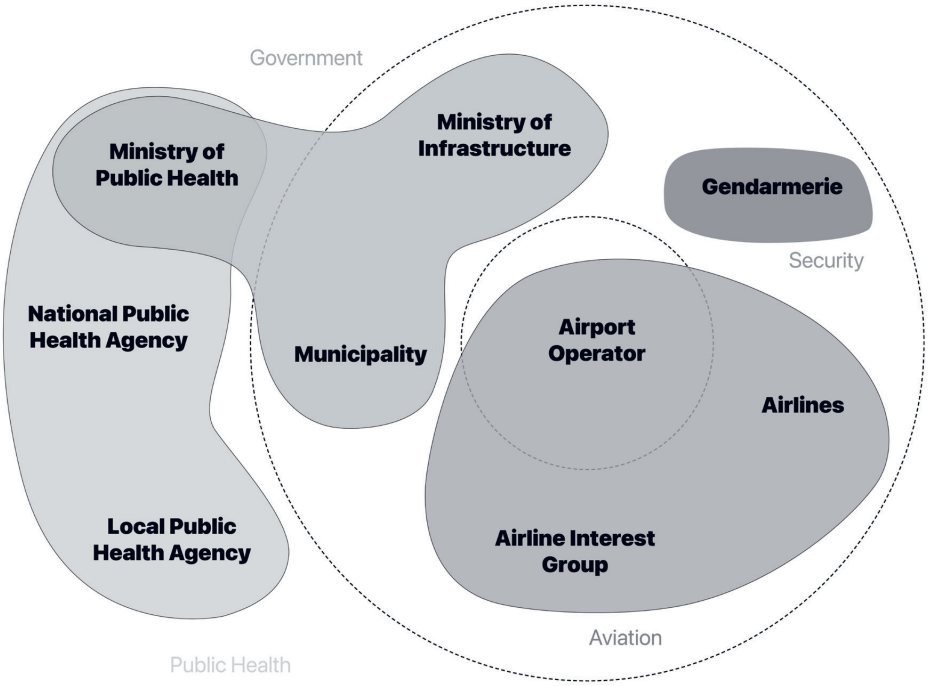

Figure 2.1 The stakeholder map used for expert recruitment.

With the key stakeholders identified, primary and secondary inclusion criteria were defined for expert recruitment. As primary criteria, experts had to represent a key stakeholder, to hold a managing or advisory function at the start of the pandemic, and their profession had to be heavily impacted by the COVID-19 pandemic. For secondary criteria, experts ideally had extensive experience in the airport system and had been exposed to other high-impact disruptions (e.g., 9/11 terrorist attacks, SARS, the eruption of the Eyjafjallajökull volcano and/or Ebola). Experts were sourced through a combination of personal networks and snowballing. To ensure diversity, experts from each relevant organisation and internal department were selected. From this point onwards, experts are referred to as participants.

2.2.2 Data Collection

Participants were invited for a one-on-one semi-structured interview where they were asked to discuss their key experiences and lessons learned concerning the COVID-19 pandemic in the context of the airport system. An interview guide and timeline supported the interviews. The interview guide provided a set of introductory (7) and reoccurring questions (24) concerning the timeline (Figure 2.2). These questions served as a structure and were introduced conversationally. Questions included, for example, *What were key moments during the first wave of the COVID-19 pandemic?*; *How did your organisation react?; What stakeholders were involved?;* and *What are your key lessons learned from the COVID-19 pandemic?*

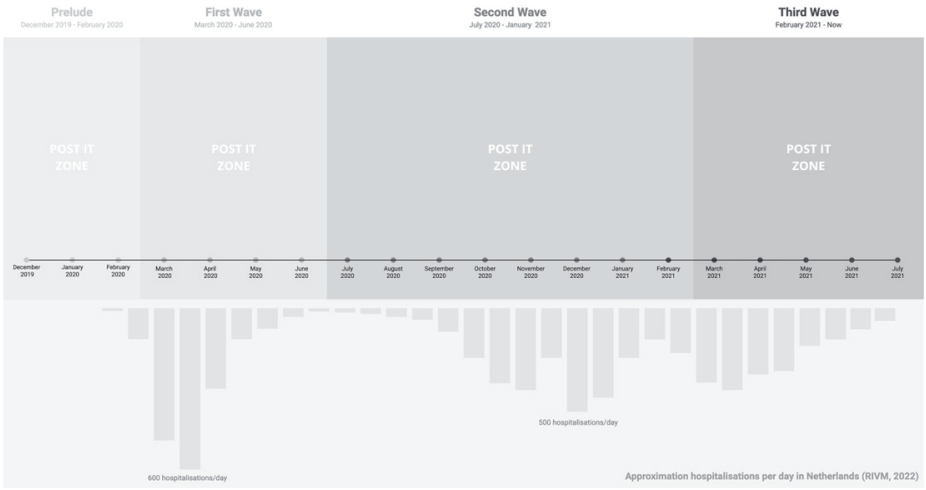

Figure 2.2 The timeline used during the interviews presents four pandemic time blocks: prelude, first wave, second wave, and third wave. The graph shows the approximate number of daily hospitalisations in the Netherlands (RIVM, 2022). *The grey blocks labelled "Post-it zone" functioned as a space where the interviewer made live notes using digital Post-its in Miro*.

The timeline (Figure 2.2) consists of four COVID-19 pandemic time blocks in the Netherlands: a prelude (December 2019 - March 2020), the period from the first cases in Wuhan (China) until the start of the so-called first wave; the first wave (March 2020 - June 2020); the second wave (July 2020 - January 2021); and the third wave (February 2021 - May 2021). The timeline functioned as a conversation starter and a frame of reference to support the participants in recollecting the order of certain events and their relation to the broader time blocks.

The interviews were in Dutch and held via Microsoft Teams. The interviews lasted between 40 and 120 minutes. During the interview, the timeline was placed on an online whiteboard (Miro) and shared with the participants via Microsoft Teams' screen sharing. The online whiteboard allowed the interviewer to make live notes in the "Post-it zone" using digital Post-its. Following Francis et al. (2010)sample size is often justified by interviewing participants until reaching 'data saturation'. However, there is no agreed method of establishing this. We propose principles for deciding saturation in theory-based interview studies (where conceptual categories are pre-established by existing theory, the initial analysis sample required representing the nine key stakeholders. Then, data collection continued until saturation occurred. This study defined the saturation point when three consecutive interviews yielded no new themes, excluding the initial analysis sample.

2.2.3 Data Analysis

Inductive thematic analysis was conducted to identify, categorise, and report patterns in the participants' experiences. Methodologically, Braun & Clarke's (2006) six-phase approach was used with a constructionist lens and an emphasis on latent patterns. The six-phase approach consists of (1) familiarising with the data; (2) generating initial codes; (3) searching for themes; (4) reviewing themes; (5) defining and naming themes; and (6) reporting.

Data familiarisation consisted of three steps: listening to the interviews, transcribing the interviews, and reviewing the transcripts. Transcripts were created verbatim and formed the primary data source for the following research steps and were reviewed by the first author. The timelines presented during the interview supported the familiarisation process.

Initial coding occurred in three rounds. In the first round, the primary author coded all transcripts utilising ATLAS.ti software. In the second round, two transcripts were independently coded by the second and third authors and compared to the first-round coding results. Based on this comparison, a third round of coding took place for all transcripts. The goal of these three-round approaches was to ensure the consistency and validity of the coding while reducing interpretation bias.

After coding, the main- and subthemes were searched, developed, and reviewed in collaboration by the first, second, and third authors throughout several workshops. Several codes were discarded as they were deemed irrelevant by the first, second, and third authors. This process used Post-its, a digital (Miro), and an analogue whiteboard.

Defining and naming the main and subthemes was primarily the task of the first author; all authors then reviewed this. To support the themes, illustrative quotes from the participants were translated from Dutch to English and paraphrased to improve readability. The first author translated and paraphrased the quotes; the second and third authors then reviewed these. Finally, the report was drafted and reviewed by all authors.

2.2.4 Ethics

This study was approved by the TU Delft Human Research Ethics Committee (reference number 1630). None of the authors had any hierarchical relation with the participants before the study. All participants were given an informed consent form, which was presented by the first author and signed before the interview. Participants were informed that participation was voluntary and withdrawal could be made at any point. Opinions expressed during the interview were confidential and anonymised, allowing participants to speak freely.

2.3 Results

2.3.1 Participants

In total, 16 participants representing all stakeholders in the AMS airport system were interviewed until saturation was achieved. The participants included representatives of the gendarmerie, airport operator, airlines, national government, local government, national public health agency, and local public health agency. In the case of the airport operator and airlines, all participants worked in different departments, allowing for diverse perspectives. More detailed characteristics of the participants are given in Table 2.1. In general, the participants were eager to share their experiences, giving the interviews a conversational nature. The timeline supported the participants in structuring the interviews and reflecting on their experiences.

Table 2.1 Interview participants, coded with the first letter of their main area of expertise (S=Security, A=Aviation, G=Government and P=Public Health) followed by a number.

Participant	Function	Affiliation	Area of expertise
S1	Deputy Commander	Gendarmerie	Security
A1	Program Manager Security	Airport Operator	Aviation, Security
A2	Crisis Manager	Airport Operator	Aviation, Security & Public Health
A3	Manager Finances	Airport Operator	Aviation
A4	Lead Operations	Airport Operator	Aviation
A5	Lead Operations	Airport Operator	Aviation
A6	Program Manager Operations	Airport Operator	Aviation
A7	Manager Airline Partnerships	Airport Operator	Aviation
A8	Vice President Operations	Airline	Aviation
A9	Managing Director Health	Airline	Aviation & Public Health
A10	Secretary General	Airlines Interest Group	Aviation
G1	Manager Public Health	Ministry of Public Health	Government & Public Health
G2	Senior Policy Advisor Infrastructure	Ministry of Infrastructure	Government
G3	Manager Security	Municipality	Government & Security
P1	Infectious Diseases Specialist	Local Public Health Agency	Public Health
P2	Infectious Diseases Specialist	National Public Health Agency	Public Health

2.3.2 Themes

The thematic analysis generated 521 codes, aggregated into four main themes and 12 subthemes. The four main themes are (1) limited readiness in the face of the looming COVID-19 pandemic; (2) constant firefighting; (3) complex relational dynamics; and (4) lessons learned for future public health disruptions. Table 2.2 provides an overview of each theme, and subthemes supported with illustrative quotes.

Table 2.2 Overview of the themes and subthemes supported with illustrative quotes.

Limited readiness in the face of the looming COVID-19 pandemic	
Trivialisation of pandemics despite prior experiences	And those [models for easily transferable airport diseases] were very serious models, which were treated somewhat laconically at the time. […] during the initial COVID-19 outbreak there was this sentiment of 'it won't come here'. […] The COVID-19 pandemic seemed more like a theoretical exercise." (G2)
Underestimation of weak signals	"I think we were quite naive in that period, […] COVID-19 is there [China], and it'll stay there" (A8)
The unimaginable pandemic	"We had an awayday with the management team and then we thought about a few "what-if" scenarios. […] This included a scenario that we had to close a large part of the airport because the world was closing. We could mostly laugh about that because we just couldn't imagine it." (A6)
Constant firefighting	
Running behind the facts	"You're running behind the facts, because the situation is already decided: China is closing, the US is closing, and suddenly there's a lockdown […] it just happens" (A2)
Operational interventions with mixed success	"[intervention] never got off the ground because time caught up" (A7)
Reorganisations in aviation	"Now we're scaling up with fewer employees […] but the number of projects hasn't decreased so then you see a problem." (A3)
Complex relational dynamics	
Hesitant public health stakeholders	"The National Public Health agency was very wary of conflicting interests. So they didn't want the aviation industry […] on their emergency committee." (A9)
Difficult government relations	"Yes, all kinds of decision models have been set up, but they still had the function of informing rather than consulting. No public private coordination." (G2)

Lessons learned for future public health disruptions	
Need for a systemic approach	"The pandemic showed […] that if you do not think more in ecosystems, you will not survive […] as an airport" (A6)
Need for sensemaking capabilities	"[…] you cannot be naive anymore […] You must arm yourself by making plans and scenarios for the next pandemic" (A10)
Indispensable informal relations	"The informal has removed the noise and provided the solutions" (S1)
Effective organisational interventions in practice	"In the beginning we were a bit of a stiff mammoth tanker […] but the tanker moved faster and faster […] and was increasingly able to quickly anticipate the everyday hustle and bustle." (A8)

2.3.2.1 Limited readiness in the face of the looming COVID-19 pandemic

While reflecting on the prelude, all participants indicated that the airport system was limitedly prepared for the COVID-19 pandemic. First, prior experiences with public health disruptions (e.g. SARS, H1N1 & Ebola) seem trivialised. Second, the airport system underestimated the weak signals given at the start of the COVID-19 outbreak. Finally, the looming pandemic was unimaginable and approached anecdotally rather than as an existential threat.

A. Trivialisation of pandemics despite prior experiences

Despite prior experiences with public health disruptions (e.g., placing disinfection mats for SARS, preparing AMS regarding H1N1 and quarantining Ebola-infected passengers), the airport system seemed to trivialise the concept of a pandemic. However, participants indicated that knowledge regarding public health was predominantly theoretical. Participant G2 mentioned that pre-COVID models, stating the extreme impact of infectious diseases, were often treated laconically. The models seemed more like a theoretical exercise rather than an actual threat. Participant G1 reaffirmed this sentiment by stating that the pre-COVID experience with infectious diseases was more of an incidental nature, as no recent significant public health disruption had reached the Netherlands. Finally, several participants mentioned

feeling that the Dutch public health system would be capable of dealing with an infectious disease outbreak; the Netherlands seemed well prepared.

B. Underestimation of weak signals

Many participants quickly became aware of the initial outbreak in China through first-hand channels. Several aviation participants attributed this to having close commercial relations with the Chinese aviation industry. Participant A8 illustrates this by mentioning that their airline had direct connections from AMS to several Chinese cities while their partnering airline maintained a direct connection to Wuhan. The public health participants noted having different channels, referring to an international surveillance network for infectious diseases, a Program for Monitoring Emerging Diseases (ProMED) mailing list, and an aviation health advisory group.

During the prelude phase, a reoccurring sentiment was that COVID-19 was mainly perceived as a regional public health disruption rather than a potential pandemic. Participant A6 mentioned that the focus was predominantly on the impact on the traffic to and from Asia rather than their system. There seemed to be a certain naivety that COVID-19 would remain in China. Participant A9 illustrated this with an anecdote whereby an airline, in a gesture of friendship, provided medical equipment to China during the prelude. The key assumption was that the Netherlands had plenty of equipment while being unaware of the looming pandemic. Nevertheless, A9 reflected positively on this anecdote, as the Chinese returned this gesture throughout the COVID-19 pandemic.

Throughout the prelude, China reacted rigorously by imposing travel restrictions and lockdowns. Although worrying, most participants were shocked when the US suspended travel with most European countries on the 11th of March 2020. This was viewed as a so-called “showstopper” moment.

C. The unimaginable pandemic

Although the stakeholders of the airport system were generally aware of the COVID-19 outbreak through prior experience and weak signals, actual preparations for a potential pandemic remained scarce. Several participants attributed this to the pandemic being 'unimaginable'; there were no precedents. To illustrate, participant A6 reflected on a management team day whereby several "what-if" scenarios were developed. One scenario tackled a pandemic and the subsequent closure of a large part of the airport; reactions were fleeting as it seemed unimaginable. Other participants had similar experiences, referring to meetings where they were ridiculed when suggesting the potential impact of a pandemic. However, some preparations were made. Participant A2 referred to setting up an internal crisis team to prepare for a pandemic threat and to explore how flows of potentially infected passengers could be separated.

This unimaginability of the crisis reoccurred throughout the pandemic itself. Participants suggest that this subtheme resurfaced at the end of the first wave, whereby the sentiment of "the crisis is over" was prevalent. This unimaginable aspect is related to the theoretical experiences addressed in subtheme A and the naivety noted in subtheme B.

2.3.2.2 Constant firefighting

When the first wave hit Europe, the airport system was underprepared. Subsequently, aviation stakeholders were pushed into a position where they had to constantly react to emerging problems due to evolving knowledge of the SARS-CoV-2 virus, government regulations, and travel restrictions. Participant A8 portrayed this theme well with a firefighting analogy:

> *"It was quite a big fire brigade at one point, putting out fires everywhere."*

This reactive approach is also illustrated by the many diffuse interventions (e.g., health declarations, personnel protective equipment (PPE), and travel corridors) and the reorganisations by aviation stakeholders.

D. Running behind the facts

A reoccurring topic during the first wave was the volatility of the COVID-19 pandemic. Several participants referred to having no sense of control as the situation seems to be ever-changing, something uncommon in the carefully orchestrated aviation industry. Participant A2 mentioned a sentiment of running behind the facts. Events like the closure of China or the first lockdown just happened as "the situation has already been decided for you". The running behind the fact aspect seemed most apparent during the first wave and then gradually simmered down, but never disappeared entirely. To summarise, the airport system seemed to be in a highly reactive mode throughout the pandemic. A quote from participant A7 captures the overall sentiment well:

> *"A lot of running, but actually also a lot of standing still."*

The 'running behind the facts' nature was also illustrated by an inability to conduct long-term planning during the pandemic, as the situation constantly evolved. While traditional planning in the aviation sector (e.g., flight routes and gate planning) is developed months in advance, during the pandemic, multiple scenarios had to be continuously developed and adjusted as reality overtook existing plans. To illustrate, participant A7 stated that operational forecasts, traditionally done on a six-monthly basis, were reduced to a bi-daily basis. Subsequently, this added greatly to the workload of the aviation stakeholders' operational departments.

E. Operational interventions with mixed success

To deal with the COVID-19 pandemic, a wide range of interventions were explored throughout the airport system. These included the use of PPE; social distancing; COVID-19 factsheets; quarantining; repatriations; temperature measuring; analogue and digital health declarations; contact tracing; introduction of homeworking; on-airport testing; cargo-in-cabin; deployment of office personnel in operational functions; travel rules engines; and travel corridors. Implementing these interventions was challenging as they were often "caught up by time", making them obsolete because of new knowledge or a shifting context. Participants often attributed this to the "running behind the facts" aspect addressed in subtheme D.

Additionally, the effects of the interventions were often subject to discussion. The general ambition was to make the smartest measures with as few operational disruptions as possible. Participants from the aviation, government, and public health sides discussed the careful balancing acts that took place. For example, participant P2 elaborated on the difficulties of giving purely medical advice in a context with many political and economic interests. From the aviation side, scepticism arose as the effectiveness or operational viability of certain interventions was questionable. Participant A1 added that they were occasionally forced to act to maintain appearances.

Interestingly, the standstill of the aviation industry formed an opportunity for the airport system regarding large infrastructure and innovation projects. For example, participant A5 mentioned that due to a minimum of airport operations, research could be done into autonomous taxiing of aeroplanes. Testing these autonomous platforms would have been nearly impossible in a fully operational airport.

F. Reorganisations in aviation

Although COVID-19 was primarily a public health disruptor, the economic fallout for the airport system was immense. As a reaction to the standstill of air transportation, government aid kicked in, and aviation stakeholders were forced to cut jobs to maintain future viability. Although considered proportional, these reorganisations hit the industry hard while creating a brain drain as many experienced personnel left the industry. As a side-effect, informal networks disappeared throughout the airport system. Gradually, the aviation industry recovered, and flight numbers increased. However, the economic pressure and personnel numbers remained constant. This combination led to disproportionate and increased workloads for the already understaffed airport system.

2.3.2.3 Complex relational dynamics

Throughout the COVID-19 pandemic, complex dynamics emerged within the airport system as stakeholder relations were redefined. These complex dynamics were especially apparent between the public health and aviation stakeholders, as the former maintained a hesitant posture due to fears of conflicts of interest. Concurrently, the government imposed a strong top-down relationship towards the aviation stakeholders.

G. Hesitant public health stakeholders

Several participants labelled their formal relationship with the Ministry of Public Health and the public health agencies as slow and distant. Participant A9 referred to a fear of conflicts of interest as the main reason. Public health organisations are viewed as neutral and independent entities, so engaging in direct conversation with the aviation sector could tarnish their reputation. Subsequently, aviation stakeholders could not be part of the public health emergency committee. Participant A3 reaffirmed this and spoke of a long-standing mistrust as the Ministry of Public Health has an "allergy" to everything that sounds commercial. Participant A10 nuanced this, mentioning that if public health organisations had direct contact with the aviation sector, they would also have to talk with other sectors, such as hospitality and sport; this seemed impossible during the pandemic.

Another recurring aspect is the knowledge mismatch between the highly complex and specific domains of aviation and public health. Participant A4 illustrated this, stating that while public health is knowledgeable about infectious diseases and reproduction numbers, aviation knows how to manage big crowds in a complex system.

Lastly, the COVID-19 pandemic put public health stakeholders in charge, something completely novel, as traditionally high-impact crises are chaired by the security services. This proved difficult for some participants during the first wave but was gradually accepted.

H. Difficult government relations

Relations between the government, predominantly the Ministry of Infrastructure and Public Health, and aviation stakeholders are generally reported as being problematic. Participants refer to the relations as slow, viscous, siloed, and extremely theoretical. Participant A1 mentioned that the ministries had little understanding of aviation processes. The ministries consistently underestimated the complexities of the airport system and their ripple effects. For example, when the government decided to change the testing regime for passengers entering the Netherlands, the aviation stakeholders were pushed to implement these changes within 24 hours. However, implementing this was impossible for aviation stakeholders, as it required inbound passengers, from all around the world, to do novel tests within those same 24 hours.

Another reoccurring theme mentioned by aviation, public health, and government participants when referring to the government is its hierarchical top-down mentality. As participant G2 stated, the emphasis was on informing the aviation sector instead of consulting with it. Participant A2 captured this sentiment well, referring to the government's press conferences and their subsequent regulations as a '*diktat*'. Participant A4 stated that this top-down approach made the sector braindead as it prevented people from thinking for themselves; they simply waited for new government orders.

A dynamic which potentially caused these complex relations was the high turnover of governmental personnel. Several aviation participants noted that of those present during the first COVID-19 meeting, no civil servant remained involved. This so-called "carrousel of government" significantly hampered collaboration as the aviation sector had to re-explain the complexities of the airport system to ever-changing civil servants. Subsequently, the government was unable to build adequate domain knowledge.

2.3.2.4 Lessons learned for future public health disruptions

Four themes emerged when reflecting on the key lessons learned from the COVID-19 pandemic and preparations for future public health disruptions. First, a need was expressed for a more systemic approach by bringing together stakeholders from aviation, public health, and the government. Secondly, the pandemic exposed a shortage of sensemaking capabilities, indicating the need for improved forecasting and decision-making tools. Thirdly, participants underlined the indispensable value of fostering informal relations as this accelerates decision-making while clearing organisational "noise". Finally, participants mention three organisational interventions that, to an extent, address the abovementioned organisational needs.

I. Need for a systemic approach

Many participants expressed the need for a more systemic approach within the AMS airport and international air transportation systems. This desire reoccurred in three contexts. First, participants expressed the importance of harmonisation regarding health entry requirements (e.g., PCR test, antigen test, vaccine). To paraphrase participant A10, a systemic approach is required as a virus does not stop at a border.

Secondly, participants mentioned the need for a more integral, international, and multidisciplinary approach across organisations and countries. Participant A3 stated that it seems extremely difficult to deal with new people during a crisis; hence a more multidisciplinary preparation seems critical. To cite A3, "*There comes a time when we need each other*". Participant G3's experiences during the pandemic build on this by referring to a steering committee meeting where roles and responsibilities were misidentified, leading to preconceptions and a degree of friction within the committee.

Thirdly, participants expressed the need for a systemic approach throughout the airport processes, stating that a collective approach is essential as resources such as personnel and money are scarce. To paraphrase participant A6, a siloed system is no longer viable.

J. Need for sensemaking capabilities

Participants indicated the need for more sensemaking capabilities to support long-term planning, decision-making and risk assessment during high-impact disruptions. References to sensemaking came in two contexts. First, participants advocated more extensive and continuous use of scenario thinking and utilising what-if constructions. Participant A2 mentioned that the goal of these scenarios is not necessarily to predict but rather to provide a framework during decision-making. Participant A10 went further, advocating that we should prepare for the next pandemic by making plans and scenarios. Participant P1 agreed, stating that public health guidelines should be revised and include more scenarios related to a long-term pandemic.

Secondly, participants suggested the need for a more risk-based approach. Instead of preventing any infectious disease from spreading, a focus should be on defining acceptable risks. As participant G2 illustrated, passengers' body temperature could be monitored, adhere to all kinds of hygienic measures, and walk around in a plastic bag, guaranteeing zero transmission, but this is unrealistic. Finding the balance between risks is a more viable option.

K. Indispensable informal relations

Many participants referred to the indispensable value of informal networks in the airport system during the COVID-19 pandemic. These networks supported the participants in bypassing slow, formal structures and avoiding competitive issues. For example, participant A9 referred to the informal and collegial relations with public health agencies regardless of the fear of conflicts of interest.

Informal relations also helped to create clearer information flows while helping participants understand each other's issues and bottlenecks. To quote participant S1, "*The informal relations removed the noise and provided solutions*". Maintaining and expanding informal networks is essential in times of crisis.

L. Effective organisational interventions in practice

Participants indicated three interventions addressing prior organisational needs: the Crisis Management Teams (CMTs), the Airport Operation Centre (APOC) and a cross-organisational steering committee. Many stakeholders started up their CMTs before and during the COVID-19 pandemic. These CMTs were often internal structures with decision-making powers consolidating different departments of a singular organisation. The frequency of meetings was usually based on emerging problems caused by the pandemic, giving it an ad hoc and informal nature. A significant asset of CMTs was their ability to increase the speed of decision-making while reducing organisational complexity. Participant A8 drew the analogy with an accelerating mammoth tanker, as decision-making was slow at the beginning of the pandemic. However, the CMT enabled his organisation to accelerate and even anticipate certain disruptions. As the pandemic became the so-called "new normal", CMTs became more formalised. This required a shift from a crisis mode to, as participant A2 stated, a novel form of business management. In practice, formalisation mainly occurred by reducing the ad hoc nature of CMTs and giving them a fixed position in the organisation.

The Airport Operation Centre (APOC) emerged as a pre-COVID initiative of the airport operator in reaction to the increasingly congested European airspace. To manage scarce airspace, the APOC consolidates information and data sharing with others, predominantly aviation stakeholders, in one physical control centre to improve the

planning and predictability of airport operations. Although the APOC was still in development during the prelude, its implementation was accelerated and repurposed to help manage the first wave of the pandemic. Participants reflected positively on the APOC as it facilitated a systemic approach. Participant S1 noted that it also gave reaction time and helped alignment.

During the first wave, a cross-organisational steering committee representing all major airport system stakeholders except the public health agencies was set up. Several participants referred to this committee as it created a formal platform for stakeholders to discuss, for example, upcoming regulations or operational interventions. No participants reflected on the functioning of this committee.

2.4 Discussion

2.4.1 General discussion

The COVID-19 pandemic proved to be an existential economic and public health crisis for the airport system. To be prepared for future public health disruption, this study conducted a series of expert interviews to capture and reflect on the experiences and learnings made by the airport system utilising Amsterdam Airport Schiphol (AMS) as the use case. The subsequent research question was: *What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic?* The study took a systemic approach by consolidating perspectives from aviation and non-aviation stakeholders. After conducting a thematic analysis, four main themes and 12 subthemes emerged, capturing key experiences and lessons learned.

The first theme depicts the limited readiness of the airport system in the face of the looming COVID-19 pandemic. Although infectious diseases were not novel for the airport system and weak signals of the initial COVID-19 outbreak were detected, the actual pandemic's occurrence appeared to be approached anecdotally rather than as an existential threat. A possible explanation may be the lack of experienced precedents, as the only pandemic comparable to COVID-19 was the Spanish flu in 1918. This concept of a high-impact disruption being unimaginable, often referred to as 'Black Swans'[5], is not unique and reoccurs throughout history, for example, in the Fukushima nuclear

5 Taleb (2007) defines Black Swans as rare events with an extreme impact which are only predictable with the benefit of hindsight.

disaster (Piore, 2011), hurricane Katerina (Perla & McGrady, 2011), and the 9/11 terrorist attacks (de Wit, 2022). In the latter case, the National Commission on Terrorist Attacks upon the United States (2004) even explicitly labelled 9/11 as “a failure of imagination”. The aspect of unimaginability continues throughout the COVID-19 pandemic and seems to be a root cause for the constant firefighting addressed in the second theme.

Nevertheless, the unimaginable nature of the COVID-19 pandemic is frequently contested. For example, de Wit (2022) and Linden (2021) argue that the pandemic was indeed imaginable and predictable, referring to a plethora of studies that addressed the dangers of infectious diseases pre-COVID (e.g., Center for Strategic and International Studies, 2019; Global Preparedness Monitoring Board, 2019; World Economic Forum, 2020), and attributed the limited prepared state of aviation to a lack of proactive risk management. This lack of proactive risk management seems to align with subtheme J, the need for sensemaking capabilities, whereby participants refer to the need for scenario thinking, risk-based approaches, and decision-making frameworks.

To operationalise these sensemaking capabilities, de Wit (2022) advocates for more judgement approaches such as scenario building or simulations through serious gaming, Linden (2021) introduces a framework for strategic thinking in times of shocks, and Gössling (2020) emphasises the need for thinking the unthinkable. An opportunity might also lie in wargaming, a form of serious gaming whereby decisions are made in a syntenic environment of conflict or competition (Perla, 2022). Instead of a hostile military, the pandemic could then be the adversary of the airport system. Its value goes beyond public health disruptions, as Perla & McGrady (2011) frame wargaming as an antidote against Black Swans. Further investigating these sensemaking practices seems crucial for the airport system.

The pandemic exposed segmented stakeholder dynamics, whereby aviation and public health stakeholders maintained a hesitant relationship, and government stakeholders used a strong top-down approach. These segmented dynamics negatively impacted the inner workings of the airport system as information flows, and feedback loops were fragmented. Additionally, underlying aspects such as fear of conflicts of interest between aviation and public health, large discrepancies in domain knowledge between aviation, public health, and government stakeholders, and the difficulties in knowledge building due to a high employee turnover - predominantly apparent in the ministries - are all issues requiring reflection and must be addressed by the airport system in anticipation of a future public health disruption.

Utilising a systemic approach, as addressed in subtheme I, can mitigate or reduce the complex relational dynamics within the airport system. On the one hand, similar to Arora et al. (2021), this refers to the need for an internationally harmonised and standardised approach between airport systems. On the other hand, as indicated by Postma & Yeoman (2021), this refers to the need for closer collaboration within the airport system. Following Sun et al. (2021), fostering such a systemic approach is crucial, as a siloed approach is undesirable and untenable for managing complex crises. Finally, the importance of informal relations among stakeholders must be highlighted; they are catalysts for a systemic approach.

Constructions like the CMTs and the APOC are crucial for the future, as they operationalised a systemic approach by physically consolidating multiple stakeholders and building informal relations while collectively conducting sensemaking. Further developing and institutionalising these organisational interventions can proactively support the long-term survival of the airport system and possibly transform it from a potential pandemic liability to a strategic asset in mitigating public health disruptions.

2.4.2 Limitations

The participants were asked to reflect on events from December 2019 until July 2021. The study itself took place from July 2021 until March 2022. Subsequently, depending on when the interviews took place, participants had to recollect what had happened one and a half to two years earlier, which may have resulted in a hindsight bias. The broad data collection interval can predominantly be attributed to the primary inclusion criteria where participants had to originate from a position heavily impacted or focused on the COVID-19 pandemic. As the pandemic left the third and entered the fourth wave during data collection, participants were often busy dealing with the crisis. The participants were sourced through the personal network of the authors and snowballing, which may have resulted in a selection bias.

The study captures experiences and lessons learned until July 2021, but it does not give a complete account of the COVID-19 pandemic. During the data collection, the so-called fourth wave emerged in the Netherlands, leading to another lockdown in December 2021, which lasted until February 2022. Afterwards, the effects of the COVID-19 pandemic quickly simmered down as countries opened again. Although the period from July 2021 until February 2022 was still impactful for the airport system,

it is assumed that the key experiences and lessons learned already emerged as the airport system dealt with three prior COVID-19 waves. During data collection, from July 2021 until March 2022, several participants confirmed this assumption in casual conversation.

The study used semi-structured interviews in a conversational style supported by an interview guide. This method is designed to capture rich qualitative data, so conversations were free-flowing, resulting in a general interview duration of about 60 minutes. Some outliers occurred, where interviews took 40 or 120 minutes. This variance in duration may have influenced the results; however, the number of codes and findings remained consistent per participant.

Finally, the study used the AMS airport system and the Dutch context as a central use case, thus excluding international bodies or non-Dutch stakeholders. However, the COVID-19 pandemic was a global crisis impacting the whole air transportation network. Subsequently, our findings may only apply to the AMS airport system and the Dutch context.

2.5 Conclusions

As the COVID-19 pandemic proved to be an existential crisis for the airport system, expert interviews were conducted to support preparations for future public health disruptions. When looking ahead, airport system practitioners and researchers should consider the following key experiences and lessons learned. First, the airport system was poorly prepared for the upcoming pandemic, as prior experiences with public health disruptions were trivialised, and weak signals were underestimated. During the pandemic, the airport system constantly ran behind the facts, had difficulties implementing operational interventions, and dealt with impactful reorganisations. This limited readiness and constant firefighting is predominantly attributed to the pandemic being unimaginable. An important lesson learned from the unimaginable pandemic is that airport systems must improve their sensemaking capabilities. Practices such as scenario thinking, decision-making frameworks, and simulation through wargaming must be further investigated and operationalised.

In parallel, complex relational dynamics emerged whereby public health stakeholders hesitated to collaborate with aviation stakeholders. Concurrently, the government enforced a strong top-down relationship. To improve the relation between stakeholders, the airport system should move away from a siloed approach and towards a systemic approach. Fostering informal relations among internal and external stakeholders is assumed to be a critical catalyst for facilitating such a systemic approach.

Finally, airport systems should further investigate organisational constructions like CMTs and the APOC, as they embedded systemic sensemaking by physically consolidating multiple stakeholders. Since the emergence of novel public health disruptions is a given, further reflection and operationalisation of this study's findings are critical. They will proactively support the airport system's transition from a potential pandemic liability to a strategic asset in mitigating public health disruptions.

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3
THE
RESILIENCE
TOWER
OF
BABEL

3. The resilience Tower of Babel

In this chapter, the conceptual ambiguity lingering around resilience is addressed. A scoping review is utilised, investigating the many conceptualisations of resilience-as-an-outcome in relation to the then-popular concept of antifragility. Initially, antifragility was positioned as a central concept in this dissertation. However, based on the outcome of this chapter, the focus shifted towards resilience, with antifragility regarded as an underlying concept or sub-aspect. Subsequently, the following SRQ2 is considered central to this chapter: What aspects constitute resilience? The additional question posed in this chapter, "How does resilience relate to antifragility?" is regarded as having secondary relevance to the dissertation as a whole.

Based on a scoping review, four recurring aspects or categories, of resilience emerged: (1) fragility, (2) robustness, (3) adaptation and (4) transformation. Fragility refers to the state of an organisation that breaks or loses value due to a disruption. Robustness indicates an indifference to disruptions. Adaptation refers to evolutionary change triggered by a disruption. Finally, transformation implies revolutionary change. Resilience is considered to consist of these four aspects, either individually or in any combination.

The findings of this chapter were fundamental for this dissertation. First, it constructed a shared understanding of resilience within the supervisory team from the Delft University of Technology and the Royal Schiphol Group. Second, the categorisation influenced the conceptualisation of all upcoming chapters. Finally, the aspects validated in Chapter 6 enable collective sensemaking, thereby reducing the ambiguities lingering around resilience while enabling its operationalisation.

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Abstract

The COVID-19 pandemic exposed the existential public health and economic fragilities of the civil aviation industry. To prevent future public health disruptions, the civil aviation industry is gaining interest in becoming more "resilient" but rarely elaborates on its meaning, hampering decision-making and strategy development. When looking into the academic literature it seems that a proliferation of resilience-related concepts occurred. Although enriching resilience, it also dilutes its meaning and reduces its use for practice. This paper aims to create concept clarity regarding resilience by proposing a categorization of resilience. Based upon a scoping review, this categorization dissects resilience into four reoccurring aspects: fragility, robustness, adaptation, and transformation. This categorization is expected to support sensemaking in disruptive times while assisting decision-making and strategy development on resilience. When applying this categorization in the civil aviation and public health context, the transformative aspect seems underused. Further research will focus on maturing the categorization of resilience and its use as a sensemaking tool.

3.1 Introduction

In the wake of the COVID-19 pandemic, the need for creating a "resilience" strategy significantly increased within the civil aviation industry (Tuchen et al. 2020; ICAO 2020; Terry 2020; Gössling 2020; Lenot and Stewart 2020; Arora et al. 2021; and Bouwer et al. 2022). As the civil aviation industry is arguably one of the hardest-hit industries by the pandemic and instrumental in the spread of COVID-19 (Nakamura and Managi 2020; Sokadjo and Atchadé 2020; Zhang et al. 2020; and Coelho et al. 2020) the value of being more resilient is becoming apparent. However, there is no concept clarity on resilience in general, and the literature on aviation likewise rarely elaborates on what resilience means. This is assumed to hamper the civil aviation industries' sensemaking capabilities while obstructing decision-making and strategy development on resilience.

When looking into the academic side, resilience has become an almost elusive concept. Originating from the Latin verb 'resilire' meaning 'to bounce' (Alexander 2013) the concept was initially used to refer to a system's ability to bounce back after a disruption (Dahlberg 2015). However, a proliferation occurred creating a sprawl of

resilience-related concepts such as ecological resilience (Holling 1973), engineering resilience (Holling 1996), community resilience (Norris et al. 2008), and transformative resilience (Ramezani and Camarinha-Matos 2020) just to name a few.

Although these resilience-related concepts tend to have a lot of overlap, novel meanings have been linked to the concept such as robustness or indifference to disruption; transformation or fundamentally changing after a disruption; and antifragility or gaining from exposure to disruptions. All these nuances enrich resilience but also dilute its meaning, making it an umbrella term (Hillmann and Guenther 2021). If an organization wants to implement resilience as a strategy, should it then aspire to a more robust, transformative, or antifragile approach? By having these ambiguities, misalignment might occur thus reducing the effectiveness of resilient decision-making and strategy.

During the COVID-19 pandemic, the resilience-related concept of antifragility (Taleb 2012) seemingly gained popularity (Diedruch et al. 2021). Although an intriguing concept, its relation to the broader resilience field remained ambiguous. The unclarities in the civil aviation industry and the academic literature regarding resilience in combination with the emergence of antifragility formed the starting point of this study. The aim is to conceptualize a novel categorization that consolidates resilience and antifragility while distinguishing its main aspects. Additionally, the research will lay the resulting categorization on top of the civil aviation industry in the context of the COVID-19 pandemic. The goal here is to gain an initial insight into how the aspects are already applied and to detect areas of opportunity. The overall ambition of the categorization is to support the civil aviation industry with sensemaking in disruptive times, with an emphasis on public health, while assisting decision-making and strategy development.

3.2 Materials and methods

To better understand the many interpretations of resilience and antifragility, a scoping review was conducted using the approach of Arksey and O'Malley (2005) with the goal of identifying gaps in the literature. This approach consists of five stages: identifying the research question(s); identifying relevant studies; study selection; charting the data; and collating, summarizing, and reporting the results. The underlying ambition is to dissect the main aspects of resilience in relation to antifragility and categorize them.

First, the research question(s) were identified and defined as: “how does resilience relate to antifragility?” and “what aspects does resilience consist of?”. In accordance with Taleb (2012) resilience and antifragility were primarily approached as an outcome or a state after facing a disruption giving it an ex-post quality (Canizares et al. 2021). Secondly, relevant studies were identified by consulting three electronic databases: SCOPUS, Web of Science, and PubMed. The search term used was “antifragil* AND resilien*”. This search query yielded a total of 210 articles and decreased to 127 after deduplication.

Thirdly, selection occurred by screening the title and abstract while keeping in mind the research questions. Additionally, inclusion criteria were added which initially focused on the aviation and COVID-19 context. However, this did not yield any results. Subsequently, the inclusion criteria were expanded to resilience and antifragility in the context of disruptions, organizations, and complex systems. This resulted in a total of 29 articles. After a full review, six articles remained. Additionally, snowballing added another six resilience-related publications. The inclusion of the snowballed publications was based on references from the six original publications and suggestions from peers. Only journal articles and conference proceedings in English were included. No date restrictions were applied.

Charting the data occurred by using a physical and digital whiteboard (Miro). On these whiteboards, all different aspects of resilience (40) were consolidated and clustered. The aspects were clustered based on their meaning and the interpretation of the authors. This process was initiated by the first author and then reviewed and discussed with all the other authors. The clustering process consisted of three rounds and narrowed down to four clusters in the first round. However, the nuances between each cluster remained subject to discussion throughout the following rounds. The clusters, further referred to as aspects, form the basis of the resulting categorization. Finally, the results were collated, summarized, and reported in this study. The identification and selection protocol is visualized in Figure 3.1.

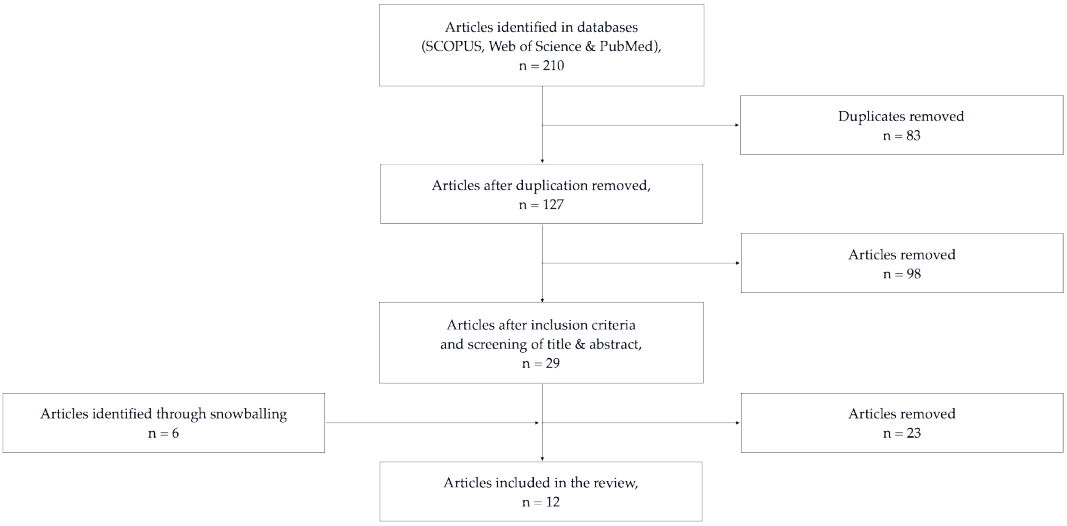

Figure 3.1 Identification and selection protocol.

3.3 Results

To better understand the many interpretations of resilience, the following section reviews all resilience models of each included article. Subsequently, these models are dissected into their respective aspects or characteristics. In section four, a categorization is presented based on these outcomes. Table 3.1 gives an overview of each model and its key aspects.

Table 3.1 Overview of the included resilience-related model and their aspects.

Author	Aspects		
Holling (1996)	Engineering Resilience	Ecological Resilience	
	Stability; Return to an equilibrium state; Efficiency of function; Temporary	*Persistence; Flip between equilibrium states; Existence of function; long-term*	
Cutter et al. (2008)	Vulnerability	Absorptive Capacity	Adaptive Resilience

Author	Aspects				
	Potential for harm	*Absorbing impacts; Predetermined coping responses*	*Reorganization, change, and learning*		
Martin-Breen & Anderies (2011)	Vulnerability	Robustness	Adaptive Capacity	Transformability	
	Does not continue to function after shock	*Small time scale; Continues to function after shock; Does not change*	*Small time scale; New ways of operating; Maintains identity*	*Long time scale; Changes identity*	
Taleb (2012)	Fragile	Robust/Resilient	Antifragile		
	More downside than upside after shock	*Resists shocks & stays the same; Perfect robustness is unattainable*	*Gets better due to shocks; growing capacity*		
Chroust & Aumayr (2017)	Fragile	Fault Tolerant/ Robust	Elastic	Resilient	Antifragile
	Breaks down in face of a disruption	*Remain unchanged against pre-defined disruptions; undesirable long-term*	*Change & return to the original state; Incremental change*	*Return to a new acceptable state*	*Learning from disruptions and improving; the ability to create new conditions of fitness*
Manca et al. (2017)	Absorptive Capacity	Adaptive Capacity	Transformative Capacity		
	Absorbs a disruption without changing; Short-term; Small disruptions	*Incremental change while being flexible; Greater disruptions*	*Improvement; Shift from the status quo; Unbearable disruption*		
Ruiz-Martin et al. (2018)	Fragile	Robust	Resilient	Antifragile	
	Unable to withstand a changing environment and thus collapse	*Survive changes within pre-designed parameters*	*Capable to survive unforeseen events*	*Prosper and thrive in turbulent times*	
de Bruijn et al. (2020)	Fragile	Robust	Resilient	Antifragile	

Author	Aspects				
	Breaks due to exposure to randomness; undesirable but essential for achieving antifragility	*No significant changes when exposed to disruptions; Fragile in the long term.*	*Absorption of disruptions and a possible reorganization; learning capability*	*Long-term; System always gains more than it loses after a disruption*	
Ramezani & Camarinha-Matos (2020)	Fragile	Robust	Resilience	Transformative resilience	Antifragility
	Breaks due to disruption	*Sustains shocks & remains unchanged*	*Absorbs shocks & returns to an acceptable state; Stability; Absorptive coping capacity; Persistent response*	*Reorganize, reconfigure, restructure & reinvent; Dynamic stability; Adaptive & transformative capacity; Elastic response*	*Absorbs shocks & gets better; Improvement Learning capacity; Transformative response*
Blečić & Cecchini (2020)	Fragile	Robust	Resilient	Antifragile	
	The only possibility of harm	*Does not lose or gain anything; Finite number of disruptions*	*Possibly low gains from disruptions*	*Possibility of large gains*	
Hillmann & Guenther (2021)	Stability domain	Change domain	Growth domain		
	Ability to maintain; Ability to bounce back or recover; Ability to resist; Ability to recover (speed); Ability to cope	*Ability to adapt; Ability to renew, reconfigure and/or reinvent*	*Ability to emerge strengthened; Ability to learn from experiences; Ability to thrive, grow & flourish*		
Munoz et al. (2022)	Robustness	Resilience	Antifragility		
	Ability to maintain; Ability to resist; Ability to cope	*Ability to bounce back or recover*	*Ability to emerge strengthened; Ability to learn from experiences; Ability to thrive, grow & flourish*		

3.3.1 Engineering resilience and ecological resilience

Regarded as one of the founders of the resilience concept (Dahlberg 2015; Ruiz-Martin et al. 2018), Holling (1996) introduced "engineering resilience" and "ecological resilience" using respectively an engineering and ecology lens. Engineering resilience emphasizes stability or the return of a system to an equilibrium state after a temporary disturbance. Maintaining the efficiency of function in the short term is a key tenet in the theory of Holling.

Ecological resilience refers to the ability of a system to absorb changes while being able to switch between multiple equilibrium states. The emphasis is on the existence of function, the persistence of relationships, change, and unpredictability. Holling (1996) describes ecological resilience as a long-term strategy where flexibility is essential.

3.3.2 Disaster resilience of place model

Cutter et al. (2008) created the Disaster Resilience of Place (DROP) model which conceptualizes the relation between vulnerability and resilience in the context of natural disasters at the community level. In this model, vulnerability is defined as a characteristic or quality of a system that creates the potential for harm.

DROP implicitly dissects resilience into two aspects: absorptive capacity and adaptive resilience. The absorptive capacity refers to the ability to absorb impacts with predetermined coping responses. Adaptive resilience can come into play when absorptive capacity is exceeded. It emphasizes reorganization, change, and learning.

3.3.3 From vulnerability to transformability

Martin-Breen and Anderies (2011) define resilience as "the capacity of a system to continue to function given external shocks". They link resilience with the following system capacities: vulnerability, robustness, adaptive capacity, and transformability. First off, vulnerability is labeled as the antonym of resilience referring to a system that does not continue to function after a shock. Robustness is similar to resilience in the sense that a system "continues to give function" due to a shock.

However, it is argued that robustness is typically applied to a fixed set of systems and shocks implying that it is predominantly useful over small time scales. It also suggests a large degree of stability as the system and anticipated shocks do not change.

Finally, Martin-Breen and Anderies (2011) label adaptive capacity and transformability as "aspects" of resilience. Adaptive capacity refers to the capability of a specific system to cope with shocks and, although not explicitly mentioned, the capability to generate "new ways of operating". Similar to robustness, adaptive capacity is mostly used in small time scales. Transformability is the capability to reorganize into new systems when the current system is no longer sufficient. It implies a larger time scale. Martin-Breen and Anderies (2011) note that the adaptive capacity maintains the identity of the system while transformability changes the identity.

3.3.4 Antifragility

Taleb (2012) introduced a new concept into the resilience family named: "antifragility". Taking a more philosophical and financial approach, he argues that anything that matters can be classified into one of three categories: fragile, robust, or antifragile. Note that he seemingly does not make a nuance between robustness and resilience thus merging them into one concept. The fragile refers to things that experience more downside than upside from certain shocks, leading them to break over time. Taleb (2012) elaborates by stating that the fragile do not enjoy volatility, randomness, uncertainty, disorder, errors, and stressors.

The robust (or resilient) is indifferent to shocks. As Taleb (2012) states "the resilient resists shocks and stays the same". However, he nuances that perfect robustness is unattainable thus giving it a finite nature. The antifragile refers to things that get better due to exposure to shocks. It is framed as the antonym to the fragile thus the antifragile loves volatility, randomness, uncertainty, disorder, errors, and stressors. Although not explicitly mentioned, Taleb (2012) seems to suggest a strong adaptive and transformative nature by often referring to a growing capacity.

3.3.5 Reaction of systems

Chroust and Aumayr (2017) classify systems into five states or vulnerability classes based on their reaction against disruptions which include: fragile, fault-tolerant or robust, elastic, resilient, and antifragile. The fragile state refers to a system breaking down in the face of disruption. Chroust and Aumayr (2017) seemingly use fault-tolerant and robust as nascent concepts. Fault-tolerant emphasizes absorption while the robust remains unchanged. Systems in both categories can only cope with a limited set of pre-defined hazards. Maintaining this state might be undesirable due to costs, high effort, and difficult evolution.

Elastic is defined as a short state change whereafter the system returns to its original state. While referring to physics, 100% elasticity is not possible thus implying that the original state is incrementally changed. Resilient is interpreted as the capacity of bringing a system into an acceptable state after a disruption. This acceptable state can be different from the original state implying change or growth. Finally, antifragile refers to a system being able to learn from disruptions and becoming better at countering similar events. It includes the system's ability to create new conditions of fitness (François 2004).

3.3.6 Framework on vulnerability and resilience

The European Commission's Joint Research Centre developed a framework for vulnerability and resilience (Manca et al. 2017). The framework defines three capacities of resilience when facing a disruption which are context-specific: absorptive capacity, adaptive capacity, and transformative capacity. Absorptive capacity is related to stability and resistance. The system absorbs a disruption without changing its behavior. The absorptive capacity has value in the short term with low-intensity disruptions. Adaptive capacity plays a role when the duration and intensity of the disruption increases. However, it is implied that the disruption remains "bearable". The adaptive capacity allows for incremental change while being flexible. Finally, the transformative capacity has value when a disturbance becomes unbearable and when the required change is too large. This capacity can be deliberate but also forced by its surroundings. It implies learning from past events and improvement of conditions considering current constraints. It is seen as a shift from the status quo.

3.3.7 Four-level maturity model for organizational resilience

Ruiz-Martin et al. (2018) approach resilience as an aspect of a larger dynamic concept, the Maturity Model for Organizational Resilience, which evolves over time. An organization can shift through four of these aspects or levels: fragile, robust, resilient, and antifragile. A fragile organization is referred to as unable to withstand a changing environment and thus will collapse. A robust organization can survive some changes in its environment. However, if these changes fall outside so-called "pre-designed parameters", the organization will collapse.

A resilient organization goes beyond being robust and can survive unforeseen events. Finally, the antifragile organization is not only able to survive unknown disruptions but can also prosper and thrive in disruptive times.

3.3.8 Four system types

Similar to Ruiz-Martin et al. (2018), de Bruijn et al. (2020) define four system types: fragile, robust, resilient, and antifragile. As the fragile breaks by exposure to randomness, it is approached as an undesirable system type. However, the authors point out that fragility is an essential part of achieving antifragility. The robust shows no significant changes in behavior when exposed to disruption. Small positive or negative changes are possible, but they tend to cancel themselves out. The robustness becomes fragile in the long term.

Resilient emphasizes absorption of disruptions and a potential reorganization after the shock. The resilient has a learning capability, making it less susceptible to disruptions it already experienced. The antifragile is approached as a long-term survival capability as the system always gains more than it loses when facing a disruption.

3.3.9 Transformative resilience

Ramezani and Camarinha-Matos (2020) see resilience as a type of response to disruption for systems and organizations. They identify five typologies: fragility, robustness, resilience, transformative resilience, and antifragility. Ramezani and Camarinha-Matos (2020) define fragility as a system that is destroyed or broken as a consequence of a disruption. Robustness refers to the capability of sustaining shocks and remaining unchanged.

Resilience in this case refers to a system capable of absorbing shocks and returning to an acceptable state emphasizing stability, persistence, and an absorptive coping capacity. Ramezani and Camarinha-Matos (2020) introduce a novel concept of transformative resilience inspired by Dahlberg (2015). It refers to a system's ability to "reorganize, reconfigure, restructure and even reinvent" in response to a disruption. Transformative resilience maintains a "dynamic stability" meaning that a system can evolve to a new "acceptable state" after a disruption. This suggests an adaptive and transformative capacity giving the system an elastic response. For antifragility, Taleb's (2012) definition of a system that absorbs shocks and gets better afterwards is used. They argue that resilience and transformative resilience are different from antifragility due to their focus on absorption while having a dynamic stability. Antifragility emphasizes improvement by not only surviving shocks but also employing them to become stronger. It contains a strong learning capacity, allowing for a more fundamental long-term system transformation.

3.3.10 Resilience as a limit case of antifragility

Blečić and Cecchini (2020) make use of a response (gain-harm) × responsivity (static-dynamic) matrix. It consists of four aspects: fragile, robust, resilient, and antifragile. Fragile is labeled as both a static (e.g., an object) and dynamic (e.g., a system) concept that only has a possible harmful outcome. The robust does not get harmed but also does not gain anything. It is seen as a static limit case of fragility as it can withstand a finite number of disruptions.

The resilient is put in the dynamic category and could gain from disruptions; however, these gains remain low. Antifragile is put in both static and dynamic categories and refers to the possibility of large gains. Antifragile can be seen as the superlative of resilience.

3.3.11 Six conceptual domains

Hillmann and Guenther (2021) conducted a systematic review of organizational resilience including an analysis of 71 definitions of the concept. The systematic review clustered these definitions into six conceptual domains with three of them being relevant for this study as they refer to resilience as a state: stability domain, change domain, and growth domain. Note that Hillmann and Guenther (2021) see the stability domain as the most essential domain for understanding resilience. Although other domains enrich the concept, they argue that it moves resilience away from its original meaning.

The stability domain consists of five abilities: the ability to maintain an organizational configuration; the ability to bounce back or recover while maintaining the same structure and functions; the ability to resist thus enduring or bearing the impact of change or a disruptive event; the ability to recover refers to the recovery speed; and the ability to cope referring to the capability of improvising and finding solutions.

The change domain talks about the ability to adapt and the ability to renew, reconfigure, and/or reinvent. Note that the nuances between both abilities remain vague. The ability to renew seems to have more of a proactive nature and has dynamic capabilities while the ability to adapt emphasizes an adaptation to a disruptive event. The growth domain refers to the growth organizations can experience in the wake of a crisis. It includes the ability to emerge strengthened; the ability to learn from experiences and develop new capabilities; and the ability to thrive, grow and flourish despite adversity.

3.3.12 Clustering the conceptual domains

As Hillmann and Guenther (2021) emphasize stability as the essential domain for resilience, Munoz et al. (2022) argue to move away from this singular interpretation while dissecting resilience into multiple “outcomes after facing adversity”. Based on Hillmann and Guenther’s (2021) conceptual domains, they see three outcomes: robustness or insensitivity to change; resilience or performance degradation followed by recovery; and antifragility or upside gained.

According to Munoz et al. (2022), robustness is closely related to Hillmann and Guenther's (2021) essential domain of stability. It encompasses Hillmann and Guenther's (2021) ability to maintain; the ability to cope; and the ability to resist. Munoz et al. (2022) emphasize the absorptive nature of robustness while noting, in accordance with Holling (1973), that it is a temporary capacity, as systems cannot be robust for infinity.

Munoz et al. (2022) make a nuance regarding resilience. As it refers to the ability to bounce back and the ability to recover, which was previously placed in the stability domain by Hillmann and Guenther (2021). Munoz et al. (2022) argue that absorbing a disruption is distinctively different from recovering from a disruption thus making it a different outcome.

Finally, antifragility refers to Taleb's (2012) definition of gaining from adversity and is coupled with Hillmann and Guenther's (2021) growth domain including the ability to emerge strengthened; the ability to learn from experiences and develop new capabilities; and the ability to thrive, grow and flourish despite adversity. Since growth is fundamentally different from absorption or recovery, Munoz et al. (2022) classify it as their third outcome after facing adversity.

3.4 A categorization of resilience

This section summarizes and categorizes the resilience models of the previous section. Regarding the categorization, Norris et al.'s (2008) anecdote regarding a theory of relativity formed a key inspiration. This anecdote argues that relativity might only be a metaphor or abstraction. They note that there is no variable called "relativity" in the theory of relativity while leading to revolutionary hypotheses about energy, mass, and the speed of light.

Analogous to the theory of relativity, our resulting categorization does not contain an aspect called resilience. Instead, the overarching concept is referred to as resilience and consists of four aspects: fragility, robustness, adaptation, and transformation. The relation between the included resilience models and each aspect of the categorization is presented in Figure 3.2. An overview of the categorization of resilience is shown in Figure 3.3.

We believe that all these aspects contribute to the overarching concept of resilience. For example, when a system does not change due to a disruption it manifests the robust aspect of resilience. The choice of terminology in the aspects aims to reduce ambiguity and increase actionability. We want to note that one aspect is not necessarily more desirable than another. For example, antifragility seems to be more desirable than adaptation; however, financial, time, and/or complexity constraints can make it unfeasible for the organization to become antifragile. The following section will delve deeper into what each aspect means, and how it relates to the previous models and illustrate it with an example from the civil aviation industry and COVID-19.

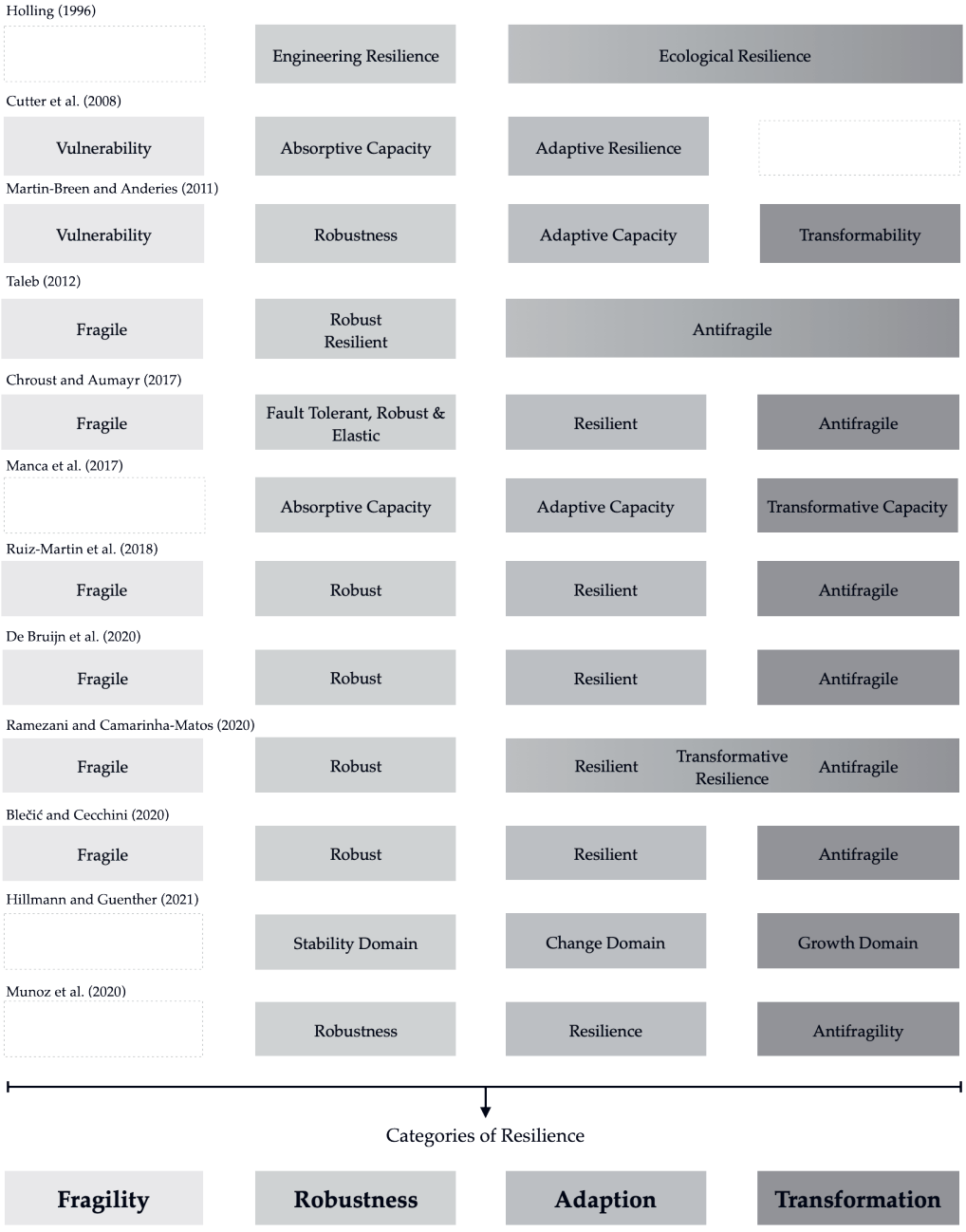

Figure 3.2 The relation between the included resilience models and each aspect of resilience. (Holling 1996; Cutter et al. 2008; Martin-Breen and Anderies 2011; Taleb 2012; Chroust and Aumayr 2017; Manca et al. 2017; Ruiz-Martin et al. 2018; De Bruijn et al. 2020; Ramezani and Camarinha-Matos 2020; Blečić and Cecchini 2020; Hillmann and Guenther 2021; and Munoz et al. 2020)

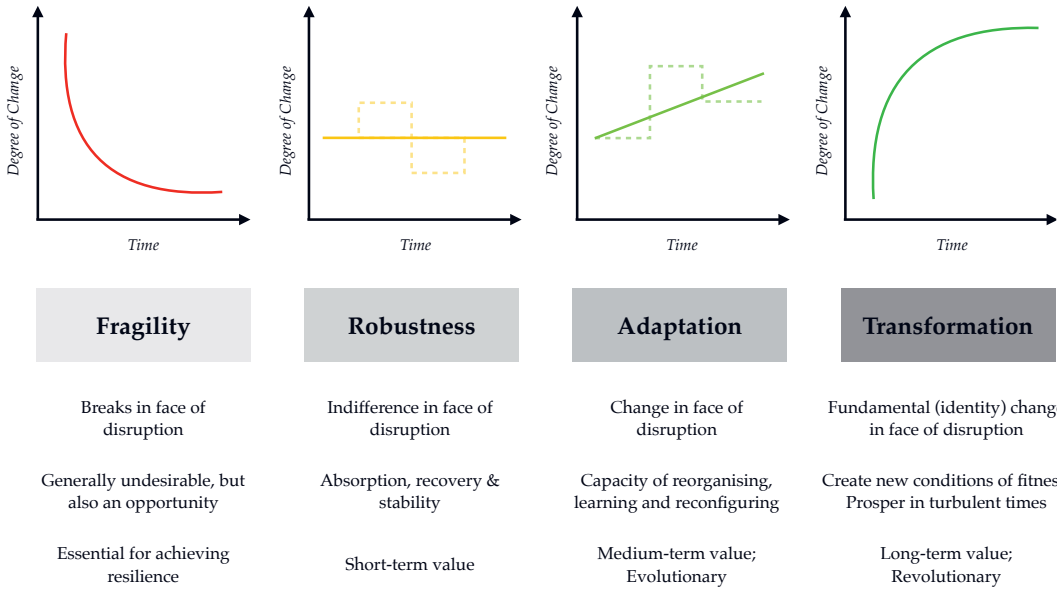

Figure 3.3 A categorization of resilience including graphs as an illustrative support.[6]

3.4.1 Fragility

Regarding the aspect of fragility there is consensus between the resilience models of all included articles. It refers to a system that deteriorates or breaks when exposed to a disruption thus not fulfilling its intended function. The fragile is included in this model since it is an essential trait for achieving overall resilience. As Holling (1973); Taleb (2012); and de Bruijn et al. (2020)whereas merely robust systems cannot in any case. Yet the aim to design robust systems is almost as old as the system dynamics field itself. This research therefore aims to investigate the extent to which an antifragile system design criterion is more valuable than a robust one. By means of an extensive literature review, a simulation model was constructed, which is demonstrated to be antifragile. Comparing the antifragile and robust versions of the model shows that the former-as theorized-yields more favourable results in an environment with impactful outlier events.

6 Figure 3.3 has been revised to correct a spelling mistake in the original version, where "adaptation" was incorrectly spelt as "adaption".

Implementing antifragility in systems involves the difficult task of changing policies (and, eventually, the mental models point out, a system needs a degree of fragility to adapt and/or transform making these concepts strongly related. Although fragility is generally undesirable, using fragility intentionally might transform it into a desirable trait.

To illustrate, the civil aviation industry showcased existential economic and public health fragilities when exposed to an infectious disease. By facilitating intercontinental connectivity, COVID-19 was able to spread creating a pandemic and resulting in major public health disruptions. Subsequently, multiple countries started to impose travel restrictions, or bans, pushing the civil aviation industry into an economic recession.

3.4.2 Robustness

Similar to fragility, there seems to be a lot of consensus amongst the included authors about the concept of robustness. In this categorization, robustness contains the following traits: stable nature, indifference to shocks, absorptive capacity, and value over a short time scale. The latter emphasizes that permanent robustness cannot be achieved since systems are bound to degrade at some point and become fragile.

A point of discussion is the notion of recovery or bouncing back. Several concepts related to this such as engineering resilience; the elastic state; the stability domain; and resilience in general. To what extent does recovery reflect indifference or stability, the key traits of robustness? de Bruijn et al.'s (2020) notion of robustness offers insight by stating that the robust can change; however, gains and losses cancel each other out over time. To summarize: if a system recovers while its net changes are zero, it is labelled as robust.

Robustness can be observed in the air cargo during the COVID-19 pandemic. While passengers' numbers decreased dramatically, cargo remained relatively stable and occasionally grew due to the high demand for medical supplies, e-commerce, and vaccines. Few cargo airlines were even able to profit during the COVID-19 crisis (Jeong, 2020). Although the increased profitability of these airlines might imply antifragility, no actual change is occurring thus keeping air cargo in the robust category.

3.4.3 Adaptation

In our categorization of resilience, adaptation expands on robustness's mere stability by adding a net change component. Although there is no clear consensus on the traits and naming of this aspect, several themes reoccur. Multiple authors mention the evolution towards a new state implying a capacity for reorganizing, learning, and reconfiguring. Other authors add the notions of improvement or gaining from disruptions. Note that the resulting changes, or gains, are usually seen as larger than the robust but less than the transformation, thereby giving it an evolutionary nature. Additionally, the adaptive is only able to withstand a limited range of disruptions on a limited time scale.

The included authors use different names for the aspect of adaptation such as ecological resilience, adaptive resilience, adaptive capacity, antifragility, resilience, transformative resilience, and the change domain. Although resilience and its denominations are the most prevalent, adaptation is chosen as the overarching aspect as it offers a stronger portrayal of the net change component and seems more actionable. Additionally, the overall model is called a categorization of resilience with the assumption that resilience consists of four different aspects. Labelling one of those aspects as resilience might create confusion. Note that some concepts seem to fit both in the adaptation and transformation category, similar to ecological resilience, Taleb's antifragility, and transformative resilience.

To illustrate, a case of adaptation occurred during the introduction of the Digital Covid Certificate (DCC) in the civil aviation industry by the European Union (European Commission n.d.). Resulting health certificates allowed the industry to process passenger health credentials (e.g., used testing regime or vaccination status) automatically and uniformly thus making international travel more accessible. Prior to the introduction of the DCC, verification of health credentials happened manually leading to immense queues in airports and increases in demand for customer support due to unclarity regarding travel regulations. DCC is considered adaptive since it is in essence an adaptation of the World Health Organization's International Certificate of Vaccination or the "Yellow Card".

3.4.4 Transformation

Similar to adaptation, there is no explicit consensus regarding transformation but there are multiple reoccurring themes. First, several authors distinguish a revolutionary or fundamental change taking place, referring to a change of identity; the ability to create new conditions of fitness; prosper, thrive, and flourish in turbulent times; and transform. It has a long-term value with the potential for large gains.

Although this categorization uses transformation as the overarching aspect, several authors use nascent concepts such as ecological resilience, transformability, antifragility, transformative capacity, transformative resilience, and the growth domain. The transformation was chosen as it strongly represents the fundamental change component thus giving the aspect a more actionable nature.

Examples of transformation in the civil aviation industry during the COVID-19 pandemic seem missing until now. While restrictions are being lifted and passenger numbers are increasing, the underlying operational and organizational dynamics that allowed for this pandemic to occur in the first place are assumed to remain. As the impact of the COVID-19 pandemic seemingly shimmers down, the urgency and interest in a transformative strategy decreases as well. Failing to fundamentally address current pandemic fragilities can make the industry prone to future public health and economic disruptions.

3.5 Discussion & limitations

As the civil aviation industry unwillingly facilitated the spread of COVID-19 (Nakamura and Managi 2020; Sokadjo and Atchadé 2020; Zhang et al. 2020; and Coelho et al. 2020) and subsequently was hit by an immense economic recession, interest in a more "resilient" approach gained popularity throughout the sector (Tuchen et al. 2020; ICAO 2020; Terry 2020; Gössling 2020; Lenot and Stewart 2020; Arora et al. 2021; and Bouwer et al. 2022). Preparing for future public health disruptions thus has a clear societal and economic value. However, discussions remain about what resilience means in this context. The proposed categorization of resilience aims to bring clarity by dividing resilience into four aspects: fragility, robustness, adaptation, and transformation. Currently, it is assumed that all aspects contribute to achieving overall resilience.

The results of this scoping review are seen as a first step towards a unified categorization of resilience. In its current state, the categorization can also function as a sensemaking tool that can support organizations in decision-making and strategy development in disruptive times. As the categorization aims to create a common understanding of resilience and its aspects, decision-makers are equipped with more granular terminology. This allows for a more accurate description of one's resilience when facing disruption and creates a common understanding.

To further mature this categorization of resilience, future research is required. Currently, two research gaps are identified in the literature: the operationalization of aspects; and the occurrence of the aspects in practice. Although the categorization of resilience is meant as a sensemaking tool, research is needed regarding strategies or tools that are required for operationalizing each aspect. For example, imagine an organization wanting to use the fragility aspect as an asset. How could this be operationalized? Inspiration can be drawn from cybersecurity's "honeypots", whereby cybercriminals are purposefully lured into a fragile information system so that their way of working can be monitored and analyzed. Further maturing the aspects of resilience and its strategies can support its operationalization and serve as inspiration during disruptive times.

Secondly, further research on the occurrence of each aspect in the industry is needed to assess their value in practice. When coupling back to the civil aviation industry and COVID-19, anecdotal evidence was gathered to illustrate each aspect. As a result, the notion of transformation seemed underdeveloped but necessary as the pandemic instigated an existential public health and economic crisis. Expanding the anecdotal evidence of the occurrence of the aspects of resilience in the civil aviation industry during disruptive times is seen as a critical next step.

Currently, this study has limitations regarding the terminology of the aspects, the included literature, and resilience as a process. First off, the categorization of resilience aims to create concept clarity but a degree of ambiguity can remain due to the choice of terminology. Reducing this ambiguity is assumed to be a continuous process with dialogue between academia and practice.

Although the focus of this study was on resilience and antifragility, a broader systematic literature review that combines resilience with for example transformation, adaptation, robustness, and/or fragility seems critical to propose

more complete insights. Additionally, the resulting categorization and visualization are made by the authors of this paper and based on their interpretations of the resilience models.

Finally, this study approached resilience primarily as an outcome and ex-post value. However, resilience can be interpreted in many ways such as an ability, capacity, behavior, process, or a mix (Hillmann and Guenther 2021). Although the distinctions between these interpretations are often vague, the notion of resilience as a process is not explicitly present in this study. At this point, it is suspected that systems can move through the aspects of resilience thus for example going from fragile to transformation and then robustness. However, further research is required on how the aspects relate to resilience as a process and concepts such as the Panarchy Theory (Holling 2001).

3.6 Conclusions

The raison d'être of this paper originated from the civil aviation industry's interest in a "resilience" strategy for future health disruptions in the wake of the COVID-19 pandemic. However, the concrete meaning or significance of resilience remained vague thus hampering decision-making and the creation of a long-term strategy. When consulting the academic literature, this trend seemed to reappear as the concept of resilience proliferated in the last years and evolved into an umbrella term.

In response, a scoping review was conducted to dissect resilience leading to the categorization of resilience. This categorization divides resilience into four distinct aspects: fragility, robustness, adaptation, and transformation. These aspects are expected to support sensemaking in disruptive times while assisting decision-making and strategy development.

When overlaying the aspects of resilience over the civil aviation industry and the COVID-19 pandemic, a transformative approach seems significantly underdeveloped but of existential value for overcoming future disruptions. Further research will focus on maturing the categorization of resilience and how it can be the basis for actionable decision-making and strategy development in disruptive times.

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4
THE
RESILIENCE
IN
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WILD

4. Resilience in the wild

Building upon the findings of Chapter 2, this chapter explores how resilience-as-a-process is operationalised by observing six training sessions of Amsterdam Airport Schiphol's operational CMT involving 54 managers. The chapter aims to gain insight into crucial resilience capabilities. The corresponding SRQ3 was: *What resilience capabilities do airport CMTs use?*

Through thematic analysis, three novel resilience capabilities were identified: (1) proficiently navigating the rules of play, which refers to the effective use of protocols, procedures, and leadership styles; (2) metacognition, a reflective decision-making approach enabling other known resilience capabilities such as shared situational awareness and the anticipation of future developments; and (3) directionality, a capability whereby a team establishes and reflects upon a shared goal during a crisis. Furthermore, doubt was identified as a critical disruptor of the decision-making process. Finally, the training methodology related to red teaming proved to be an effective approach for evaluating and enhancing resilience capabilities. Therefore, it can be considered a tool in operationalising resilience.

The results of this chapter provide a preliminary answer to the MRQ: *How can resilience be operationalised in airports to prepare for and respond to looming Black Swans?* This answer lies in fostering three key capabilities: proficient navigation of the rules of play, metacognition, and directionality. Furthermore, this chapter delves deeper into the "how" of operationalisation, by examining the employed training methodology, an approach that may be considered a form of wargaming. Finally, the analysis and writing of this chapter occurred in parallel with the development of Chapters 5 and 6. Although the lens of resilience-as-a-process was not explicitly used in those chapters, it significantly influenced their development and is addressed in the discussion section of Chapter 6.

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Abstract

As the aviation industry faces increasing volatility and high-impact disruptions, it is committed to strengthening its resilience. To support its operationalisation of resilience, we observed six training sessions and debriefs with 54 operational managers to examine what resilience capabilities airport Crisis Management Teams (CMTs) use. After conducting a reflective thematic analysis, we identified a resilience capability; an enabling resilience capability facilitating the development of two established and one novel resilience capability; and a barrier to the resilience process. The first resilience capability highlights the importance of proficiently navigating the rules of play, referring to protocols, procedures, and leadership styles. Given the high turnover of aviation personnel, further research is needed to ensure that protocols and procedures are easy to use. The second enabling resilience capability emphasises the importance of metacognition, a reflective decision-making approach. Metacognition supports the development of resilience capabilities such as shared situational awareness (SSA), the capacity to anticipate future developments and directionality. Directionality is considered a novel resilience capability and involves establishing and reflecting upon a shared goal during disruptions. Directionality helps align CMTs, prioritise goals, and provide a benchmark for success. Moreover, it facilitates timely escalation to higher-management CMTs when necessary. Third, we noticed that doubt disrupts and delays decision-making, thus hampering the resilience process. Finally, the training methodology used in this study proved effective for evaluating and improving resilience capabilities.

4.1 Introduction

The aviation industry operates in an increasingly volatile environment where high-impact disruptions seem to become the norm instead of the exception. Events such as the COVID-19 pandemic, the Russo-Ukrainian war, and multiple natural disasters expose fragilities within the aviation industry while underscoring the urgent need for greater organisational resilience (Arora et al., 2021; Linden, 2021). This need is echoed by the recent Directive on the Resilience of Critical Entities (European Commission, 2024), outlining that protecting critical infrastructure, such as airports, is vital for our modern society as they provide essential services.

However, operationalising resilience in airports, other critical infrastructure or organisations in general remains a significant challenge (Hermelin et al., 2020; Ketelaars et al., 2024; Linnenluecke, 2017; Van Der Vegt et al., 2015).

A major difficulty in operationalising resilience is assumed to be its lack of conceptual clarity (Nieuwborg et al., 2023). Throughout the years, resilience has become an umbrella concept encapsulating multiple different interpretations (Hillmann & Guenther, 2021; Linnenluecke, 2017) such as community resilience (Norris et al., 2008), engineering resilience (Holling, 1996) and graceful extensibility (Woods, 2015). Generally, these interpretations refer to a desirable organisational characteristic for managing disruptions (Linnenluecke, 2017), which is context-dependent and related to an organisation's goals (Hillmann & Guenther, 2021; Ketelaars et al., 2024; Martin-Breen & Anderies, 2011).

A key conceptual distinction is made regarding the nature of resilience, either approaching resilience as an outcome or a process (Hillmann & Guenther, 2021; Ketelaars et al., 2024; Williams et al., 2017). On the one hand, resilience as an outcome refers to its state after facing a disruption, giving it an ex-post quality (Canizares et al., 2021). The underlying logic is that an organisation's resilience against a certain disruption can only be determined after exposure. Resilient outcomes can be divided into four categories (Nieuwborg et al., 2023): fragility, robustness, adaptation, and transformation. Fragility refers to an organisation that loses value or collapses due to a disruption. Robustness depicts a system that remains stable or recovers after facing a disruption. Adaptation indicates evolutionary change after a disruption whereby an organisation learns, reorganises, and reconfigures. Finally, transformation refers to revolutionary change whereby organisations conduct an identity change and create new conditions of fitness due to a disruption.

On the other hand, resilience as a process focuses on the capabilities of an organisation and its decision-makers to manage disruptions, with the expectation that these capabilities lead to a resilient outcome (Canizares et al., 2021; Sutcliffe & Vogus, 2003). Approaching resilience as a process enables a proactive way of managing resilience as it is assumed to emerge before a disruption occurs, giving it an ex-ante characteristic (Canizares et al., 2021). In this study, we interchangeably use resilience as a process and capabilities.

Williams et al. (2017) suggest that Crisis Management Teams (CMTs), defined by Coombs (2015) as a multidisciplinary team within an organisation which has been designated to handle crises, are assumed to operationalise resilience capabilities throughout their decision-making processes. Burnard and Bhamra (2011) reaffirm this perspective, conceptualising resilience capabilities as an emergent property that arises through the processes conducted by an airport CMT. Besides Nieuwborg et al. (2024) highlighting the importance of sensemaking in airport CMTs, academic literature on the specific resilience capabilities utilised by CMTs in aviation or other transportation-related critical infrastructure (e.g. train stations or seaports) seems non-existent. Thus, we note a knowledge gap regarding those airport CMT processes that enable resilience. This gap is significant, as understanding how airport CMTs create and maintain resilience capabilities is expected to contribute to the operationalisation of resilience within aviation and possibly other critical infrastructure. To address our knowledge gap, we defined the following research question: What resilience capabilities do airport CMTs use?

4.2 Background

To the best of our knowledge, no academic literature has researched the resilience capabilities of airport CMTs. However, extensive research has been conducted on resilience capabilities and CMTs in other contexts, such as firefighters (Weick, n.d.), SWAT teams (Bechky & Okhuysen, 2011), and the oil and gas industry (Tveiten et al., 2012). In this section, we summarise recurring trends that, while not yet studied in airport CMTs, provide a useful lens for examining how resilience is operationalised. This summary does not aim to be exhaustive, and its findings are predominantly drawn from relevant systematic literature reviews by Hillmann & Guenther (2021), Ketelaars et al. (2024), Linnenluecke (2017), Ruiz-Martin et al. (2018), and Williams et al. (2017). The discussed resilience capabilities include shared situational awareness (SSA); management of crucial vulnerabilities; capacity to anticipate future developments; bricolage; systems thinking; and effective communication and information-sharing.

Maintaining SSA and its nascent concept of sensemaking are frequently mentioned as critical resilience capabilities within CMTs (McManus et al., 2008; Nieuwborg et al., 2024; Olsén et al., 2023; Son et al., 2020; Weick, n.d.; Williams et al., 2017). Three levels of SSA are defined: the shared perception of elements in an environment; the shared

comprehension of the elements' meaning; and the shared projection of the elements' status in the near future (Endsley, 1995; Perla et al., 2000). Shared task knowledge, common workflow expectations, and plenary (de)briefs within CMTs are assumed to support the creation of SSA (Bechky & Okhuysen, 2011; Gomes et al., 2014). The use of metacognitive skills, a reflective approach whereby practitioners recognise, critique, and correct their decisions as a course of action is being taken (Cohen et al., 1996), is recommended as a supplement to SSA, as opposed to mindlessly following rule-based procedures (Frye & Wearing, 2016).

Managing crucial vulnerabilities is a second capability contributing to resilience (McManus et al., 2008). This capability shows great overlap with the concept of reliability-seeking organisations, which is assumed to be a key aspect of High Reliability Organisations (HROs), or organisations that operate high-hazard technologies requiring error-free operations (e.g. aircraft carriers and arguably airports) (Linnenluecke, 2017; Sutcliffe, 2011). Being proactive in handling a crisis (Tveiten et al., 2012), and harmonising work-as-imagined and work-as-done (Son et al., 2020) are valuable strategies for managing keystone vulnerabilities.

Linked to the management of crucial vulnerabilities and the third SSA level (i.e. projection), is a CMT's capacity to anticipate future developments (Hillmann & Guenther, 2021). Such anticipation can be achieved by thinking in terms of multiple futures (Välikangas & Georges L. Romme, 2012), generating alternative courses of action (Olsén et al., 2023), and conducting scenario planning (Hillmann et al., 2018).

As a crisis often arises unexpectedly, capabilities such as bricolage or improvisation within CMTs enable resilience (Bechky & Okhuysen, 2011; Romano et al., 2022; Weick, n.d.). Bricolage refers to a process whereby resources at hand are used to address arising problems and opportunities (Baker & Nelson, 2005) and is assumed to be an enabler for constructing SSA (Bechky & Okhuysen, 2011; Son et al., 2020).

When dealing with complex crises, a systems thinking approach is essential as it enables CMTs to grasp the bigger picture, accommodate and understand different stakeholders, identify emergent hazards, and even improve an organisation after a disruption (Kahn et al., 2013; Luther et al., 2023; Olsén et al., 2023; Romano et al., 2022). In order to effectively use this approach, it is essential to establish a common direction amongst stakeholders (Olsén et al., 2023) and coordinate the crisis plans of different CMTs (Gomes et al., 2014).

Finally, effective communication and information-sharing practices within CMTs and other stakeholders enable coordinating activities and resources among stakeholders while reducing uncertainty (Olsén et al., 2023; Son et al., 2020; Tveiten et al., 2012; Williams et al., 2017). Importantly, CMTs should also include the general public and those affected in the communication process to avoid misinformation (Olsén et al., 2023). Using narrative or pictorial communication is deemed necessary to convey the complexity and nuance that coincides with a crisis (Luther et al., 2023). Additionally, the use of cognitive aids such as visual wall displays (Gomes et al., 2014), maps (Son et al., 2020), and an event history log in combination (Tveiten et al., 2012) with a plotter or event mapper (Bharosa & Janssen, 2009), can support the coordination process.

4.3 Method

4.3.1 Research setting

Addressing the call for more empirical research (Linnenluecke, 2017; Van Der Vegt et al., 2015), we employed an activity-based case study approach (Patton, 2015) by observing a series of training sessions and debriefs of the Commissie van Overleg (CVO). The CVO is the operational CMT of the Royal Schiphol Group, which operates Amsterdam Airport Schiphol (AMS), one of Europe's largest airports. The CVO has extensive experience in crisis management, having handled events such as the COVID-19 pandemic and the Turkish Airlines Flight 1951 crash.

Within AMS's crisis management organisation, the CVO team focuses on managing disruptions or incidents that negatively impact the continuity of essential airport processes while ensuring order, safety and security (Veilgheidsregio Kennemerland, 2023). Whenever the disruption infringes upon AMS's tactical or strategic position, the CVO must activate the internal tactical and strategic CMTs. Besides AMS's internal CMTs, more than ten CMTs can be active in parallel to the CVO, increasing the complexity. These CMTs include first responders (e.g. fire services), local government (e.g. municipalities), national government (e.g. ministries) and other stakeholders (e.g. airlines). Communicating and collaborating with all these CMTs is a crucial responsibility for the CVO.

Given the CVO's critical role in managing airport disruptions, continuous training is essential to ensure effective crisis response. To gain insights into its resilient capabilities, we observed a series of CVO training sessions and debriefs facilitated by three AMS crisis trainers, who also develop the training scenario. The sessions are held in an operations room and realistically simulate the first hour of an unfolding disruption in real-time.

When a CVO is alerted, a multidisciplinary team of operational managers assembles in an operations room. The CVO team varies in size and expertise depending on the disruption, but it usually has a core of 8 to 10 managers responsible for their respective airport processes. Together, they represent all branches of the airport operations. The core team consists of the following roles: Flow Manager Aircraft (FMA); Flow Manager Passengers (FMP); Communication Manager (DCA); Safety and Security Manager (SSM); Airport Operations Centre Manager (APOC); IT Manager (IT); Information Manager (IM); Asset manager (AM); Airline Partnership Manager (APM); and a plotter. On a case-by-case basis, other stakeholders (e.g. airlines, security services, and health services) join the CVO. To ensure continuous airport operations, at least eight managers share the same role on a rotational basis. Consequently, the team composition in a CVO is rarely identical.

The training sessions begin with a briefing by a facilitating crisis trainer outlining the initial problem. Subsequently, the CVO starts its decision-making process. Throughout the session, each CVO member is paired up with a so-called antagonist. The antagonists are seated in a separate room and simulate the broader airport system, such as frontline workers (e.g. security personnel or baggage handlers), other stakeholders (e.g. airlines and the government) or society (e.g. social and national media). The goal of the antagonists is to provide a feedback loop regarding the decisions made within the CVO, provide an infeed for scenario injects, and simulate the volatile, uncertain, complex and ambiguous aspects that coincide with managing a crisis. The antagonists are usually experienced AMS managers with expertise similar to that of the CVO members they are paired with. Communication between the CVO members and their antagonists happens via WhatsApp text messages. Besides contributing to the evaluation of the training sessions, no data is collected from the antagonists. Figure 4.1 provides an overview of the research setting.

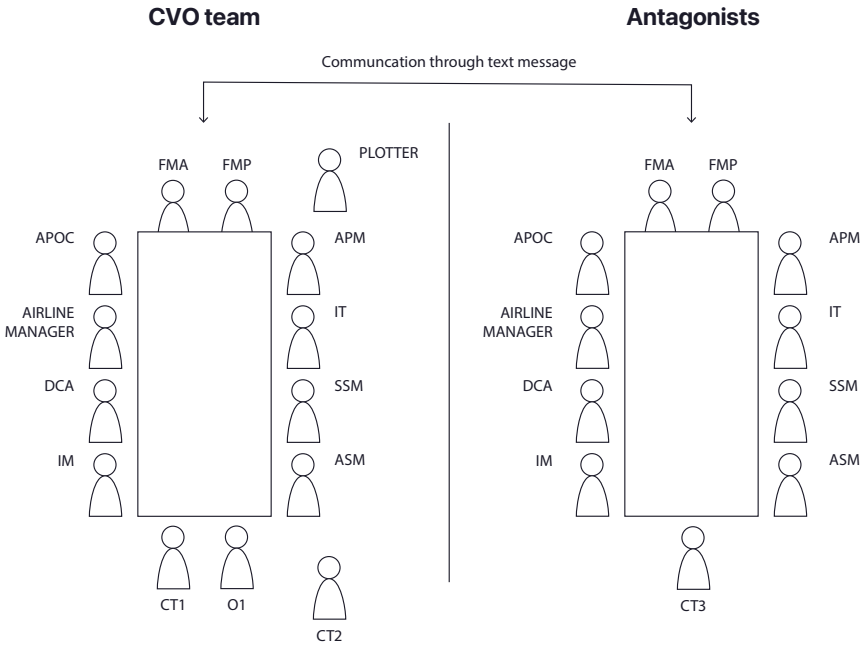

Figure 4.1 Overview of the research setting with the CVO team and the antagonists. CT stands for crisis trainer. O stands for observer. All other abbreviations are introduced in the text.

Leadership within the CVO is shared between the FMA and FMP, whose roles shift depending on the nature of the disruption. In an aircraft-related disruption, the FMA focuses on managing the disruption, while the FMP chairs the CVO and oversees the decision-making process. In a passenger-related disruption, their roles are reversed. All other members manage their respective processes. If the disruption continues to escalate or a crisis looms, the CVO is responsible for activating the internal tactical or strategic CMTs.

After the training session, the crisis trainer facilitates a debrief with all CVO members. During the debrief, an evaluation is conducted on the resilience capabilities of the CVO team. The evaluation is based on the team's capabilities to effectively manage airport processes, maintain the airport's tactical and strategic position, and ensure a desirable outcome by the end of the training session. Given that resilience is highly context-dependent, the evaluation is conducted collaboratively by the crisis trainers, antagonists, and CVO members. To minimise interpretation bias, each party contributes independently to the evaluation.

Both training sessions and debriefs were observed by the study's first two authors (Figure 4.1: O1 and CT1). Following the training and debrief sessions, the three crisis trainers hold a separate informal discussion to reflect on the session and determine the CVO's resilience.

4.3.2 Scenario

A CVO training session follows a predesigned scenario created by the AMS crisis trainers. For this study, the authors and crisis trainers jointly designed two scenarios, reviewed by a panel of airport experts. The scenarios were inspired by the early phases of a looming pandemic, comparable to the period from December 2019 (i.e. the first cases of SARS-CoV-2) to March 2020 (i.e. WHO declaring a pandemic). While inspired by real events, the scenarios are not identical recreations. Instead, they provide a structured outline, allowing the CVO teams to influence how the scenario unfolds. In line with the naturalistic decision-making approach (Klein, 2008), participants are free to draw on their prior experiences, as these are considered integral to the real-life decision-making process. The reasoning for selecting a pandemic scenario is twofold. First, it aligns with the AMS's ambition to build resilience against pandemics. Second, similar public health disruptions (e.g. COVID-19, Ebola, SARS) provide a relevant frame of reference for the crisis managers, antagonists, and CVO members to evaluate resilience.

Both scenarios start with a briefing presented by the crisis trainer at the start of the training session. The briefing outlines the emergence of a novel virus, SARS-CoV-3, in South America and the arrival of several sick passengers in airports near AMS. In scenario two, the briefing is extended to include the announcement that the WHO has declared the start of a pandemic. This addition was made at the request of the Royal Schiphol Group, which sought to assess its impact on the decision-making process. The CVO chair then receives a text message from the antagonists outlining the first inject: an inbound aeroplane for AMS with a sick passenger onboard. At predefined time stamps, new injects are sent to the CVO, such as the arrival of a second aeroplane with sick passengers while having the Dutch U21 football team onboard, an outage of the security system, and unrest among passengers and personnel as well as on social media. Any situational aspects not directly addressed by the scenario are communicated through interactions with the antagonists (e.g. border control and government policies). Table 4.1 summarises the briefing and the injects.

Table 4.1 Overview of the briefing and training injects with their respective timestamp. The addition made in scenario two is indicated with an asterisk.

Briefing	
Timing	Injects
T-5	Medical information on SARS-CoV-3
	Cases of SARS-CoV-3 passengers in nearby airports
	* WHO declared the start of a SARS-CoV-3 pandemic with its epicentre in South-America
Training	
T+0	Inbound flight 0749 from Bogota with sick passenger
T+10	Flight 0749 lands
T+20	Inbound flight 0744 from Lima with sick passenger. Dutch U21 football team onboard
T+30	Flight 0744 lands
T+35	Camera system outage in the terminal
T+40	Unrest among passengers in the terminal and on social media

4.3.3 Data collection

This study included six training sessions and debriefs from 21 September 2023 until 26 October 2023. The training sessions were audio-recorded and lasted between 45 and 69 min. The debriefs were also audio-recorded and lasted between 10 and 33 min. During the training sessions, the first two authors made fly-on-the-wall observations through timestamped field notes, which focused on aspects the audio could not capture, such as atmosphere and movement. The reflections were captured through field notes.

4.3.4 Data analysis

We conducted inductive and deductive reflective thematic analysis (RTA) to seek and develop patterns or themes across the collected data (Braun & Clarke, 2021). RTA is a qualitative research method that goes beyond description or summary and focuses on conceptualising patterns of shared meaning. In accordance with the qualitative research paradigm, RTA approaches researcher subjectivity as a resource, as subjectivity inevitably shapes the research process while knowledge is always partial, perspectival, and contextual (Braun et al., 2022). The data analysis utilised Braun and Clarke's (2022) six-phase approach consisting of: (1) familiarisation, (2) inductive coding, (3) initial theme generation, (4) reviewing and developing themes, (5) refining, defining and naming themes, and (6) producing the report.

First, familiarisation commenced with listening to the audio recordings and reading the field notes. Then, transcriptions were made of all audio recordings in verbatim by a student assistant and reviewed by the first author. This was followed by three rounds of inductive coding using ATLAS.ti software. In the first round, the first author coded the debrief transcripts and field notes. In the second round, the third and fourth authors independently coded the debrief transcripts and compared them to the first-round coding results. In the third round, the results of the first two rounds were compared, and a third round of coding took place. This three-round process was used to enrich codes and create alignment among the authors.

After coding, the first author generated initial themes. To enrich these initial themes, the first author conducted an additional deductive coding round applying the initial themes to the transcribed training data. This additional deductive coding round aimed to enrich and expand the initial themes. The themes were further reviewed and developed into main- and subthemes. Furthermore, each main theme was conceptualised as either a resilience capability or a barrier hampering the resilience process. This phase was conducted by the first and second authors and reviewed by all authors. The first author then refined, defined, and named the themes, which all authors again reviewed. The recurring resilience capabilities discussed in the background provided an additional lens for refinement. Finally, the themes were translated into narratives and drafted in a report, which was reviewed by all authors.

Additionally, the first author extracted illustrative quotes from the training sessions and debrief transcripts. These quotes were translated from Dutch to English. The second, third and fourth authors peer-reviewed the translations.

4.3.5 Ethics

This study was approved by the TU Delft Human Research Ethics Committee (reference number 3142). All participants were given an informed consent form, which was introduced by the first and second authors and signed before the training sessions. Participants were informed that participation was voluntary and that withdrawal could be made at any point. Opinions expressed during the training sessions and the debrief were confidential and anonymised, allowing participants to speak freely. None of the authors had any hierarchical relation with the participants.

4.4 Results

Six CVO training sessions and debriefings were observed, with a total of 54 participants, three of whom participated twice due to rostering constrictions. Subsequently, the CVO team size varied from eight to 11 participants. Table 4.2 presents an overview of all participants, detailing their distribution across the six training sessions and debriefs, along with the respective scenarios.

As evaluated by the crisis trainers, antagonists and CVO members, teams two and five were deemed to have delivered a desirable and robust outcome. Both teams effectively managed the airport processes while maintaining the airport's tactical and strategic position. The other teams delivered more fragile outcomes as their responses were generally deemed insufficient.

Table 4.2 Overview of all the participants distributed across the six training sessions and debriefs, along with their respective scenarios. Participants who attended multiple sessions are marked with subscript 1, 2 and 3.

Roles	**Training sessions and debriefs**					
	Scenario 1			Scenario 2		
	CVO1	CVO2	CVO3	CVO4	CVO5	CVO6
Flow Manager Passengers (FMA)	x	x	x	x	x	x
Flow Manager Aircraft (FMP)	x_1	x	x	x_1	x	x
Communication Manager (DCA)	x	x	x	x	x	x
Safety and Security Manager (SSM)	x	x	x	x	x	x
Airport Operations Center Manager (APOC)	x	x		x	x	
IT Manager (IT)	x	x_3	x_3	x	x	
Information Manager (IM)	x	x	x	x	x	x
Asset Manager (ASM)	x	x	x	x	x	x
Airline Partnership manager (APM)	x		x	x	x	x
Airline Manager	x					
Plotter	x_2	x_2	x	x	x	x
Total participants	11	9	9	10	10	8

The reflective thematic analysis generated three main themes and 10 subthemes. These themes capture different aspects related to the resilience capabilities of airport CMTs. The first theme, navigating the rules of play, is conceptualised as a resilience capability. The second theme, metacognition matters, was identified as an enabling resilience capability, supporting the development of established resilience

capabilities and the novel capability of directionality. Finally, theme three, disruptive doubt delaying decision-making, introduced a barrier hampering the resilience process.

4.4.1 Navigating the rules of play

Throughout the training sessions, the CVO teams had to navigate a set of "rules of play", a term used to encompass informal dynamics (e.g. leadership styles) and formal guidelines (e.g. protocols, procedures and roles). Applying the intent of the rules of play correctly, considered a resilience capability, positively influenced how disruptions are managed. First, leadership played a crucial role in accelerating the decision-making process by putting the CVO teams in the driver's seat. Second, maintaining proper decision-making housekeeping by adhering to CVO meeting protocols is essential to ensure order and efficiency throughout the decision-making process. Third, CVO participants need a solid understanding of public health disruption procedures to avoid confusion and delays. Finally, an active and assertive plotter can immensely support the quality of the decision-making process.

4.4.1.1 Taking the driver's seat through leadership

Leadership is a crucial aspect within the CVO teams, and is expected from the chair as formal leader as well as from each participant. According to the crisis trainers and antagonists, strong leadership is characterised by decisiveness and the ability to guide the team toward achieving a resilient outcome within a reasonable amount of time. As observed in several CVO meetings, strong leadership puts the CVO team in the driver's seat, accelerating the decision-making process and ensuring effective crisis management.

First, a recurrent manifestation of strong leadership occurred whenever the chair framed and set shared expectations of the disruption. To illustrate, after the first plane's arrival, one chair framed the collaboration with the public health services as slow and bureaucratic. Additionally, the chair pointed out that communication and passenger accommodation would be crucial throughout the upcoming hours. The framing and setting of expectations seemed to contribute to the SSA while also setting a direction for resolving the disruption. Second, whenever chairs provided a clear division of labour and responsibilities amongst the team, it enabled participants to take on responsibilities and pushed the decision-making process forward. Third, participants showcased strong individual leadership whenever they,

on their initiative, intervened during moments of indecision or lapses in protocols and procedures. The following quote illustrates this individual leadership as the IM assertively intervenes when not included during a roundtable discussion.

> *IM: [sarcastically] Of course I will be skipped as information manager [...]!*
>
> *FMP: Apologies*
>
> *- CVO2*

Cases of weak leadership emerged in a number of CVO meetings. This was primarily evident when chairs assumed too many responsibilities instead of delegating decisions or emerging issues to the appropriate CVO members. For example, one chair retained ownership of a security issue which should have been assigned to the SSM. This overloaded the chair, leading to other participants taking a more passive stance and causing decision-making to stagnate. Additionally, on occasions when a chair was indecisive or took a reactive posture, the whole CVO was placed in the back seat.

4.4.1.2 Proper protocol housekeeping

The CVO uses prescribed protocols which elaborate on the conduct of the meeting, the decision-making process structure, and the designated roles and responsibilities of CVO members. These protocols include introducing the general rules of play by the chair: a round of introductions; the participants' expertise and experience; the IM's timekeeping role; the chair or plotter's responsibility to make summaries; and conducting roundtable discussions involving each participant.

Teams following the protocols, thus creating a solid protocol "housekeeping", seemed to have a more resilient response to the scenario. This was observed in CVO teams when the decision-making process was well-structured, typically guided by strong leadership from the chair, actively engaging all members. However, adhering to the protocols proved challenging, as several teams struggled with effective time management and failed to conduct comprehensive roundtable discussions. These teams were then stuck in a meandering, indecisive discussion while disregarding participants who held valuable input. Subsequently, decision-making stagnated, and the team lost its grip on the disruption. On several occasions, participants noticed these protocol lapses and intervened, pushing the CVO to self-reflect and reinvigorate the decision-making process.

4.4.1.3 Procedural puzzles

In addition to protocols, the CVO has a wide array of operational procedures to support them in managing a disruption. These procedures include scenario cards outlining what to do during a certain disruption (e.g. a plane crash or fire); an extensive public health disruptions playbook; and a general procedure regarding crisis management.

All CVO teams were aware of these procedures however navigating them proved to be difficult as confusion frequently arose regarding the procedures' meaning and execution. Minor confusions were predominantly centred around the meaning of an abbreviation and had a low impact on the disruption. More significant confusion arose regarding the location of Personal Protective Equipment (PPE), lines of communication towards employees and other stakeholders (e.g. public health services), and the chain of internal and external command.

As an illustration, one procedural discussion was notable as it recurred in almost all the CVO training sessions: accommodation of stranded passengers with a high risk of infection. The accommodation procedure for up to 30 passengers is clear, but confusion increased significantly when more high-risk passengers arrived. On the one hand, more accommodation space at the airport can be added based on space available at that time. On the other hand, accommodation can be delegated to the public health services whereby passengers are transferred off the airport. Deciding which accommodation procedure to follow proved challenging.

4.4.1.4 Plotters, unsung heroes?

Plotters are responsible for making time-stamped notes that track the CVO's decision-making process. The notes are written on a large whiteboard visible to all CVO participants and summarise events, decisions made, and decisions to be made. During the training sessions, the plotters generally remained in the background in the CVO's decision-making process, functioning predominantly as scribes. Nevertheless, they significantly influenced the decision-making process whenever they took an active and assertive role. Throughout multiple CVO meetings, plotters proactively intervened when the CVO was embedded in an indecisive discussion. This intervention pushed the CVO team to self-reflect, giving the decision-making process momentum.

Additionally, several plotters provided a recurrent summary, which helped develop SSA. The chair played a critical role in facilitating the plotters' active posture by actively involving the plotter in the decision-making process and giving the plotter a formal space to make summaries and interventions.

4.4.2 Metacognition matters

The second main theme highlights the importance of managing the CVO's metacognition, which is regarded as an enabling resilience capability. It supports the development of established resilience capabilities, such as SSA and the capacity to anticipate future developments, as well as the novel capability of directionality. The three subthemes illustrate how metacognition enables these capabilities. First, it was observed that a metacognitive understanding of the team's position within the SSA process enhanced the overall SSA. Second, when the CVO was running behind, metacognition enabled the team to pick up the decision-making pace and anticipate future developments. Third, it appeared essential for CVO members to have a metacognitive awareness of what constitutes a resilient outcome, essentially their criteria of contextual success, as this awareness provided directionality within the decision-making process.

4.4.2.1 Bridging the situational awareness gap

Although obtaining a proper SSA was challenging, some of the CVO teams seemed to bridge the SSA gap. These CVO teams achieved this whenever the chair actively posed plenary questions (e.g. what are we missing?), encouraging the CVO to engage in discussion and create SSA. Additionally, some chairs took a metacognitive approach regarding decision-making by explicitly mentioning the level they were at (i.e. according to Endsley (1995), perceiving, comprehending and projection), thereby creating a shared understanding regarding the position of the CVO's SSA. To illustrate:

> *FMP: [...] picture has just been perceived [...] then we do a new round of comprehension and finally a bit of decision-making.*
>
> *- CVO2*

Other aspects we observed that support the creation of SSA included the use of airport maps to create a shared geographical understanding, concise communication within the decision-making process, the framing of the disruption by the chair (4.4.1.1), the frequent use of summaries (4.4.1.2), and plotter interventions (4.4.1.4). Several

CVO teams struggled to obtain SSA primarily due to insufficient plenary information sharing. This led to misalignment and duplication of efforts, reducing the team's overall cohesion.

4.4.2.2 Getting ahead of the disruption

Whenever CVO teams discussed projecting the future, they seemed to get ahead of the disruption. This was predominantly apparent when CVO teams were metacognitive regarding the second and third-order consequences of the disruption and corresponding decisions made by the CVO. The successful projection coincided with increased pressure on the antagonists, who had to put more effort into simulating a challenging disruption for the CVO team. Additionally, a successful projection seemed to coincide with a strong framing of the incident (4.4.1.1), a clear distinction between the primary and secondary objective (4.4.2.3), concise decision-making, and a resilient outcome.

Failing to adequately anticipate future developments was a frequent issue, causing several CVO teams to fall behind. As a result, the use of a quick scenario analysis became a recurring theme in the evaluations. This lack of foresight often aligned with CVO discussions focused on operational aspects (e.g. the number of incoming flights) but overlooking the strategic layer. Furthermore, projections were typically not accompanied by specific follow-up actions or decisions. Finally, projections were observed to occur towards the end of the training sessions, limiting their effectiveness in helping participants stay ahead of the disruption.

4.4.2.3 Decisive directionality

During the CVO team evaluations, a discussion often emerged around the desired success criteria during a disruption or the aspired resilient outcome. The formal goal of the CVO, to manage the continuity of the airport process during a disruption, was generally well known. However, applying this goal and relating it to the context of the disruption was challenging. CVO teams that established a well-defined goal within their zone of control and maintained a metacognitive approach were able to accelerate the decision-making process, creating what some participants described as directionality. Making the goal collective, concrete, and concise was mentioned to support the CVO team in developing directionality. The following quote illustrates a well-defined goal, where the FMA puts the focus on resolving an incident at a specific geographical location, apron G-20:

FMA: [...] our biggest problem is managing G-20 [...]

- CVO4

Nevertheless, CVO teams seemed to lose grasp of the disruption whenever their directionality became vague or undefined. Subsequently, difficulties arose in separating the main and side objectives. This was predominantly manifested when participants had difficulties focusing on detailed operational issues, thus losing sight of the larger strategic picture. The following quote illustrates a goal deemed too generic and vague:

FMP: My goal was to [hesitation] manage this calamity, this incident, as best as possible, so that the passengers are affected as little as possible.

- Debrief, CVO4

4.4.3 Disruptive doubt delaying decision-making

As the scenarios advanced, doubts emerged within all CVO teams about handling the disruptions, significantly delaying decision-making and acting as a barrier to the resilience process. The three subthemes illustrate how these doubts emerged. First, doubts occurred whenever communication with other stakeholders was required, leading to a discussion on what to communicate, to whom, and when. Second, on multiple occasions, CVO teams hesitated about escalating the crisis to the airport's tactical or strategic crisis teams. Third, participants hesitantly argued that prior knowledge of a pandemic would not change their management of the disruption, further highlighting their reluctance to escalate.

4.4.3.1 To communicate or not to communicate

During the training sessions, the CVO teams had to conduct crisis communication with internal (e.g. employees or higher management) and external stakeholders (e.g. public health services, passengers, and the press). Discussions frequently arose regarding the communication strategy (e.g. whether to communicate, when to do so, and what to convey), consuming valuable time without leading to decisions. Consequently, these CVO teams no longer had a grip on the disruption. A common point of contention was what should be communicated to the public. Should the CVO be specific in its message (i.e. explicitly mention that a novel virus may have infected passengers on an inbound aeroplane), purposefully vague (i.e. there is a disruption

ongoing at the airport) or not communicating anything? The communication medium varied from a live blog, social media, and the airport website.

Communication with aviation (e.g. airlines or ground handlers) and public health stakeholders generally ran smoothly. However, CVO participants expressed the value of the physical presence of a liaison to public health services and other stakeholders. Additionally, the evaluators encouraged the CVO to reach a consensus on the communication strategy and delegate specifics to the DCA.

4.4.3.2 Hesitant to 'call in the cavalry'

As the disruption steadily became more complex, the CVO teams could escalate the situation and call in internal (e.g. tactical or strategic CMTs) and external stakeholders (e.g. regional government and ministries) to help manage the situation. However, CVO teams hesitated to call for assistance, the metaphorical "cavalry". Regardless of the scenario, this hesitancy was predominantly apparent towards internal stakeholders as the teams rarely asked for assistance from the airport's tactical or strategic CMTs. Although outside the scope of these CVO training sessions, this hesitancy to escalate to other CMTs would have weakened decision-making at later stages of the disruption. During the debrief, the evaluators explicitly addressed this hesitancy. However, the participants did not provide any reflections.

Some CVO teams called for assistance from internal and external stakeholders, allowing them to delegate certain responsibilities, thereby reducing the CVO's workload and improving the overall decision-making process. However, sharing this call for assistance plenary was observed to be crucial as its absence led to differences in SSA among CVO members

4.4.3.3 Pandemic or not; same procedure, right?

Two nearly identical scenarios were used during the training sessions. The difference between both scenarios lay in the initial briefing (Table 1), whereby scenario one implies a looming pandemic, and scenario two explicitly mentions the looming pandemic. The influence of either scenario was minimal, as the CVO teams showed comparable behaviour during the decision-making process, procedures, and leadership.

During the debrief, all CVO teams working on scenario one indicated they would not have reacted differently if they knew a pandemic was looming. Participants noted, often doubtfully, that there was no procedural difference, and any changes would then be the responsibility of the public health services. Although procedurally correct, CVO teams did have the power to escalate the situation to internal (e.g. tactical or strategic CMTs) and external stakeholders (e.g. ministries). Although in scenario two, the teams had a solid case for escalation (i.e. a looming pandemic), none of the CVO teams did so, as there seemed to be procedural puzzlement (4.1.3) and a general escalation hesitancy (4.4.3.2).

4.5 Discussion

This article investigated the research question: What resilience capabilities do airport CMTs use? To answer the research question, we observed six airport CMT training sessions and their subsequent debriefs. After conducting a reflective thematic analysis, three main themes and 10 subthemes emerged. The themes can be respectively considered as a resilience capability; an enabling resilience capability facilitating the development of two established and one novel resilience capability; and a barrier to the resilience process. The following section will discuss each resilience capability and intertwine the corresponding barriers.

Theme one introduces the first resilience capability, which lies in an airport CMT's proficiency in navigating their rules of play. Weak leadership or failure to correctly apply the intent of protocols and procedures places CMTs in a fragile position, resulting in meandering discussions, hesitancy to 'call in the cavalry', a slowed decision-making process, and potentially losing grip on the disruption. Practices such as training and checklists can enhance leadership capabilities and familiarity with procedures and protocols. Moreover, CMT training outputs can provide input for revising protocols and procedures by identifying recurring ambiguities, usability issues, or gaps. For example, in this study, it became apparent that the accommodation and communication strategy was the main cause of discussion, dominating the decision-making process. Revising corresponding procedures and protocols might streamline this. Formalising such organisational learning processes could help to improve organisational resilience (Chekkar-Mansouri & Onnee, 2013).

However, as the aviation industry is experiencing significant personnel turnover, this poses challenges for efficient knowledge transfer and overall familiarity with its complex stakeholder landscape. Rapid staff changes may outpace training in highly specialised and complex operational procedures and protocols. Consequently, we argue that new approaches towards protocols and procedures that are easily accessible, need a low cognitive load, and require little specialised knowledge or training are needed. To improve the accessibility, opportunities lie in improving the usability of current protocols and procedures by, for example, increasing the use of visual artefacts such as flowcharts or system maps (Luther et al., 2023) and leveraging metacognitive practices (Frye & Wearing, 2016).

Theme two introduces metacognition as an enabling resilience capability. The value of metacognition is extensive and is considered a foundational capability of airport CMTs. It supports the development of resilience capabilities such as SSA (McManus et al., 2008) reaffirming Cohen et al. (1996) and Frye and Wearing (2016); the capacity to anticipate future developments (Hillmann & Guenther, 2021); and directionality. This study identified two ways in which metacognition was applied. First, when CMTs are reflective and explicit about their SSA level, a shared meta-understanding is created about the team's overall SSA state. Second, posing metacognitive questions in plenary discussions (e.g. "what are we missing?") encouraged participants to reflect on their SSA process collaboratively. Additionally, posing metacognitive questions (e.g. "what is our goal?") enabled the airport CMT to create directionality.

To operationalise metacognitive capabilities, experiential learning methods such as simulations have been identified as key approaches (Cohen et al., 1996; Frye and Wearing, 2016). Furthermore, maintaining a metacognitive posture could be formalised as a general responsibility for all CMT participants, though an opportunity lies in delegating this role to the plotters. As plotters track all decision-making, they are ideally positioned for maintaining a reflective perspective; some plotters de facto already fulfilled this role. Further investigating and formalising this responsibility while embedding it within airport CMT training programmes can significantly improve resilience. Nevertheless, since the foundational work by Cohen et al. (1996), little progress has been made in exploring metacognition within crisis management or organisational resilience. Research is required to further operationalise metacognition within CMTs.

Enabled by metacognition, directionality is seen as an underlying resilience capability. Building on Williams et al. (2017) and Wilson's (2005) emphasis on shared goals, directionality concerns the process of continuous reflection on and adjustment to that shared goal. Subsequently, a metaphorical 'dot on the horizon' is created, helping the CMT benchmark the impact and success of certain decisions. This benchmarking seems linked to what Burnard and Bhamra (2011) conceptualise as the ability to recognise and interpret threats in relation to the organisation. However, directionality is not confined to threats but also includes opportunities and differentiation between primary and secondary objectives. Additionally, by setting shared expectations, directionality could enable other resilience capabilities addressed by the literature, such as the management of keystone vulnerabilities (McManus et al., 2008), proactive handling (Tveiten et al., 2012), common workflow expectations (Bechky and Okhuysen, 2011) and harmonising work-as-imagined and work-as-done (Son et al., 2020). Explicitly including tactical and strategic goals into the directionality of operational CMTs may reduce the reluctance to 'call in the cavalry', thus enabling a timelier inclusion of higher management CMTs, increasing overall organisational resilience (Hillmann & Guenther, 2021; Van Der Vegt et al., 2015). As in the operationalisation of metacognition, directionality could be formalised as a shared responsibility for all CMT participants or delegated to plotters, who were observed fulfilling this role. Additionally, further research on adjacent concepts such as mission command, a concept from the military whereby the strategic layer decides the intent and allows the operational layer the freedom to fulfil that intent (Storr, 2003), may yield novel insights.

Finally, as an unexpected finding outside the scope of the original research question, the CVO training methodology proved a valuable tool for developing and evaluating resilience capabilities. As these training sessions simulate decision-making in an environment of conflict, with the crisis acting as the opponent, they could be conceptualised as wargames (Perla, 2022). Expanding the use of these methodologies addresses de Wit's (2022) and Linden's (2021) call for more wargaming-like approaches within aviation in the wake of the COVID-19 pandemic. Furthermore, the use of antagonists, resembling a red team (Development, Concepts and Doctrine Centre, 2017), allows for a realistic and in-depth evaluation of each participant and could function as a qualitative resilience indicator.

Current practices for resilience evaluation predominantly focus on quantitative aspects (Ruiz-Martin et al., 2018), but these have been critiqued for their inability to be

applied ex-ante (Sevilla et al., 2023) and to insufficiently reflect reality (Linnenluecke, 2017). During the training sessions, it was observed that when the CMT got ahead in the disruption, pressure increased on the antagonists, positively correlating with the CMTs overall resilience. Subsequently, the amount of pressure on the antagonists could be a qualitative resilience indicator. Further investigation into this correlation may provide novel insights into measuring, standardising, and operationalising resilience.

4.6 Limitations

We note limitations regarding the observed CMT, the airport context, and cultural factors. Firstly, we investigated an operational CMT within an airport context. These CMTs focus predominantly on disruptions within the airport process and potential escalations to higher management CMTs. Subsequently, the generalizability of the findings to more tactical or strategic CMTs may be limited as these CMTs cover a different decision-making space with other stakeholders, responsibilities and goals. Then, the composition of the CMT varied depending on the training sessions, which might have impacted their resilience performance. Additionally, it is important to note that airport operators rarely take the lead during disruptions as they are often part of a broader multi-stakeholder landscape (e.g., airlines and ministries) with certain dependencies and power dynamics. Thus, generalising these results to a setting whereby a dominant stakeholder controls a disruption may be limited.

Secondly, this study used AMS as its case study. AMS is one of the largest European hub airports and has a rich experience dealing with crises. However, the AMS setting may not be representative of other, smaller, or less experienced airports as organisational structures, stakeholder landscapes, and resources may differ. Additionally, AMS operates within the context of Dutch laws and regulations, which may further limit the applicability of these findings to airports in other countries.

Finally, the Dutch culture might influence generalisability. As the Dutch culture can be characterised by open and direct communication combined with an egalitarian social structure, it can shape the behaviour and decision-making processes of the CMTs. Subsequently, the findings of this study may not be fully generalisable to CMTs operating in countries with different cultural norms and values.

4.7 Conclusion

As the aviation industry operates in an increasingly volatile environment where high-impact disruptions are becoming the norm instead of the exception, its interest in becoming resilient soared. To support the operationalisation of resilience, we observed six training sessions and debriefs to uncover what resilience capabilities are used by an airport CMT. After conducting a reflective thematic analysis, we identified a resilience capability; an enabling resilience capability facilitating the development of two established and one novel resilience capability; and a barrier to the resilience process.

The first resilience capability highlights the importance of proficiently navigating the rules of play, such as protocols, procedures and leadership styles, making decision-making processes robust. Due to the current high turnover of aviation industry personnel, a further investigation into the ease of use of protocols and procedures is essential. The second enabling resilience capability emphasises the importance of metacognition or an approach whereby partitioners maintain a reflective posture concerning their decision-making. Metacognition supports the development of resilience capabilities such as SSA, the capacity to anticipate future developments and directionality. We observed two ways to foster a metacognitive approach: being explicit and reflective about the SSA level and posing metacognitive questions. Directionality is considered a novel resilience capability which involves establishing and reflecting upon a shared goal during disruptions. It offers CMTs alignment, a filter between primary and secondary objectives, and a benchmark for measuring success while fostering timely escalation to higher-management CMTs. Third, we noticed that doubt disrupts and delays decision-making, thus hampering the use of resilience capabilities.

Finally, the training methodology proved a valuable tool for further evaluating and developing resilience capabilities within CMTs. It enables a near real-life experience, which allows for in-depth analysis. Further investigating the interplay between the participants and antagonists could lead to a qualitative resilience indicator, yielding novel insights into measuring, standardising and operationalising resilience.

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5
WARGAMING
LOOMING
BLACK
SWANS
THE
DESIGN

5. Wargaming looming Black Swans – the design

Consolidating the findings of Chapters 2 and 3, an intervention to operationalise resilience through wargaming was developed. This chapter introduces the wargaming resilience blueprint, referred to in the article as a seminar-style wargame, and its corresponding four playtesting workshops. These workshops involved 52 researchers and practitioners from the fields of crisis management, aviation, healthcare, and serious gaming. The corresponding SRQ4 was: *How to design a minimum viable seminar-style wargame that supports decision-makers in achieving systemic resilience in the face of looming Black Swans?*

The blueprint consisted of four steps, referred to in the article as modules, each with two variants, whereby participants: (1) gigamap their organisation's stakeholders and their relations, (2) design a Black Swan utilising a premade template, (3) simulate the impact of the Black Swan on their organisation through red teaming, thereby revealing the organisation's resilience and (4) design interventions to operationalise resilience through blue teaming.

The blueprint was positively received during the workshops, and participants provided valuable input for improving and streamlining the design. The findings from this chapter form a critical foundation for Chapter 6, in which the blueprint is further refined and validated.

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Abstract

Black Swans have become the norm rather than the exception. These unimaginable events with massive consequences seem to be a by-product of our society dominated by complex systems. As more Black Swans are looming, an interest in becoming more resilient is rising. However, achieving resilience against Black Swans remains an ambiguous endeavour. Looking into academic literature, "wargaming" Black Swans is often proposed as an antidote since it explores decision-making in an adversarial and unimaginable context. However, how these Black Swan-focused wargames can take shape is unclear. In response, this paper proposes a minimum viable design of a seminar-style, or dialogue-based and explorative, wargame addressing systemic resilience in the face of looming Black Swans. The paper presents the iterative design process based on four playtesting workshops with 52 researchers and practitioners in design, crisis management, aviation, healthcare, and serious gaming. The paper concludes with recommendations and directions for future research.

5.1 Introduction

From the 2020s onward, our society had to deal with multiple highly disruptive crises such as the COVID-19 pandemic; the Suez Canal obstruction; the Russian invasion of Ukraine and subsequent energy and food crises; and multiple natural disasters such as the recent earthquake in Morocco and floodings in Libya. Generally, these crises, often conceptualized as Black Swans[7], caught us by surprise and were considered unimaginable beforehand. McDaniel (2003) and Taleb (2007) argue that these Black Swans are an inherent by-product of our society riddled with complex systems[8], and more are yet to come. In response to this Black Swan world, an interest in becoming more "resilient" peaked within multiple complex systems such as aviation, healthcare, and logistics. But if those Black Swans are unimaginable surprises, are they, per definition, unavoidable? Can a complex system even become resilient against a Black Swan, thus achieving systemic resilience? And if so, how?

7 Defined by Taleb (2007) as an event that comes as a surprise, has a major effect, and is often inappropriately rationalized after the fact with the benefit of hindsight.
8 Described by Mitchell (2009) as systems showcasing complex collective behaviour that produce and use information and signals while being able to adapt.

Enter wargaming. According to Perla (2022), a wargame is an experiment in human interaction whereby people make decisions in a synthetic environment of conflict or competition, see the effects of their decisions on that environment, and react again to those changes. The method merges aspects from system analysis, role-playing and scenario building (Geurts et al., 2007). Although wargaming emphasizes the aspect of war, the adversary does not have to be a hostile military; the adversary could be a Black Swan. Multiple authors (Augier et al., 2018; Development, Concepts and Doctrine Centre, 2017; Hanley, 1991; Perla, 2022; Perla, 2008; Rubel, 2006) expand on this idea, arguing that wargames are almost an antidote against Black Swans, as its open-ended, systemic and reciprocal nature allows participants to go beyond conventional wisdom by creating foresight in weakly structured and highly complex problems.

It is important to note that wargames do not produce and neither forecast a potential future. However, they can indicate a set of choices that lead to certain outcomes, making the unimaginable surprises of Black Swans imaginable. The strengths of wargames lie in the synthetic experiences they offer. As the games can be repeated indefinitely, experience with Black Swans also increases, improving decision-making, situational awareness (Caffrey, 2019) and assumingly, resilience. Wargaming helps participants broaden their horizons as they explore a range of possibilities or memories of the future (Schwarz, 2009) as moves and countermoves are mapped out. Interestingly, this method approaches a concept that Taleb (2012) refers to as optionality, or the state of having options, which is assumed to be one of the safeguards in the face of a looming Black Swan.

According to Perla & Curry (2011), wargames can generally be divided into two distinctive styles: system and seminar-style games. System games refer to the more traditional wargames as they heavily rely on a highly detailed and structured set of rules. Players make their decisions, and the system, for example, a computer, determines the outcome. System games are often closed and are heavily reliant on a strong model and its data. Seminar-style wargames consist of a guided dialogue whereby opposing players discuss a set of moves and countermoves, which are usually assessed by a control team. Seminar-style wargames tend to be open-ended, as there is no underlying system or model allowing players to explore courses of action freely. Subsequently, seminar-style wargames seem the most useful for chasing Black Swans.

Red teaming is a concept frequently used within wargaming (Development, Concepts and Doctrine Centre, 2017). With its first formal use tracing back to the Vatican and its office of the Devil's Advocate, red teaming can be described as a process that seeks to better understand the interests, intentions and capabilities of an adversary by thinking like the adversary (Zenko, 2015) or in this case the Black Swan. Usually, red teaming implies using a red team, attacking force, and a blue team, defending force. It is seen as a valuable tool to overcome biases such as groupthink while challenging failures of imagination (Hoffman, 2017).

So, seminar-style wargaming and the underlying concept of red teaming seem ideal tools for supporting decision-makers in complex systems to achieve resilience against Black Swans. The tools can be used in a complex environment and address the unimaginable nature of Black Swans while offering insights into one's systemic resilience. But how can this be operationalized and made actionable for decision-making in complex systems? How could such a seminar-style wargame be designed? What would be the minimum viable design, assuming time is scarce for decision-makers in complex systems? That is the primary goal of this study, leading to the following research aim: designing a minimum viable seminar-style wargame that supports decision-makers in achieving systemic resilience in the face of looming Black Swans. This study focuses mainly on the wargame's design, participant's experiences, and usability. Further research will investigate and evaluate the impact.

The paper is structured as follows: section two provides an overview of the seminar-style wargame design consisting of four modules and two variants per module. Section three presents the results of four playtesting workshops, elaborating on each variant's rationale. Section four discusses the results and proposes directions for future research. Section five summarizes and concludes the paper.

5.2 Research design

This section provides an insight into the design of the seminar-style wargame. While reflecting on the research question, the seminar-style wargame must address three themes: a complex system, Black Swan(s) and resilience. These themes were reframed to four game modules: mapping the system, Black Swan thinking, red teaming resilience, and blue teaming resilience. Within each module, two variants were iteratively designed and tested through four playtesting workshops. The following subsections will present the design process and the design of each module and variant. Figures 5.1 to 5.4 visualize each variant. The rationales of the variants will be discussed in the results section as they are seen as an outcome of the iterative design process.

5.2.1 Participants & workshops

The design of the seminar-style wargame was tested through four workshops utilizing an iterative approach. The workshops were held during a design and aviation knowledge-sharing session, a crisis management course, a serious gaming conference, and an acute care research project. The workshops were designed to take between an hour and a half and four hours to gauge the ideal duration. Each workshop consisted of at least two teams of three participants. Participants were recruited through convenience sampling, but an emphasis lay on researchers and practitioners experienced with complex systems, Black Swans, or resilience. In total, 52 researchers and practitioners from aviation, design, crisis management, serious gaming and acute care participated. The content of the workshops focused on two complex systems: the airport system and the acute care system. After each workshop, participants engaged in a round table discussion whereby the facilitators captured their experiences and reflections. The participants' experiences and reflections, in combination with the field notes of the facilitators, formed the basis for the design iterations discussed in the results section. Table 5.1 provides an overview of the specifications of each workshop.

Table 5.1 Overview of the specifications of each workshop

Workshop	N (52)	Expertise	Context	Length
1	20	Aviation & Design Practitioners/ Researchers	Airports	1h30
2	16	Crisis Managers	Airports & Acute Care	2h
3	8	Serious Gaming Practitioners/Researchers	Airports	2h
4	8	Policy Advisors Acute Care	Acute Care	2x2h

5.2.2 Module 1: mapping the system

First, the participants must collectively define the complex system that should be resilient in the face of a looming Black Swan. Therefore, gigamapping was used. Conceptualised by Sevaldson (2011), gigamapping is a tool which visualises complex systems by creating a rich picture. The tool offers an open platform to grasp and embrace the "wickedness of real-life problems" while creating a shared understanding among its creators (Sevaldson, 2011, 2021).

Due to gigamaps' open-ended nature, the process can be an extensive undertaking ranging from hours to days or weeks. Although the authors acknowledge and underline the value of creating in-depth gigamaps, it could be considered too time-consuming in practice. Subsequently, the ambition was to create a minimum viable gigamap, mappable in a maximum of 20 minutes, predominantly scoped on the stakeholders and their relations (e.g. structural, thematic, social relation). Two variants were tested to speed up the process: one with predefined stakeholders and one without (see Figure 5.1). Note that participants were still free to add additional stakeholders in the predefined variant. The gigamaps were created on large flip-over papers utilising pens, papers, and sticky notes.

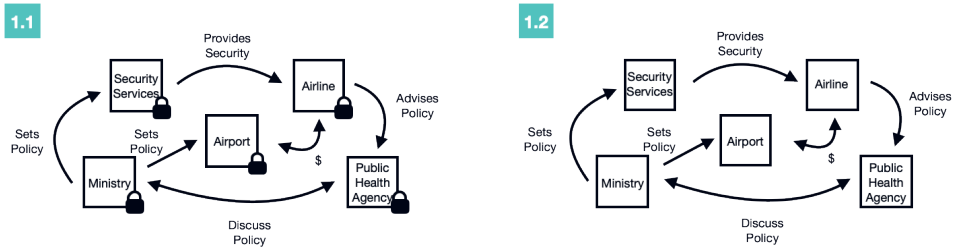

Figure 5.1 Graphic representation of the predefined (1.1), illustrated by the lock symbol, and undefined (1.2) gigamap variant. The case illustrated is fictional and inspired by the COVID-19 pandemic and aviation.

5.2.3 Module 2: Black Swan thinking

The second module tackles the Black Swan theme of the research question by exploring what the system should be resilient against. During this module, participants are asked to design their own Black Swan. The design process commenced with the introduction of essential Black Swan criteria referring to Taleb's (2007) definition of a rare event with an extreme impact which is only retrospectively predictable. Additionally, the seminar-style wargame approached Black Swans as a multi-layered phenomenon with ripple effects instead of a singular event. To illustrate, COVID-19 consisted initially of a public health crisis, but its ripple effects had a far-reaching impact. Just think about the sudden flight restrictions, curfews, toilet paper shortages, e-commerce spike, Zoom fatigue, etc. The combination of the initial public health crisis and its consequences is considered the Black Swan. To capture the ripple effects, participants were encouraged to design their Black Swan's first, second and third-order effects using one of two variants: linear and branching Black Swan thinking (see Figure 5.2). In the linear variant, participants developed only one set of n-order effects. In contrast, the branching variant used an iteration of the Futures Wheel (Glenn, 2021), allowing for the exploration of multiple n-order effects. This module took around 20 minutes and was done by filling in a Black Swan thinking template.

After the design of the Black Swan, participants were asked to hand over their design to another team. This step aimed to highlight the unpredictable nature of Black Swans, as this step should surprise the participants. The design of the Black Swan was hidden from its new owners and revealed during the next module.

Figure 5.2 Graphic representation of the linear (2.1) and branching (2.2) Black Swan thinking variant. The numbers represent the first, second and third-order effects. The case illustrated is fictional and inspired by the COVID-19 pandemic and aviation.

5.2.4 Module 3: red teaming resilience

The third module diagnosed the resilience of the gigamapped complex system against the designed Black Swan using a red teaming approach. The module started with a theoretical introduction to resilience to create a shared understanding for the participants. To establish this shared understanding, the categorisation of resilience (Nieuwborg et al., 2023) was presented to the participants, which dissects resilience into four reoccurring aspects: fragility, robustness, adaptation, and transformation. Then, participants were asked to diagnose the resilience of their complex system against the Black Swan by pasting colour-coded stickers, representing each aspect of resilience, on their gigamap. This process happened in three steps, gradually revealing each order effect. The colour-coded stickers were then numbered corresponding to the first, second and third-order effects, visualising how the Black Swan moved through the system. For example, if stakeholder X (e.g. an airport) was fragile against Black Swan Y's first-order effect (e.g. a pandemic), a red sticker, representing fragility, was pasted upon stakeholder X and numbered one. This module took around 20 minutes.

Two variants of red teaming of resilience were tested: all-aspects and limited aspects (see Figure 5.3). In the first variant, participants were encouraged to utilise all aspects of resilience while red teaming the impact of the Black Swan themselves. The second variant restricted the use of the aspects to fragility and robustness only. Additionally, the team that designed the Black Swan sent a representative to the other team to partake in the red teaming.

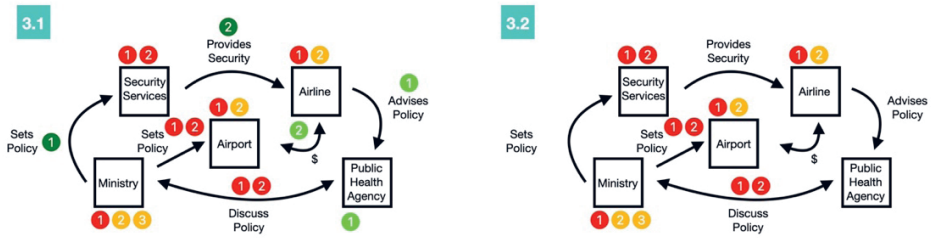

Figure 5.3 Graphic representation of the all-aspects (3.1) and limited aspects (3.2) red teaming resilience variant. The colours represent the aspects of resilience with fragile (red), robustness (orange), adaptation (light green), and transformation (dark green). The numbers represent the first, second and third-order effects. The all-aspects variant includes all F, R, A and T, while the limited aspects focus on F and R. The case illustrated is fictional and inspired by the COVID-19 pandemic and aviation.

5.2.5 Module 4: blue teaming resilience

The fourth module reflected upon prior modules and investigated design interventions. First, participants were asked to define the critical points, for example, fragile stakeholders or relations, in their gigamap and reflect upon their current and desired state of resilience. Then, participants were asked to design interventions for this desired state. For example, if stakeholder X (e.g. an airport) reacts highly fragile on the Black Swan (e.g. a pandemic), how can they become robust or even adaptive?

The module consisted of two variants: quick design and leverage points (see Figure 5.4). The quick design variant encouraged participants to develop one intervention for their desired state in a maximum of five minutes. The leverage point variant went more in-depth and was presented as a separate workshop of two hours. First off, it built upon the limited aspects variant of module three. As fragility and robustness were uniquely used in the red teaming module, adaptation and transformation were reserved for the blue teaming. Participants thus discussed if their desired state needed adaptation or transformation. Then, participants designed interventions for their desired state supported by an iterated version of Meadows's (1999) twelve leverage points or places within a complex system where a small shift can lead to major changes. The iterated version categorises the leverage points into a hierarchy of system characteristics: parameters, feedbacks, design and intent (Abson et al., 2017; Murphy, 2022). The characteristics of design and intent seem highly correlated with the design goal of adaptation or transformation, thus serving as an additional structure and source of inspiration.

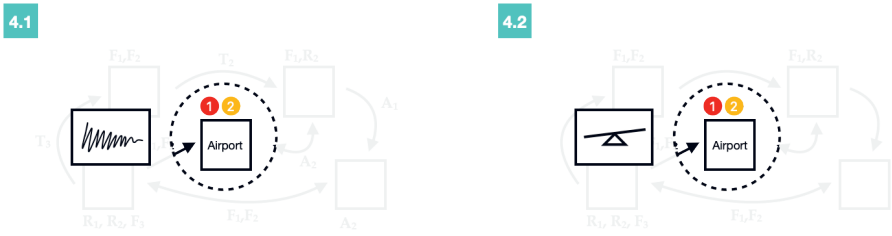

Figure 5.4 Graphic representation of the quick design (4.1) and leverage points (4.2) blue teaming variant. The dotted circle refers to focus on the critical points within the gigamap. The case illustrated is fictional and inspired by the COVID-19 pandemic and aviation

5.3 Results

This section presents the results of the iterative design process, reviews the outcomes of each module, and elaborates on the rationales of the variants. The section rounds off with general reflections of the participants. Figure 5.5 illustrates several resulting gigamaps.

Figure 5.5 Overview of three resulting gigamaps. 5.1 shows a predefined gigamap in detail with a highlighted stakeholder, relations, and the colour-coded stickers of the red teaming resilience module.

Module one, mapping the system, was received positively by the participants as co-creating a gigamap helped to foster a shared understanding of their complex system. The variant with predefined stakeholders worked well as participants could

quickly create a gigamap and have an in-depth discussion, allowing for a well-paced experience. Although participants were free to add new stakeholders in the predefined variant, the predefinition could create tunnel vision as they were already primed. Subsequently, a variant was introduced without predefinition. This variant allowed for more breadth and a meandering discussion. However, timeboxing and introducing a stakeholder's limit was more important here as the gigamaps became more expansive. A recurring theme during the mapping process was the difficulty of defining relations between stakeholders. Participants sometimes struggled to find the proper description because they are highly context-specific, dynamic, and multi-faceted.

Module two, Black Swan thinking, put the participants in the shoes of the crisis. This change of perspective was considered atypical but engaging and exciting. The workshops started by utilising the linear variant. Although this variant worked well, only one layer of the Black Swan was explored, which reduced the richness of unforeseeable consequences. In reaction, the branching variant was introduced based on the Futures Wheel (Glenn, 2009). This variant allowed the participants to capture the complexities of Black Swans more accurately. This module's main difficulty came predominantly from the linear variant regarding delineating the different order effects as participants frequently discussed whether a particular event was a first, second or third-order effect. The anticipated surprise effect of swapping the created Black Swans between teams worked well. A sigh emerged whenever the instructions were given, indicating the participants were caught off guard. Participants reaffirmed this sentiment during the roundtable discussions after each workshop and reflected enthusiastically upon it.

Module three, red teaming resilience, invited participants to map out their systemic resilience in the face of the swapped Black Swan. Participants were invited to map out their system's fragility, robustness, adaptation and transformation in the all-aspects variant. However, this proved difficult, particularly with participants unfamiliar with the resilience field. Confusion occurred regarding the difference between adaptation and transformation aspects. Additionally, the participants were quite liberal in labelling their system as adaptive or transformative using the argumentation "it will be fine" or "we will manage", thus not taking an actual red team approach. In reaction, the limited aspects variant was introduced whereby participants only had the work with the fragility and robustness aspects. This variant reduced the complexity and forced the participants to make distinct decisions. To reinforce the red team nature, the swapped-out Black Swans were supported by a team representative who created

them. The function of these representatives was to be the red teamer and challenge their new teams in their resilience analysis. As each team took a moment to consider which of their members could best act as a representative, there was a sense of responsibility and dedication to take a critical stance. Additionally, the representative presented their Black Swan and clarified any confusion regarding the order effects.

Module four, blue teaming resilience, often felt rushed compared to the other modules. The quick design variant was done in about five minutes, too short for creating in-depth interventions. Nevertheless, this approach seemed necessary to reduce the cognitive load of the participants as they had already made a gigamap, created a Black Swan, and red teamed their resilience in an hour and a half or two hours. Subsequently, the leverage point variant was tested, whereby the blue teaming resilience became its dedicated workshop of two hours. This variant led to promising interventions with paradigm shifts aimed at adaptation and transformation. The participants focused their design interventions mainly on increasing the self-organisation of system parts, proposing new information flows, rules, overarching system goals and initiatives to change the paradigms of the system. However, as both adaptation and transformation imply a fundamental systemic change, it was difficult to establish the effects of the interventions on the diagnosed fragile system parts.

Participants reacted positively to the seminar-style wargame in the round table discussion after each workshop. They were enthusiastic about the methods used as it was regarded as novel and innovative. The different modules sparked diverse discussions while helping participants change and exchange perspectives on systemic resilience. Additionally, the wargame supported the creation of a shared understanding and situational awareness of their complex system and looming Black Swans. During the workshops, two distinct contexts were explored, airports and healthcare, in combination with participants originating from the design, acute care, aviation, crisis management and serious gaming fields. Regardless of context or area of expertise, the seminar-style wargame performed well and proved to be easily adjustable.

5.4 Discussion

Reflecting on the workshops, the designed seminar-style wargame seems to support systemic resilience in the face of a looming Black Swan. However, more design iterations and validations are required. This section recommends several areas of improvement for the modules, the positioning concerning other resilience-related workshops, and future design validation.

The gigamapping module can be made more extensive. However, this is dependent on the context and availability of the participants. If time is of the essence but more systemic depth is required, complete predefined gigamaps could be made, capturing multiple layers with stakeholders, processes, communication flows, etc. Usually, such gigamaps already exist within complex systems through, for example, visualizations of the concept of operations and organograms. However, these might require graphic iterations before use in a seminar-style wargame. An anticipated pitfall with such premade gigamaps is that participants are encouraged to think inside the box, thus limiting their view and potentially creating novel fragilities. Spending more effort in exploratory gigamapping is encouraged if time is less stringent, thus capturing a richer picture. The additional time could range from an additional 15 minutes to a day-long standalone workshop. The following gigamapping iterations will also aim to go beyond the mapping of only stakeholders and include other layers, such as processes and information flows.

The Black Swan thinking module could use more guidance to support participants in delineating different order effects. The participants could design their own Black Swan freely in the current setup. By offering this blank canvas, the participants could be creative and think out of the box, which is essential for uncovering the unimaginable. However, some order effects were too trivial or extremely difficult, thus impacting the red and blue teaming resilience modules. In response, some quality control might be required, or additional guidelines, to streamline the experience. However, this should not hamper the creativity of the participants. Reflecting on the variants, the branching future seemed the best practice, allowing for a richer exploration in a comparable timeframe to the linear variant.

The red teaming resilience module proved the most difficult as novice participants had difficulties with the aspects of resilience while red teaming insufficiently. Regarding the aspects, focussing on fragility and robustness in module three while

emphasizing adaptation and transformation in module four reduced complexity. However, more support seems necessary. Exploring the use of resilience heuristics or causalities, for example, if stakeholder X is fragile, its relations Y and Z are probably also fragile, is a focus for future workshops. Using a representative of another to red team worked remarkably well and is expected to become a best practice for future iterations.

As prior modules already introduced multiple novel concepts (i.e., gigamapping, Black Swans and resilience), it became apparent that the blue teaming resilience module was too much, considering the ambition of creating a minimum viable design. The rushed, quick design variant suggested design interventions, but they remained shallow. Making the blue teaming a separate workshop or introducing a break helped as it gave the participants more mental breathing room. To conclude, further iterations are required to mature this module.

Although the use of seminar-style wargames in the context of resilience is novel to the best of our knowledge, conducting resilience-related workshops is not. Similar concepts emerge predominantly in the human factors field with practices such as the Functional Resonance Analysis Method (Hollnagel, 2012), AcciMaps (Rasmussen & Svedung, 2000), and Event Analysis of Systemic Teamwork (Stanton & Harvey, 2017) but also in scenario planning (Derbyshire & Wright, 2014), future thinking (Pinto et al., 2021) and design (Taysom & Crilly, 2017). Further investigating current practices seems essential for positioning this seminar-style wargame design while inspiring future iterations.

Validating that a seminar-style wargame makes a system more resilient in the face of the looming Black Swan seems extremely difficult. Although anecdotal evidence exists (Caffrey, 2019; Perla & McGrady, 2011), a standardized validation approach is lacking. This lack of validation can be attributed to the fact that systemic resilience seems only apparent after an actual Black Swan occurs. The value of the seminar-style wargame might be more in creating a shared understanding and situational awareness between participants regarding their complex systems and resilience. Additionally, participants could better understand Black Swans, emphasizing the lesser-known order effects. Validating the influence of the seminar-style wargame on the participant's shared understanding of their system, resilience, Black Swans, and interventions seems feasible through, for example, pre- and post-questionnaires.

In the last workshop, there was experimentation with such questionnaires, and although they yielded exciting results, they were deemed too preliminary for this study. Further maturing such a questionnaire and conducting more extensive validation is an objective for future iterations.

5.5 Conclusion

Black Swans have become the norm rather than the exception. As these events seem to be an inherent by-product of our society riddled with complex systems, an interest emerged in becoming resilient. Looking into academic literature, wargaming is often proposed as an antidote against Black Swans. However, how these wargames could take shape and be operationalised is unclear. Subsequently, this paper proposed a design of a seminar-style, or dialogue-based and explorative, wargame that supports systemic resilience in the face of a looming Black Swan. An essential boundary condition was to explore a minimum viable design that allows for quick and easy deployment. The proposed seminar-style wargame was iteratively designed and consisted of four modules with two variants per module. The modules and their variants were play-tested during four workshops with 52 researchers and practitioners from design, aviation, crisis management, serious gaming, and acute care. The participants reacted positively to the design of the seminar-style wargame and were enthusiastic about the methods used. Future research will focus on maturing the modules, improving the positioning, and validating the added value of the proposed seminar-style wargame.

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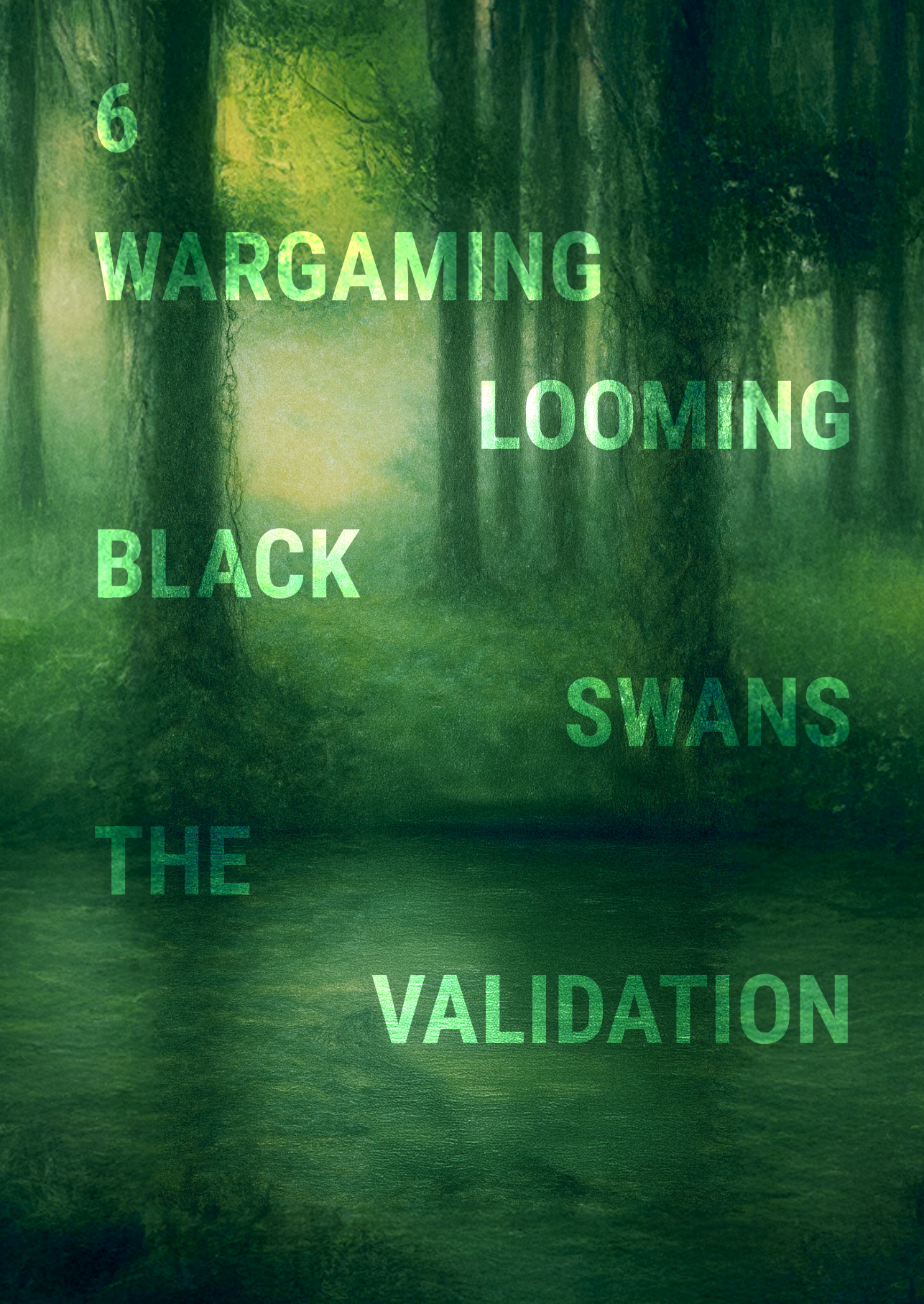
6
WARGAMING
LOOMING
BLACK
SWANS
THE
VALIDATION

6. Wargaming looming Black Swans – the validation

Finally, building upon Chapter 5, the wargaming resilience blueprint was iterated upon and validated by investigating what 57 decision-makers from the fields of aviation, crisis management, and defence learned through its application in support of operationalising resilience. The iteration streamlined the design of the prior blueprint and consisted of the following steps: (1) review premade gigamaps of the organisation, (2) design a Black Swan utilising a premade template, (3) simulate the impact of the Black Swan on their organisation through red teaming, and (4) improve the theoretical understanding and operationalise resilience utilising a matrix. The corresponding SRQ5 was: *What do decision-makers in complex systems learn from wargaming Black Swans to operationalise resilience?*

A thematic analysis revealed that the blueprint supported decision-makers to (1) develop a shared understanding of their organisation within its overarching complex system; (2) imagine the impact of type-B (unknown knowns) and type-C (ignored knowns) Black Swans on their organisation; and (3) operationalise resilience-as-an-outcome and develop a deeper understanding of it. Furthermore, conducting wargames may enhance resilience capabilities, namely shared situational awareness, the management of keystone fragilities, anticipating future developments, and sensemaking.

Chapter 6 provides crucial insights into addressing the MRQ and serves as the capstone of this dissertation. It builds upon the experiences and lessons learned from Chapter 2, utilises the categorisation of resilience from Chapter 3, draws on the resilience-as-a-process lens from Chapter 4, and iterates upon the wargaming blueprint from Chapter 5.

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Abstract

In an increasingly volatile world, organisations must be prepared to navigate high-impact crises such as pandemics, geopolitical tensions, and disasters. As a result, resilience has become a strategic priority. Operationalising resilience, however, remains challenging due to three key barriers. First, the complex, interconnected nature of organisations makes it difficult to understand interdependencies and implement effective resilience interventions. Second, many crises are considered unimaginable, so-called Black Swans, hampering proactive resilience-building. Third, resilience is highly contextual and conceptually ambiguous, leading to uncertainty about its practical application. To address these barriers, this study investigates what decision-makers within complex systems can learn from wargaming (i.e. the practice of simulating decision-making in environments of conflict or competition) Black Swans to support the operationalisation of resilience. Based on four wargames with 57 decision-makers from aviation, defence and other sectors, we conducted a thematic analysis to interpret their outcomes. Our findings suggest that wargaming helps decision-makers (1) develop a shared understanding of their organisation within its complex system; (2) imagine the impact of type-B (unknown knowns) and type-C (ignored knowns) Black Swans on their organisation; and (3) operationalise resilience-as-an-outcome while deepening their theoretical understanding of it. Finally, conducting wargames may enhance resilience capabilities, namely shared situational awareness, the management of keystone fragilities, anticipating future developments, and sensemaking. Our findings suggest that wargaming can be a valuable tool for organisations to operationalise resilience.

6.1 Introduction

From the 2020s onwards, our society has had to deal with many high-impact crises. Events such as the COVID-19 pandemic, the Suez Canal obstruction, the Russo-Ukrainian war, and multiple disasters have exposed fragilities within our respective healthcare systems, supply chains, national security, and climate policy. In response, the concept of organisational resilience, widely regarded as a desirable organisational characteristic for dealing with adversity (Linnenluecke, 2017) and hereafter referred to simply as resilience, has gained traction across various sectors. For instance, in healthcare, resilience initiatives are focusing on strengthening health system to better deal with public health challenges (World Health Organization, 2024); in defence, on

deterring and responding to geopolitical threats (Ministerie van Defensie, 2024); and in the field of critical infrastructure, on protecting essential services (e.g. energy, transportation and financial sector) against natural and man-made risks (European Comission, 2024). However, academic knowledge on operationalising resilience, by which we mean translating resilience aspirations into actionable interventions (e.g. training, products or strategies) by decision-makers (e.g. strategic managers, crisis managers or policy-makers), remains scarce (Hermelin et al., 2020; Ketelaars et al., 2024; Linnenluecke, 2017). Based on prior research (Nieuwborg et al., 2023; Nieuwborg et al., 2024a), the difficulty in operationalising resilience can be attributed to three key barriers: the complexity of modern organisations, the unimaginability of the so-called Black Swans, and the conceptual ambiguity of resilience.

The first barrier lies in the labyrinthine behaviour of modern organisations, which, more than simply being complex systems themselves, are embedded within overarching ones. Following Snowden and Boone (2007), complex systems are characterised as dynamic, emergent, unpredictable and having many non-linear interacting elements and sub-systems. Consequently, for decision-makers to fully grasp these complex systems and determine where resilience should be operationalised is a significant challenge requiring continuous engagement with them (Snowden et al., 2021), and a considerable investment in time and effort (Sevaldson, 2021). Furthermore, as operationalising resilience for individual organisations (e.g. an airport operator) could lead to different interventions than those for an entire industry (e.g. aviation) or even for society as a whole, defining a complex system's borders, while crucial, can be both highly ambiguous and dependent on the perspective taken.

The second barrier emphasises the difficulty of operationalising resilience in the face of crises that cannot be anticipated. Although many different conceptualisations exist of such crises, including Black Elephants (Friedman, 2014), Grey Rhinos (Wucker, 2016), Dragon Kings (Sornette & Ouillon, 2012), and fundamental surprises (Lanir, 1986), in this study, we utilise Black Swans as our anchoring disaster typology. As defined by Taleb (2007), Black Swans are surprising events with a major effect which are only retrospectively predictable through hindsight. Aven (2015) further refines the Black Swan concept into three types: type-A Black Swans that are true unknown unknowns; type-B are unknown knowns, recognised by decision-makers but overlooked in risk assessments; and type-C are ignored knowns, acknowledged risks that are dismissed as unlikely. While type-A Black Swans are impossible to

anticipate, the ex-ante operationalisation of resilience against type-B and C still seems feasible. As history shows, many type-B or C Black Swans, such as 9/11(National Commission on Terrorist Attacks upon the United States, 2004), Hurricane Katerina (Perla & McGrady, 2011), Fukushima (Piore, 2011), and COVID-19 (Nieuwborg et al., 2024a), were not entirely unforeseeable. However, they failed to be imagined by decision-makers in ways that translated into actionable interventions. Thus, making type-B or C Black Swans imaginable is crucial for supporting the operationalisation of resilience.

The third barrier concerns the conceptual ambiguity of resilience. Despite its widespread use, the term lacks a consistent definition, which hampers efforts to operationalise it (Hillmann & Guenther, 2021). On the one hand, closely tied to the first barrier, ambiguity arises due to resilience being highly context-dependent and related to an organisation's goal (Linnenluecke, 2017; Martin-Breen & Anderies, 2011). For example, an airport operator might require a different operationalisation of resilience than a hospital. On the other hand, the nature of resilience is frequently debated, particularly whether resilience is best conceived as an outcome or a process (Canizares et al., 2021; Hillmann & Guenther, 2021; Ketelaars et al., 2024). Resilience-as-an-outcome refers to resilience as a state after facing adversity, such as a Black Swan. These outcomes can be further divided into four categories: fragile (losing value in the face of adversity); robust (stability in the face of adversity); adaptive (evolutionary change in the face of adversity); and transformative (revolutionary change in the face of adversity) (Nieuwborg et al., 2023). Approaching resilience-as-a-process emphasises an organisation and its decision-makers' capabilities to manage adversity, ultimately leading to a resilient outcome (Canizares et al., 2021). In this study, we predominantly use the "resilience-as-an-outcome" lens.

Following the COVID-19 pandemic, wargaming has increasingly been acknowledged as a promising tool to enhance strategic decision-making in times of uncertainty (de Wit, 2022; Gates, 2022; Linden, 2021). Originating from the military, a wargame is a model that facilitates decision-making in a synthetic environment of competition or conflict (Perla, 2022). During a wargame, decision-makers are immersed in a narrative in which they make decisions, immediately see the effects, and react again to these effects, resulting in synthetic experiences. Building on de Wit (2022), Gates (2022) and Linden (2021), and as suggested by Lantto et al. (2019) and Wojtowicz (2020), we propose that wargaming could help address barriers to operationalising resilience as it provides a structured yet flexible way of simulating the interaction

between complex systems (Brightman, 2021; Development, Concepts and Doctrine Centre, 2017) and Black Swans (Perla, 2022; Perla & McGrady, 2011). The outcomes of a wargame may offer insights into the organisation's resilience-as-an-outcome, as we effectively simulate the state of an organisation after facing adversity. Subsequently, organisations could translate these insights into interventions, supporting the operationalisation of resilience.

Although academic knowledge is available on the design of a wargame within the context of complex systems, Black Swans, and resilience-as-an-outcome (Nieuwborg et al., 2024b), there remains a gap in empirical knowledge about their actual impact on decision-makers. Specifically, it is unclear whether, and how, wargames can contribute to the operationalisation of resilience. To address this knowledge gap, we investigate the following research question: What do decision-makers within complex systems learn from wargaming Black Swans to operationalise resilience?

The remainder of this article is structured as follows. Section 2 outlines the method used, including the wargame design. Section 3 presents the results. Section 4 offers a discussion, addressing limitations and potential avenues for future research. Finally, Section 5 concludes the article.

6.2 Method

6.2.1 Participants & recruitment

We recruited decision-makers from organisations based in the Netherlands that are vulnerable to looming Black Swans and interested in enhancing their organisational resilience. Using convenience sampling, three organisations were included: Amsterdam Airport Schiphol; the Dutch Ministry of Defence; and a crisis management course affiliated with Delft University of Technology. To conduct an effective wargame, a minimum of six participants were required per organisation. Participants within Amsterdam Airport Schiphol and the Ministry of Defence were recruited in collaboration with an internal sponsor, being respectively a senior manager and a senior policy-maker.

Inclusion criteria required participants to hold decision-making authority related to resilience and Black Swans, such as strategic management, crisis management, risk management, and business continuity management. For the crisis management course, participants were recruited based on their enrolment in the overarching program, forming a diverse panel of predominantly Dutch crisis managers from the logistics, aviation, healthcare, and security sectors.

6.2.2 Wargaming resilience blueprint

Building on our prior research (Nieuwborg et al., 2024b), we utilised a wargaming resilience blueprint. This blueprint is a structure to wargame the interaction between complex systems and Black Swans, aimed to provide insights into the operationalisation of resilience-as-an-outcome. The blueprint follows a seminar game approach whereby decision-makers simulate making decisions and experience their consequences through guided dialogue (Perla & McGrady, 2011). The blueprint consists of five steps: (0) preparing, (1) understanding complex systems, (2) designing Black Swans, (3) red teaming, and (4) operationalising resilience. Each wargame was planned for two hours, hosted by at least two facilitators and conducted on-site with the participating organisation.

Step 0: Preparing

Before running the wargames, a preparatory process was conducted by authors AN and JG together with an internal sponsor to tailor the wargaming resilience blueprint to the setting of the participating organisation. The process consisted of (1) selecting the relevant system maps, (2) scoping the Black Swans, and (3) dividing the participants into a minimum of two teams with a maximum of five participants per team.

Inspired by gigamapping (Sevaldson, 2011), the system maps were used to visualise and explore the organisations' complex systems. Their selection, as well as the scope of the Black Swans, was determined in consultation with the internal sponsor. For Amsterdam Airport Schiphol, the system maps included a geographical map of the airport, a process map, and a stakeholder map. No restrictions were given regarding the scope of the Black Swan. For the Ministry of Defence, the system maps included a geographical map, a stakeholder map, and several organisational maps. Regarding

the Black Swan design, participants were instructed to focus on a military conflict without nuclear exchange, a restriction requested by the Ministry of Defence. Finally, due to the diverse participant group of the crisis management course, the sponsor and authors opted to reuse the Amsterdam Airport Schiphol system maps without any Black Swan restrictions. This choice ensured familiarity among participants, as Schiphol is a widely recognised organisation within the Netherlands.

Step 1: Understanding complex systems

The wargame commenced with creating a shared understanding of the participating organisation requiring resilience and its overarching complex system. Therefore, each team collectively reviewed the system maps and discussed and agreed on their organisation's primary goal.

Step 2: Designing Black Swans

Second, each team designed their own Black Swan. Inspired by the pre-mortem analysis (Klein, 2008), this process started with participants using a template where they first defined the climax of the Black Swan, or the major effect, consisting of at least three, possibly interrelated, events. The judgement of what constitutes a major effect was up to the participants. After defining the climax, teams took a step back to identify at least three origins that could have led to it, followed by a step forward to determine at least three effects that might emerge from it. Although both origin and effect should be related to the climax, their relation is not required to be linear. Participants were free to define each origin or effect's timing (e.g. a day, week or month before or after the climax). Table 1 provides a fictionalised example of a designed Black Swan inspired by the COVID-19 pandemic and its impact on aviation.

Table 1. Fictionalised example of a designed Black Swan inspired by the COVID-19 pandemic and its impact on aviation.

Origin	Climax	Effects
Airlines express their concern regarding a novel outbreak in China.	The novel disease reaches Europe. In reaction, lockdowns are imposed. Subsequently, working from home becomes the norm.	As the impact of disease subsides, the demand for air travel rises.
There is a surge in domestic travel within China due to a national holiday.	The aviation sector has to deal with major financial losses.	The aviation sector has difficulty hiring new employees and must operate with an inexperienced workforce.
The US closes its borders for all international air travel.	The aviation sector reorganises, leading to a series of layoffs and a brain drain.	The public opinion turns against the aviation sector as it has received a significant amount of governmental aid.

Step 3: Red teaming

Third, the participants simulated the interaction between their organisation and the designed Black Swan. This interaction was simulated by utilising red teaming, a tool frequently used in wargaming (Development, Concepts and Doctrine Centre, 2017), whereby an adversary's perspective is adopted (Zenko, 2015) and Black Swans could be revealed (Masys, 2012). The simulation starts with each team being split into two subteams: a blue, or defending, team representing the organisation and a red, or attacking, team representing the Black Swan. The red team then merges with another blue team, bringing their previously designed Black Swan scenario. Figure 1 illustrates this process.

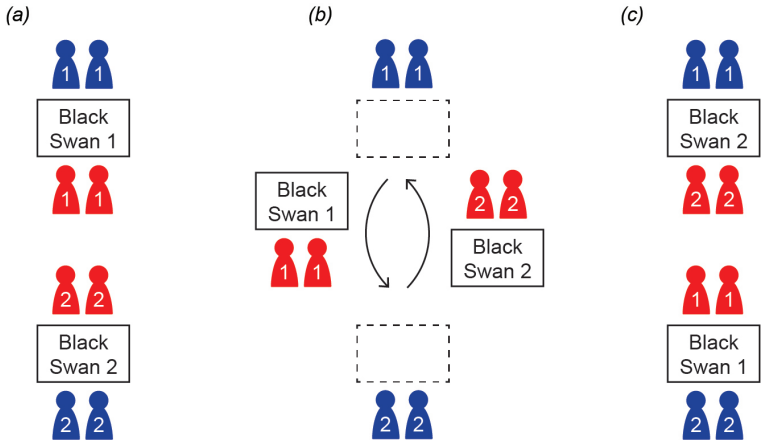

Figure 6.1 Team 1 and team 2 are divided into a red and blue team. Team 1's red team moves with team 1's designed Black Swan to team 2's blue team and vice versa

Subsequently, the red team attacks the blue team's organisation with a Black Swan, unknown to them, creating a surprise. The simulation unfolds over three rounds, each focusing on a different phase of the Black Swan: origin, climax and effect. During each round, the red team identifies organisational fragilities related to the origin, climax, and effect, marking them with red sticky notes on the system maps (i.e. geographic, stakeholders, and process). The blue team responds by devising interventions, recording them on blue sticky notes and placing them on the same maps. Figure 6.2 illustrates this process.

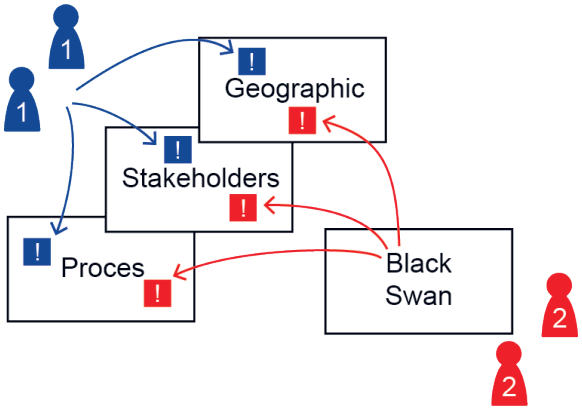

Figure 6.2 Red team 2 introduces the three origins and attacks blue team 1 by pasting red sticky notes on their system maps. The blue team defends by pasting blue sticky notes on their system maps. Repeat for the climax and three effects

After the simulation, the facilitators gave a theoretical introduction to resilience-as-an-outcome to create a shared understanding among the participants. The introduction utilises the categorisation of resilience (fragile, robust, adaptive and transformative) as its frame (Nieuwborg et al., 2023). Then, the participants focused on operationalising resilience by mapping out their sticky notes of step three on a matrix (Figure 3). The x-axis encompasses the four aspects of resilience, while the y-axis represents the required effort, from low to medium to high. The effort represents aspects such as time, financial costs, and resources required. Finally, all participants gathered around the matrix and engaged in a moderated roundtable discussion by the facilitators, whereby each red and blue team presented their sticky notes, argued their position on the matrix, and reflected.

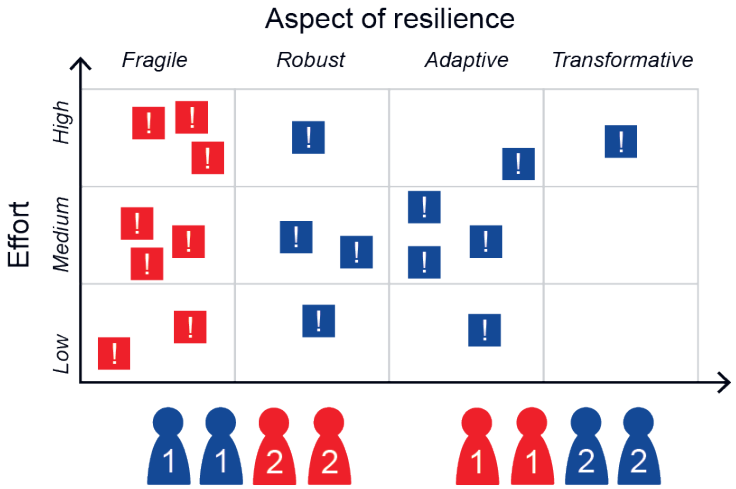

Figure 6.3 All participants place their sticky notes on the matrix. The x-axis represents the four aspects of resilience. The y-axis represents the required effort.

6.2.3 Data collection

The study collected data through (1) field notes, (2) audio recordings of the debrief, and (3) post-questionnaires. First, field notes were taken during the wargames by AN and JG or the sponsor, focusing on frequent discussions amongst participants, the overall atmosphere, and the interaction with the wargame materials such as the system maps, Black Swan design template, and the matrix.

Second, after each wargame, AN and JG or the sponsor, facilitated a debrief whereby all the participants reflected on their experience. Audio recordings captured the debrief after the wargames with Amsterdam Airport Schiphol and the crisis management course, lasting 18 and 10 minutes, respectively. For confidentiality reasons, audio recordings were not permitted during the wargames with the Ministry of Defence; however, field notes and questionnaires were allowed.

Third, the post-questionnaire explored the participants' experiences with the wargame and their learnings on resilience, complex systems, and Black Swans. This was an open-ended questionnaire with sample questions including: How was your experience?; What are your takeaways?; Did your perspective on resilience change? If so, how?; and Do you foresee new looming Black Swans? If so, which? Minor modifications were made to tailor the questionnaire to the aviation and defence contexts. While most questions were in Dutch, an English version was provided for non-Dutch speakers in the crisis management course. For the complete questionnaire, see Appendix 1.

6.2.4 Data analysis

We conducted an inductive and deductive reflexive thematic analysis to identify and develop patterns across the collected data regarding complex systems, Black Swans and resilience (Braun & Clarke, 2021). The data analysis followed Braun et al.'s (2022) six-phase approach, consisting of (1) familiarising with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) reporting.

In the first phase, authors AN and JG familiarised themselves with the data by reviewing field notes, listening to audio recordings, and reflecting on the responses from the post-questionnaires. Audio transcriptions were then generated using Amberscript's machine-made transcription service and reviewed and refined by AN. Finally, all field notes, transcribed audio recordings, and questionnaire data were imported into ATLAS.ti, a qualitative data analysis software. In the second phase, a two-step inductive coding process was conducted during a workshop. In the first step, AN and JG independently generated codes using sticky notes and flip-over sheets. In the second step, these codes were compared and refined through discussion. The resulting 27 codes were put into ATLAS.ti.

In the third phase, AN and JG generated the initial themes. In the fourth phase, these themes were reviewed and refined through a deductive approach by AN and JG, resulting in main and subthemes aligned with the wargaming resilience blueprint's core concepts: complex systems, Black Swans, and resilience. In the fifth phase, AN and JG defined and named the themes, which the other authors then reviewed. Finally, the themes were reframed into narratives and drafted in a report, which all authors reviewed. Furthermore, AN extracted exemplary quotes from the audio transcripts and post-questionnaires, with most quotes being translated from Dutch to English. JG reviewed the translations.

6.2.5 Ethics

This study was approved by the Human Research Ethics Committee of the Delft University of Technology (reference number 4239). All participants signed an informed consent form for their inclusion. Their participation was voluntary, and they could withdraw at any time during the study. Any expressed opinions during the round table discussion were anonymised to protect privacy.

6.3 Results

Four wargames were conducted: one in collaboration with Amsterdam Airport Schiphol, two with the Ministry of Defence, and one with a crisis management course affiliated with Delft University of Technology. In total, 57 participants and 13 teams participated. Table 2 provides an overview of all participants, their spread over the wargames and the data collected. While we cannot disclose specific details of the designed Black Swans, they primarily centred on (hybrid) warfare and climate-related disasters. Due to technical issues, no questionnaire data could be collected from the third wargame. AN facilitated all the wargames, JG co-facilitated wargames one and four, and the internal sponsor co-facilitated wargames two and three.

Table 6.1 Wargame participants and data collection

Wargame	Participants (teams)	Organisation	Data Collected (response rate questionnaires)
1	16 (3)	Amsterdam Airport Schiphol	Field notes, audio & post-questionnaire (9/16)
2	12 (3)	Dutch Ministry of Defence	Field notes & post-questionnaire (12/12)
3	12 (3)	Dutch Ministry of Defence	Field notes
4	20 (4)	Crisis management course with participants from sectors such as logistics, health, aviation and security	Field notes, audio & post-questionnaire (4/20)

Through reflexive thematic analysis, we generated 27 codes. These were then clustered into three main themes and seven subthemes. Each main theme clusters learnings related to the core concepts of complex systems; Black Swans; and resilience. Table 3 provides an overview of each theme, subtheme with corresponding description and example codes.

Table 6.2 Overview of the themes, subthemes and a description

Theme		Subtheme		Description	Example codes
6.3.1	Navigating complex systems	6.3.1.1	Creating shared understanding	Reviewing system maps, defining organisational goals, and red teaming fostered a shared understanding of the organisation and its role within the overarching complex system.	Scope is crucial; Making sense of complex systems; Red teaming and creativity
		6.3.1.2	Uncovering organisational zones of control	The organisation's zone of control became more clearly defined.	Black Swan & organisational goal; Scale of the crisis; Autonomy
6.3.2	Black Swans, unsurprising surprises	6.3.2.1	Are these really Black Swans?	Discussions arose on the surprise aspect of Black Swans, some only considered type-A Black Swans while others included type-B and -C's.	Awareness of Black Swans; Gasp of surprise; "we imagined it";
		6.3.2.2	Different Black Swans, same fragilities	Repeated exposure to different Black Swans revealed recurring fragilities.	Different stressor, same effect
6.3.3	Operationalising resilience	6.3.3.1	Sensemaking through categorising resilience	The categorisation of resilience provided both a theoretical foundation and a sensemaking tool in the operationalisation of resilience.	Perspective on resilience changed; Fragility awareness; Debrief created options

Theme	Subtheme		Description	Example codes
	6.3.3.2	Pinpointing fragilities	Distinguishing between fragilities and the undesirable situation that caused them, proved to be challenging	Defining fragility versus undesirable situation
	6.3.3.3	Implicit connotations of resilience aspects	Implicit connotations were often attached to the aspects of resilience (e.g. 'fragility is always undesirable').	Mind the connotation

6.3.1 Navigating complex systems

Throughout the wargame, we observed participants gaining proficiency in navigating their organisation and its overarching complex system. First, reviewing the system maps, defining the organisation's goal, and subsequent red teaming helped foster a shared understanding among participants while encouraging creative thinking. Second, through the wargame, participants uncovered the organisation's zone of influence within the broader system.

6.3.1.1 Creating shared understanding

participants create a shared understanding of the intricacies and relational dependencies within their organisation and the overarching complex systems. This was predominantly observed during steps one and three and reaffirmed by several participants during the debriefs and questionnaires of each wargame. As a participant reflects:

> *You also have a real wealth of information, because everybody in the group knows different things and has different backgrounds. [...] the most powerful thing of our group is we all know such different things – Debrief, wargame 4*

The wargame two debrief further highlighted the creation of this shared understanding as the system maps sparked debate, whereby the participants collectively reframed their perspective on their organisation while proposing new and adjusted system maps.

Participants also mentioned that defining the organisation's goal created an initial understanding of their organisation's fragilities. This understanding helped them to design and uncover looming Black Swans in step two.

> *[...] every time we started to go, what could go wrong? [...] We said, okay, wait, what was our goal? What do we say the airport does? [...] it did help in formulating [...] what could shut down things big time. – Debrief, wargame 4*

Finally, the wargame seemed to create a deeper understanding of the organisation's raison d'être. As indicated by a number of participants, they seemed able to unravel the organisational goal underneath their goal established in step one. As illustrated in the following quote:

> *through the [wargame] I identified the political and social importance of the airport and how that is also included in the goal, and is even its core [...] - Questionnaire, wargame 4*

6.3.1.2 Uncovering organisational zones of control

Participants also reflected on their organisation's zone of control, realising that multiple Black Swans extended beyond their influence. This manifested predominantly by participants noting that some Black Swans were too disruptive relative to the system maps. For example, a full-scale war affecting an airport system made some system maps, such as a geographic or process map, feel irrelevant for guiding strategic responses as decision-making power shifted towards the national and European level. As one participant reflected:

> *[...] the Black Swan was such a big issue, that you could put a giant cross over the [process map] – Debrief, wargame 1*

In reaction, a few participants stressed the importance of being more aware of dependencies on other stakeholders. As one participant illustrates:

> *[...] what is interesting is [...] we are so interwoven in a [complex] system, with all kinds of dependencies [...] it would be interesting to further explore this – Debrief, wargame 1*

6.3.2 Black Swans, unsurprising surprises

However, how to be proactive remained a point of contention, as discussions frequently revolved around the surprising nature of Black Swans. On the one hand, participants questioned whether their Black Swan's design in step two still qualified as a surprise, and thus, as a Black Swan. On the other hand, some participants noticed that regardless of the Black Swan event, the effects on their system were the same, implying that the Black Swan concept itself was unnecessary.

6.3.2.1 Are these really Black Swans?

The surprising nature of Black Swans was frequently debated among participants. First, when designing a Black Swan, participants often came up with scenarios inspired by recent crises in the media, such as a (hybrid) war (i.e. the Russo-Ukrainian war) or extreme flooding (i.e. global warming). Subsequently, these Black Swans could be considered unsurprising.

> *Well, I think there is an interesting thing about all three [designed Black Swans], they are all things that we foresee [...] We have a war, we talk about the climate, [...], hybrid warfare is addressed in a whole new report. These are already things that are already happening [...] –Debrief, wargame 1*

However, because of the rotation in step three, participants were surprised by their new Black Swan. On the one hand, this was observed by the emergence of an audible sigh of surprise. On the other hand, participants reaffirmed the sense of surprise during the debrief. However, in multiple debriefs, a debate unfolded about the nature of the designed Black Swans; were these events really surprising, and thus Black Swans, or were they just high-impact crises?

A number of participants viewed Black Swans through a type-A lens, stating that Black Swans that are predictable and somewhat expected are, by definition, not Black Swans as they do not come as a surprise and are already known. However, some participants seem to take a type-B or C lens and suggested that knowing a Black Swan can happen does not equate to being prepared or understanding the effects.

[...] you could see Black Swans coming because we don't actually have designed completely new Black Swans that pop out of nowhere, [...] even though we have them in the back of our minds, we are not sufficiently prepared – Debrief, wargame 1

6.3.2.2 Different Black Swans, same fragilities

Multiple participants noted that different Black Swans, independently designed by different teams, exposed similar fragilities within their organisation. Subsequently, participants implied that the Black Swan, or cause, was irrelevant as its effect remained the same. This sparked a discussion about whether Black Swans were still a necessary concept. For example, a (hybrid) war or extreme flooding could nullify the number of aircraft movements as runways would not be operational. Subsequently, it was discussed whether the focus should be on the fragilities of the runways instead of the causal Black Swan.

Q: What are your takeaways from the wargame?

A: [...] the cause of the crisis [i.e. Black Swan] is less important, the effects are in broad strokes, the same [...] – Questionnaire, wargame 1

6.3.3 Operationalising resilience

Participants indicated that the wargame offered a novel approach to improve their theoretical understanding of resilience while enabling its operationalisation. They mentioned that the four aspects of resilience (i.e. fragility, robustness, adaptation, and transformation) work as a sensemaking tool, providing direction to the participants in operationalising resilience. However, they did have difficulties defining the fragilities of their organisation as they often referred to the undesirable event that caused it rather than the organisational aspect that enabled it. Finally, participants seemed unaware of the connotations they attached to each aspect of resilience (e.g. 'fragile is always undesirable').

6.3.3.1 Sensemaking through categorising resilience

Multiple participants highlighted that the wargame enriched their theoretical perspectives on resilience. They approached the aspects of resilience as a sensemaking tool that provided guidance regarding the development of interventions. Subsequently, it helped them to operationalise resilience within their organisation.

> *I think [the aspects of resilience] are a coat rack to hang something on. That worked well in my opinion.*
>
> *Agreed, I see that in recent years, we have several things that we have missed or that have been done that fall perfectly into those categories – Debrief, wargame 1*

The matrix (figure 3) helped participants to make sense of their organisation's resilience. It showcased areas of opportunity and crucial fragilities, often tacitly known within the organisation but rarely formalised. They also indicated that the mapping and reflection supported the conception of multiple resilience interventions as they created options. Finally, multiple participants were particularly interested in the aspect of transformation but realised that achieving it remained challenging.

> *I like transformation a lot. [...] maybe we should consider having waterplanes in case of floodings [...] or ground handling by canoe – Debrief, wargame 1*

6.3.3.2 Pinpointing fragilities

During the red teaming of step three, multiple participants had difficulties defining fragilities within their organisation. The predominant difficulty lay in pinpointing the core of the organisational fragility, as they were often framed as the undesirable situation that caused them, instead of the organisational aspect that enabled them, for example, defining a power outage as a fragility instead of the organisation's ill-maintained power grid. When reflecting on the difficulties of defining fragilities, a participant attributed it to the Black Swans being too high-level, hampering the step towards concrete fragilities.

> *I think I find [defining fragilities] difficult because the [Black Swans] are so big? So the undesirable event and the fragility [...] you get that mixed up [...] – Debrief, wargame 1*

6.3.3.3 Implicit connotations of resilience aspects

In step four, as observed through field notes, participants implicitly coupled a connotation to each aspect of resilience. In this sense, fragility became an inherently negative aspect that should be avoided at all costs, while transformation was placed on a pedestal. Nevertheless, this was not the aim of the wargame. The ambition was to provide a connotation-less overview whereby a strategic fragility (e.g. reducing prices in the short term to acquire more customers in the long term) could be beneficial, and that the other aspects, generally regarded more positively, could have drawbacks (e.g. a transformation could spawn undesirable change).

6.4 Discussion

6.4.1 General discussion

This study investigated what decision-makers within complex systems learn from wargaming Black Swans to operationalise resilience. To this end, we conducted four wargames with 57 decision-makers. The results of the wargames were then thematically analysed, resulting in three main themes and seven subthemes. Each main theme covers learnings related to the core concepts of complex systems, Black Swans, and resilience.

Starting with the main contribution, our wargame helped decision-makers to operationalise resilience-as-an-outcome while addressing its three barriers: the complexity of modern organisations; the unimaginable Black Swan; and the conceptual ambiguity of resilience. We believe that the matrix (figure 3) functions as a capstone to operationalise resilience as it enables the creation of optionality, or the state of having options (Taleb, 2012). Optionality is frequently reported as an essential strategy for dealing with Black Swans (Taleb, 2012) and creating resilience (Olsén et al., 2023; Ramezani & Camarinha-Matos, 2020).

However, how to translate the concept of optionality to an actionable and empirically validated practice remains fuzzy. Subsequently, we consider our wargame, especially the matrix, as an initial contribution towards operationalising optionality.

Although we used a resilience-as-an-outcome lens in our study, we observed that our wargames could foster the development of key resilience capabilities. This observation aligns with Hermelin et al. (2020), who examined resilience-as-a-process through activities such as tabletop and command post exercises, which are closely related to wargaming. The following sections discuss how the wargame addressed each barrier and link these insights to the resilience capabilities it fostered.

Regarding the first barrier, the complexity of modern organisations, our findings suggest that wargaming supported decision-makers when developing a shared understanding of their organisation and its overarching complex system. We believe this shared understanding was primarily achieved through reviewing system maps and red teaming. These results align with other studies that show the value of system maps in creating shared understanding by visualising interdependencies (Geurts et al., 2007; Sevaldson, 2011; Taysom & Crilly, 2017). Furthermore, our findings empirically reaffirm the value of red teaming to simulate decision-making (Perla & McGrady, 2011) and system behaviour (Masys, 2012). Additionally, our wargame provided decision-makers with an insight into their organisational zone of influence while recognising the influence of other stakeholders. Providing insights into these zones of control could promote a more systemic approach, fostering closer collaboration between organisations, a challenge that proved to be a major hurdle during the COVID-19 pandemic (Nieuwborg et al., 2024a) and Black Swans in general (Masys, 2012).

In line with Wehrle et al. (2022), we relate our findings to the resilience capability of shared situational awareness (SSA) (McManus et al., 2008). Derived from Endlsey (1995), SSA refers to the ability of a team to develop a shared perception, comprehension, and projection of their organisation and overarching complex system. In our context, the development of shared perception and comprehension occurred through the collective analysis of system maps. The projection element was addressed during red teaming, as each blue team had to anticipate interventions in response to the simulated Black Swan. Furthermore, this anticipation often coincided with improvisation, or bricolage, which is considered another resilience capability (Bechky & Okhuysen, 2011).

Regarding the second barrier, the unimaginability of Black Swans, our wargame enabled decision-makers to imagine and simulate the impact of type-B (unknown knowns) and type-C (ignored knowns) on their organisation. These findings empirically support prior research by Perla and McGrady (2011) and Masys (2012),

highlighting the value of wargaming and red teaming in revealing looming Black Swans. Furthermore, our wargame instigated a recurring discussion on the meaning of a Black Swan. Should it solely be approached as an absolute type-A (unknown unknown)? Or is it dependent on perspective, thus including type-B and -C's? We note that the discussion mirrored a prominent debate on whether or not the COVID-19 pandemic was a Black Swan. On the one hand, Taleb (Bloomberg, 2020) and other scholars (de Wit, 2022; Krausmann & Necci, 2021) imply an absolute type-A approach; thus, they do not consider the pandemic a Black Swan. On the other hand, Mishra (2020) and Sweeney (2022) approached the pandemic as a Black Swan, referring to the importance of perspective, implying a type-B or C approach. Subsequently, although the Black Swan literature acknowledges the importance of perspective (Aven, 2015; Taleb, 2007), we observe that this is often lost in practice. While resolving this ambiguity lies beyond our study's scope, future research could benefit from exploring alternative conceptualisations which emphasise the importance of perspective such as Black Elephants (Friedman, 2014; Lin et al., 2022), a concept fusing Black Swans and the notion of the elephant in the room, or Grey Rhinos (Wucker, 2016), neglected threats with a high probability and impact.

Simulating several Black Swans per wargaming session enabled decision-makers to identify and reflect on recurring fragilities. Determining these recurring fragilities is valuable as it can support organisations in prioritising and consolidating their efforts regarding operationalising resilience. Furthermore, this process could foster the resilience capability of managing keystone fragilities (McManus et al., 2008) or dealing with organisational aspects that may have significant negative impacts in a crisis. Finally, the design of the Black Swan is assumed to support the resilience capability of anticipating future developments (Hillmann & Guenther, 2021), as it helps decision-makers to imagine Black Swans before they occur.

Finally, the third barrier, the conceptual ambiguity of resilience, was addressed by the categorisation of resilience, which provided decision-makers with a structured framework for understanding resilience-as-an-outcome. Reaffirming Nieuwborg et al. (2023), decision-makers referred to the fragile, robust, adaptive and transformative aspects as sensemaking tools that support actionable decision-making and strategy development regarding resilience. As conceptual ambiguity is a common issue when working with resilience (Dahlberg, 2015; Hillmann & Guenther, 2021), we, consistent with Weick (1993), consider this sensemaking as another important resilience capability.

6.4.2 Limitations and future research

Regarding the operationalisation, it is unclear whether the wargame led to interventions being implemented in the participating organisations. As research on the longitudinal effect of wargames remains scarce (Augier et al., 2018), we have the ambition to explore this effect further in future research. Furthermore, we also aim to explore the presence and development of resilience capabilities in more depth. In doing so, we intend to draw on observational approaches commonly used in resilience and crisis management studies (e.g. Bechky & Okhuysen, 2011; Gomes et al., 2014).

As a practical reflection outside the scope of our research question, we observed that selecting system maps in collaboration with an internal sponsor can be challenging. Determining the appropriate level of detail proved particularly difficult, as we relied on only a single perspective. Subsequently, in future wargames, we would encourage including multiple perspectives within the development of system maps. Other scholars achieve this using co-creation (Nieuwborg et al., 2024b; Sevaldson, 2011; Taysom & Crilly, 2017), interviews (Geurts et al., 2007; Taysom & Crilly, 2017) and literature reviews (Geurts et al., 2007). Furthermore, experimenting with different types of visualisations, such as AcciMaps (Rasmussen, 1997) or the Event Analysis of Systemic Teamwork (Stanton & Harvey, 2017), may yield novel insights.

Reflecting on the categorisation of resilience, we see several areas of improvement regarding the confusion between undesirable situations and fragility and the connotations regarding each resilience aspect. We suggest that both hurdles could be overcome through improved facilitation and the inclusion of examples during the wargame. We aim to investigate these hurdles in future research.

Finally, a limitation regards the cultural context in which most wargames occurred. Conducted primarily within a Dutch setting, characterised by open communication and an egalitarian social structure, our findings may have limited applicability to different cultural contexts. Furthermore, the scope of this study focused on the aviation and defence domains. Given the unique nature of these domains, it is uncertain to what extent the insights gained can be generalised to other domainsw

6.5 Conclusion

In this study, we investigated: what do decision-makers within complex systems learn from wargaming Black Swans to operationalise resilience? Our findings indicate that wargaming helps decision-makers to (1) develop a shared understanding of their organisation within its complex system; (2) imagine the impact of type-B (unknown knowns) and type-C (ignored knowns) Black Swans on their organisation; and (3) operationalise resilience-as-an-outcome while deepening their theoretical understanding of it. Furthermore, conducting wargames may enhance resilience capabilities, namely: shared situational awareness, the management of keystone fragilities, anticipating future developments, and sensemaking. To conclude, these findings suggest that wargaming can be a valuable tool to operationalise resilience.

Appendix 1

General

How was your experience?

What are your take-aways of the workshop?

How would you compare this workshop with current resilience practices (e.g. tools or workshops) that you are familiar with?

Do you have any feedback regarding the workshop?

Organisation

Did your view on the goal of the organisation change? [Y/N]

Can you elaborate on your previous answer?

Did you discover new fragilities in your organisation? ? [Y/N]

Can you elaborate on your previous answer?

Resilience

Did your perspective on resilience change? ? [Y/N]

Can you elaborate on your previous answer?

Black Swans

Do you foresee new looming Black Swans after conducting the workshop?

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7 DISCUSSION AND CONCLUSION

7. Discussion and conclusion

In this final chapter, the main research question (MRQ) is revisited: How can resilience be operationalised in airports to prepare for and respond to looming Black Swans? Then, each sub-research question (SRQ) is addressed in detail, comprehensively synthesising the findings. This is followed by a discussion of the broader implications of the research. Subsequently, the key limitations of this dissertation are outlined. The chapter concludes with recommendations for future research avenues that could further advance the operationalisation of resilience in airports and other organisations.

7.1 Key findings

7.1.1 MRQ: How can resilience be operationalised in airports to prepare for and respond to looming Black Swans?

This dissertation demonstrates that resilience in airports can be operationalised[9] through the application of wargaming, specifically, the wargaming resilience blueprint. Developed in Chapter 5 and validated in Chapter 6 with decision-makers from aviation and defence, this blueprint enables the operationalisation of resilience-as-an-outcome in the context of type-B (unknown knowns) and type-C (ignored knowns) Black Swans. Moreover, based on Chapters 4 and 6, wargaming generally appears to support the development of key resilience capabilities, such as shared situational awareness and the management of keystone fragilities.

Beyond the blueprint, Chapter 4 explores how airport crisis management teams (CMTs) have already operationalised resilience capabilities. Three essential resilience capabilities are identified: (1) proficiently navigating the rules of play; (2) metacognition; and (3) directionality. Actively fostering these capabilities, through wargaming or comparable interventions, is expected to improve organisational resilience.

9 This dissertation defines operationalising resilience as translating resilience aspiration into actionable interventions (e.g. training, products and strategies).

Furthermore, the categorisation of resilience developed in Chapter 3 and validated in Chapter 6 plays an essential role in operationalisation efforts. This categorisation, consisting of fragility, robustness, adaptation, and transformation, functions as a sensemaking tool supporting decision-makers to create actionable interventions.

Finally, the lessons learned from Chapter 2 provide a broader strategic lens by underpinning the value of a systemic crisis management approach, the need for sensemaking capabilities and the importance of informal relations. These insights offer a direction towards alternative or complementary avenues, beyond wargaming, for operationalising resilience in airports.

7.1.2 SRQ 1: What are the key experiences and lessons learned by an airport system during the COVID-19 pandemic?

Chapter 2 addressed this SRQ by interviewing 16 experts related to Amsterdam Airport Schiphol. After conducting a thematic analysis, the chapter reveals three key experiences and four lessons learned. When reflected upon in the context of the MRQ, these findings highlight both barriers to and enablers of the operationalisation of resilience, influencing Chapters 4, 5 and 6.

The first key experience concerns the limited preparedness of the airport system in the face of the looming COVID-19 pandemic. The airport system trivialised COVID-19's emergence despite past disruptions (e.g. SARS, H1N1, Ebola), underestimated weak signals, and failed to imagine its full impact. Based on these findings, the COVID-19 pandemic is considered, in accordance with Aven (2015), a type-B (unknown known) or type-C (ignored known) Black Swan. Second, during the pandemic, the airport system had to constantly "firefight", referring to a position where they were constantly on the back foot due to, for example, ever-changing government regulations, new knowledge on the SARS-CoV-2 virus and reorganisations. This firefighting hampered the implementation of operational interventions (e.g. digital health declaration). Third, complex relational dynamics emerged within the airport system, influencing collaboration. These dynamics consisted of knowledge mismatches between aviation, public health, and government stakeholders, fears of conflict of interest between public health and government stakeholders, and a top-down approach by government stakeholders.

Regarding the lessons learned, the first lesson addresses the need for a more systemic approach within the airport system, referring to increased harmonisation of regulations and improved organisational and operational collaboration. Second, experts indicate the need for more sensemaking capabilities, referring to novel long-term planning, decision-making, risk assessment and scenario thinking techniques. These techniques should better address unimaginable "what-if" scenarios while also addressing the long-term impact of crises. Implicitly addressing the first and second lessons learned, scholars suggested using wargaming (de Wit, 2022; Linden, 2021). This connection planted the seeds for the wargaming resilience blueprint addressed in Chapters 5 and 6. Third, experts highlighted the importance of fostering and maintaining informal relations within and outside an organisation to speed up decision-making processes. Fourth, organisational interventions, such as CMTs, which consolidate different stakeholders and facilitate collective sensemaking, are crucial. The fourth lesson learned formed the raison d'être for Chapter 4, whereby the workings of these CMTs are further investigated.

7.1.3 SRQ 2: What aspects does resilience consist of?

Chapter 3 answered this SRQ by conducting a scoping review taking a resilience-as-an-outcome lens, conceptualising resilience as an organisational state after facing a disruption (Ketelaars et al., 2024). In contrast, Chapter 4 focused on resilience-as-a-process, referring to the resilience capabilities that enable a resilient outcome (Ketelaars et al., 2024). The scoping review in Chapter 3 refined the resilience-as-an-outcome perspective by identifying four core categories, or aspects, of resilience: fragility, robustness, adaptation, and transformation (see Figure 7.1).

Fragility refers to organisations (e.g. an airport system) breaking or losing value in the face of a disruption. Robustness indicates an indifference to disruption, implying absorption, recovery and stability. Adaptation refers to evolutionary change after disruption, whereby an organisation reorganises, learns and reconfigures. Finally, transformation suggests a fundamental or revolutionary change whereby new fitness conditions are created in the face of disruption. These aspects can exist independently or combined to form resilience in whatever constellation. For example, a resilient organisation could have solely an adaptive aspect or a combination of robust and transformative aspects. Validated in Chapter 6, these aspects proved valuable for enabling collective sensemaking, reducing conceptual ambiguity, and supporting the operationalisation of resilience. Moreover, this categorisation shaped the conceptual

foundation of subsequent chapters and helped establish a shared understanding of resilience within the supervisory team from Delft University of Technology and the Royal Schiphol Group.

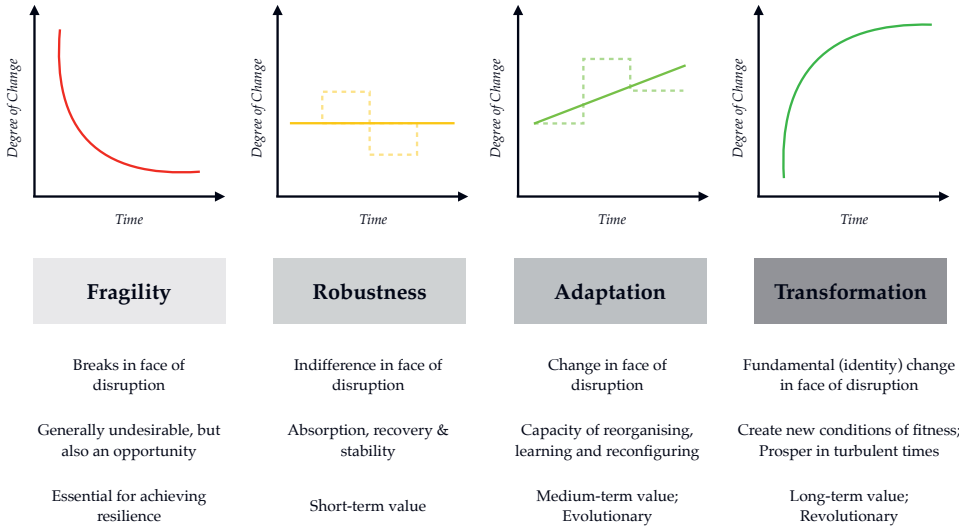

Figure 7.1 The categorisation of resilience (Nieuwborg et al., 2023)

7.1.4 SRQ 3: What resilience capabilities do airport CMTs use?

Chapter 4 builds on the lessons from Chapter 2, which underscored the importance of CMTs. It does so by analysing six training sessions involving 54 managers from Amsterdam Airport Schiphol's operational CMTs. Adopting a resilience-as-a-process lens, this chapter investigates the specific capabilities that contribute to achieving a desirable and resilient outcome.

After conducting a thematic analysis of the collected data, the findings showed three prominent resilience capabilities. The first resilience capability pertains to proficiently navigating the "rules of play", referring to the combination of operational procedures, meeting protocols and leadership styles. Second, metacognition, a reflexive decision-making approach whereby one recognises, critiques and corrects their decisions during a course of action (Cohen et al., 1996), is considered an enabling resilience capability, facilitating the development of other capabilities. These include

shared situational awareness, anticipation of future developments and directionality. The third capability, directionality, refers to establishing and reflecting upon a shared goal, a metaphorical "dot on the horizon", during a crisis. It also serves as a benchmark for evaluating the effectiveness of decisions and interventions. Together, these capabilities constitute a critical contribution to addressing the MRQ.

Beyond the scope of the SRQ, doubt was identified as a barrier to using resilience capabilities, as it delayed the decision-making process. Furthermore, the training methodology, a type of wargaming, proved to be an effective approach for evaluating and enhancing resilience capabilities. Finally, although investigated in parallel, this chapter significantly influenced the design and direction of Chapters 5 and 6.

7.1.5 SRQ 4: How to design a minimum viable seminar-style wargame that supports decision-makers in achieving systemic resilience in the face of looming Black Swans?

Building on the need for a systemic approach (Chapter 2), improved sensemaking capabilities (Chapter 2) and the categorisation of resilience (Chapter 3), Chapter 5 presents the development of an intervention to operationalise resilience through wargaming. This SRQ addressed its design process, consisting of four playtesting sessions with 52 researchers and practitioners from design, crisis management, aviation, public health, and serious gaming.

Executing the blueprint takes a minimum of two hours and consists of four steps whereby participants (1) gigamap, a method to visualise complex systems (Sevaldson, 2011), their organisation's stakeholders and relations, (2) design a Black Swan utilising a premade template, (3) simulate the impact of the Black Swan on their organisation through red teaming, an adversarial thinking methodology (Zenko, 2015), while surfacing the organisation's resilience and (4) design interventions to operationalise resilience through blue teaming. The wargaming resilience blueprint was positively received, and participants provided valuable input to improve and streamline the design. Chapter 6 further refines and validates the design.

7.1.6 SRQ 5: What do decision-makers in complex systems learn from wargaming Black Swans to operationalise resilience?

Based on the outcomes of Chapter 6, the wargaming resilience blueprint was refined. This refinement predominantly streamlined the prior version. Subsequently, the blueprint consisted of the following steps whereby decision-makers (1) review premade gigamaps of the organisation, (2) design a Black Swan utilising a template, (3) simulate the impact of the Black Swan on their organisation through red teaming, and (4) improve the theoretical understanding and operationalise resilience utilising a matrix.

To validate the blueprint, four wargames with 57 decision-makers from aviation and defence were observed and thematically analysed. The findings indicate that wargaming helps decision-makers (1) to develop a shared understanding of their organisation within its overarching complex system; (2) to imagine the impact of type-B (unknown knowns) and type-C (ignored knowns) Black Swans on their organisation; and (3) to operationalise resilience-as-an-outcome and develop a deeper understanding of it. Finally, conducting wargames may operationalise resilience capabilities, namely shared situational awareness, the management of keystone fragilities, anticipating future developments, and sensemaking.

Chapter 6 functions as the capstone of this dissertation and provides crucial insights into addressing the MRQ. This chapter builds upon the lessons learned from Chapter 2, validates the categorisation of resilience developed in Chapter 3, draws on the resilience-as-a-process lens utilised in Chapter 4 and iterates upon the blueprint proposed in Chapter 5.

7.2 Implications

Reflecting on my research, I elaborate on the impact of this dissertation's key findings: the wargaming resilience blueprint; the categorisation of resilience; metacognition; and design for resilience.

7.2.1 Wargaming resilience blueprint

By enabling the operationalisation of resilience, the wargaming resilience blueprint forms the centrepiece of this dissertation. Its impact has been significant in both educational and professional contexts. Initially, I conceptualised the blueprint while developing the Design for Complexity course at Delft University of Technology in 2022. In this master's course, which introduced students to complexity theory and systemic design, I aimed to familiarise them with the concepts of resilience, complex systems, and Black Swans through a wargame. The course was well received, and although I did not consider this course the centrepiece of this dissertation yet, the request for similar wargames increased.

Gradually, the initial concept evolved into the wargaming resilience blueprint featured in Chapters 5 and 6. In parallel, additional sessions were requested in academic and professional settings, creating opportunities for freelance engagements. In total, 16 sessions were conducted, with two more in the pipeline at the time of writing, reaching approximately 100 master's students in Industrial Design Engineering at the Delft University of Technology and around 190 professionals such as crisis managers, policy makers, designers from the aviation, defence, and public health domains. I consider this ongoing dissemination the most impactful output of the dissertation, demonstrating the blueprint's educational and practical value in operationalising resilience.

The strength of the blueprint lies in its interdisciplinary nature, fusing systemic design, foresight, and wargaming. Furthermore, utilising an effort and the categorisation of resilience matrix (see Figure 6.3), the debrief provides participants with an actionable overview of their organisation's resilience and potential interventions. While the blueprint has evolved significantly throughout this dissertation, its continued refinement should be considered an ongoing endeavour.

7.2.2 The categorisation of resilience

The categorisation of resilience, consisting of fragility, robustness, adaptation, and transformation, proved to be a valuable tool for reducing ambiguity and fostering a shared understanding of resilience-as-an-outcome. These aspects provided structure while enabling the operationalisation of resilience. This perspective was echoed

across multiple wargaming sessions in both educational and professional contexts. As one participant in Chapter 6 aptly noted, “I think [the aspects of resilience] are a coat rack to hang something on. That worked well in my opinion.”

Gradually, the categorisation is slowly disseminated and iterated upon by practitioners. A nice illustration of this is the proposal of Ed Oomes, the operational crisis manager of the Royal Schiphol Group, to reframe the aspects whereby only fragility or robustness are considered organisational states. In contrast, adaptation and transformation could be considered resilience capabilities, enabling organisations to shift from fragility to robustness and vice versa. Although I am still wrapping my head around this alternative perspective, I consider the fact that the categorisation is starting to live its own life a crucial impact factor.

7.2.3 Metacognition

Chapter 4 highlighted the importance of metacognition, framing it as an enabling resilience capability that supports the development of other resilience capabilities. While this chapter observed metacognition in action during a real-time crisis management exercise, I believe its significance extends far beyond that context. In particular, metacognition is an essential asset for operationalising resilience.

The reasoning for this lies in the fact that operationalising resilience requires grappling with inherently subjective perspectives about what resilience is (e.g. should the focus be on robustness or adaptation?), what Black Swans are and for whom, and how the boundaries of an organisation and its overarching complex system are drawn. In this context, metacognition plays a critical role. It enables decision-makers to recognise, reflect upon, and reconcile these different perspectives, ensuring that resilience can be meaningfully operationalised across the diverse perspectives within an organisation. Subsequently, metacognition should be a key competence within crisis management, policy-making and other resilience-related professions.

7.2.4 Design for resilience

Being trained as an industrial designer while writing my dissertation in the faculty of Industrial Engineering at Delft University of Technology, I realised that the practice of design complements practices such as crisis management and business continuity.

Drawing inspiration from Cross (1982), I view design as the discipline of addressing ill-defined and abstract problems and translating them into concrete, actionable interventions.

Operationalising resilience demands addressing exactly these abstract and ill-defined problems: What should be resilient? What threats should our organisation be resilient against? What does resilience mean for us? Designers, therefore, bring a different skillset that complements the expertise of crisis managers and business continuity professionals. Exploring this intersection between design and other fields, such as crisis management, holds the promise of unlocking novel approaches to anticipating and preparing for future Black Swans.

7.3 Limitations

During this PhD, I started investigating the impact of the COVID-19 pandemic on airports while the pandemic was ongoing. Although highly relevant, this tension of researching a phenomenon during the unfolding of that phenomenon hampered my research. First, I experienced this while reviewing the literature. The number of academic publications on COVID-19-related topics skyrocketed, making it challenging to gain an overview and filter the noise. Furthermore, as the pandemic's medical knowledge (e.g. think of all the SARS-CoV-2 variants) and societal impact (e.g. ever-changing policies and regulations) kept shifting around, previously published research could get dated quickly. Second, I started the PhD journey from Belgium when international travel restrictions due to COVID-19 were still imposed. It took me about nine months to visit the Delft University of Technology and Amsterdam Airport Schiphol, the latter of which I had never flown from before my PhD. This strongly impacted my research, hampering my opportunities to conduct action research in the first year.

My research primarily focused on operationalising resilience at Amsterdam Airport Schiphol in the context of the COVID-19 pandemic. While I engaged with other sectors, such as public health and defence, the primary focus on aviation means that the findings of this dissertation may not be fully generalisable to other sectors. I later expanded the scope of this dissertation from pandemics to Black Swans. However, the effects of the pandemic remained a prominent and priming influence, which could further limit the generalisability. Moreover, I conducted this research almost solely

in a Dutch context. As the Dutch culture is considered by direct communication and an egalitarian social structure, I assume it shaped my research outcomes, especially Chapters 4, 5 and 6. Subsequently, my findings may not be fully generalisable to other cultures aiming to operationalise resilience.

Finally, I started this research, primed by my action-research approach, with a predominant resilience-as-an-outcome lens. Unpacking the conceptual link towards resilience-as-a-process, although already addressed in the literature (e.g. Canizares et al., 2021), took time for me to sink in and translate to practice. This connection only became clear to me through my collaboration with Amsterdam Airport Schiphol's operational CMTs in Chapter 4 and the wargaming resilience blueprint of Chapters 5 and 6. Only when finalising this dissertation did I truly grasp how resilience-as-an-outcome and resilience-as-a-process intertwine. Lacking this unified perspective from the outset is, therefore, a limitation of my research. However, I also see it as an opportunity for future studies to explore and expand upon.

7.4 Future research

To conclude, there are many promising avenues for future research on the operationalisation of resilience. First and foremost, further developing the wargaming resilience blueprint and investigating its longitudinal impact on organisations, both within and beyond the Dutch aviation sector, offers exciting opportunities. Additionally, maturing the blueprint in an educational context could help teach students about resilience, Black Swans, and complex systems.

Second, revising and iterating on the categorisation of resilience is crucial. On the one hand, exploring the boundaries of each aspect, particularly between adaptation and transformation, would provide greater clarity. On the other hand, I am curious to introduce a resilience-as-a-process lens to the categorisation and see how it might supplement the current resilience-as-an-outcome perspective.

Third, continuing research on CMTs and resilience capabilities, like Chapter 4, seems to be a relatively under-researched field with significant research potential. In particular, a concrete research direction for me is to further explore the functioning of metacognition and how to foster it.

Fourth, I remain intrigued by the phenomenon of Black Swans. This concept sparked many debates throughout my dissertation, suggesting that Black Swans remain shrouded in ambiguity. Investigating and demystifying Black Swans has become a personal ambition for me.

Finally, I see great potential in exploring the intersection between design and fields like crisis management. Such cross-pollination could unlock novel ways of operationalising resilience and deepen our understanding of how to anticipate and prepare for ever-looming Black Swans.

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Presentations

(invited speaker) Meulemeester, R., & Nieuwborg, A. (2025). From Tabletops to War Games – Key Considerations for Crisis Simulations. Antwerp Crisis Conversations.

(invited speaker) Nieuwborg, A. (2024). Design for resilience in complex systems against Black Swans. Chair of Crisis Governance Research Colloquium.

(invited speaker) Nieuwborg, A. (2024). Design towards resilience. Greater Gothenburg Fire & Rescue Services.

(invited speaker) Nieuwborg, A. (2023). Designing towards (pandemic) resilience in airports. The hunt for looming Black Swans through wargaming. Connections NL.

(invited speaker) Nieuwborg, A., & Zekveld, J. (2022). Gaining through disorder. Towards pandemic antifragile airports. World Aviation Festival.

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About the author

Alexander Nieuwborg was born in Antwerp, Belgium, on December 16, 1995. From 2007 to 2013, he attended the Sint-Ursula Institute Wilrijk, obtaining his general secondary education degree (ASO) in Mathematics and Sciences. Afterwards, from 2013 to 2018, he pursued a Master of Science in Product Development at the University of Antwerp, specialising in Strategic Design. For his master's thesis, Alexander collaborated with the Institute for Tropical Medicine in Antwerp to develop a patented fingerstick blood self-collection device.

From 2018 to 2019, he obtained a Master of Science in Space Studies with a specialisation in Space Technology and Applications at the KU Leuven. During this program, he conducted thesis research in collaboration with the Belgian Nuclear Research Institute on the design and shielding of a future Moon habitat. His thesis was awarded the best master thesis award of the Belgian Nuclear Research Institute and nominated for the Odissea price by the Belgian Senate. Then, in 2019, Alexander joined bpost, the Belgian postal operator, where he worked on redesigning the parcel delivery chain, focusing on urban logistics and robotics.

Fusing his experiences in strategic design, medical design, aerospace and logistics, Alexander commenced his PhD research in 2021 at the Delft University of Technology in close collaboration with the Innovation Hub and the Operational Resilience team of the Royal Schiphol Group. His research focused on how organisations can operationalise resilience in the face of looming Black Swans or high-impact and surprising crises.

As of 2025, Alexander is a post-doc researcher at the Institute of Security and Global Affairs of the Leiden University and a part-time researcher at the Multi Domain Warfare Education Centre of the Netherlands Defence Academy.