USAGE OF DIGITAL TWINS IN OPTIMIZING AIRPORT OPERATIONS

A literature review and case study

Bachelor’s Thesis
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Abstract

Rising passenger numbers at airports and pressure to lower carbon emissions create a need for more efficient ways to handle and optimize airport operations. Airports around the world are facing a capacity crunch, with current estimates being that in the future, without action, airports will not be able to service all flights due to congestion. To combat this, airports need new ways to optimize their operations to keep up with rising demand, while minimizing their environmental impact. Due to advances in the digitalization of the aviation industry and an increase in collaboration between actors, new data sources and technologies are available for use.

One such technology which utilizes these new data sources is called a Digital Twin (DT). A Digital Twin consists of a physical object, a digital replica of said physical object and the data connections between them. The DT processes and analyses information from the physical counterpart and makes automatic modifications to it based on the data. The use cases of DTs vary between industries, with numerous possibilities available.

The DT shows potential in helping answer airports’ needs for more efficiency and improved communication. With numerous completed and ongoing DT implementation projects at airports, it is important to study what opportunities, benefits and challenges DTs might provide. In this thesis, the current literature on the usage of DTs in optimizing airport operations is reviewed and a case study in the form of an interview is conducted. The goal of this thesis is to answer whether the usage of an airport digital twin can help airports optimize their operations and avoid delays while also uncovering the challenges of DT implementations at airports.

The literature reviewed in this thesis suggests that adopting an airport digital twin is beneficial for airport ecosystems. The literature finds that the DT adds visibility into the processes, helps avoid critical situations, enables predictive and proactive maintenance, enhances asset management and increases safety. The completed case study confirms these findings and offers new use cases, such as leveraging computer vision to optimize underwing operations. The case study also introduces the snacking method as a viable DT deployment concept, reducing the initial investment needed. The case study also offers advice for prospective airport DT implementers.

It should be noted that while ample research has been completed on DTs in general, the research focusing on its implementations at airports is still limited. Moreover, the financial feasibility of airport digital twinning is not addressed in the literature reviewed and thus the profitability and economical viability of it is in need of more research.

Keywords  Digital Twin, Airport, Aviation, Optimization
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List of Abbreviations

AI - Artificial Intelligence

ATM - Air Traffic Management

DT - Digital Twin

FAA - Federal Aviation Administration

IATA - The International Air Transport Association

IoT - Internet of Things

ML - Machine Learning

ROI - Return on Investment

SESAR - Single European Sky ATM Research

SWIM - System Wide Information Management

ULD - Unit Load Device

VHF - Very High Frequency
1 Introduction

The aviation field is undergoing a major digitalization effort as governmental agencies and public-private partnerships have started overhauling infrastructure and legislation. This has led to new technologies being available as well as increased levels of data to be utilized by different players in the aviation field. This rising amount of data and level of digitalization provides opportunities for airports to further improve the efficiency of their operations. One such opportunity is implementing a Digital Twin (DT), which refers to a digital and virtual equivalent to a physical product. A DT exchanges and processes data automatically between the physical and digital objects, allowing changes to be made to the physical object automatically following a change in the digital one and vice versa.

DTs are a rising topic and show potential to add value to many fields. They have been listed by Gartner as one of the top ten Strategic Technology Trends every year since 2017 (Zhou et al., 2019), and already ten years ago the National Aeronautics and Space Administration (NASA) suggested that DTs could be used to improve performance in the aviation field (Barricelli et al., 2019). DTs also solve many of the aviation field’s big problems as a highly secure and reliable system. Low maintenance efficiency, high product operation costs, and intensive technologies are just some of the obstacles that digital twins can help tackle. (Xiong & Wang, 2022)

Digital twins are not a new concept in the aviation field however, as they have been used in the field since the origin of the concept (Conde et al., 2022). However, in the past they have been mainly used for predictive maintenance (Xiong & Wang, 2022), and even new research searching for novel DT applications in the aviation industry focus mainly on the aircraft itself and its design, manufacturing and maintenance, with airport operations being less explored as an option. Thus it seems that, when looking at existing literature, research on using digital twins in airport operations is still in its infancy. Consequently, there is space for future research and case studies to study the business value of digital twins in airports.

Airports themselves have recognized the potential and benefits of using a DT, as currently there are multiple large international airports with either ongoing (Hamad International Airport, 2022) or completed (Vancouver Airport Authority, 2022) digital twin implementations.
With passenger numbers growing yearly, airports need ways to manage growing passenger number efficiently. The world’s airports face a capacity crunch, and without action it is estimated that airports in e.g. Europe will face a capacity gap in the future, not being able to service all flights due to congestion (EUROCONTROL, 2022).

The aviation industry is also under heavy pressure to reduce their carbon emissions. The International Air Transport Association (IATA) has ruled that the industry has to cut CO2 emissions by 50% by the year 2050 relative to the 2005 baseline, while allowing the annual payload-distance travelled to grow by 3.2%. This means that if, e.g. aviation in the U.S. is to meet this standard, it will have to conform to a 84% CO2/kg km reduction from 2013 figures (Hileman et al., 2013).

This thesis will be carried out as a thorough review of existing literature, models and concepts done on finding ways to optimize airport operations with the usage of digital twins. As mentioned before, DTs are a very topical technology, with them being a rising trend across multiple industries. With multiple ongoing DT implementation projects at airports, it is important to study what opportunities, benefits and challenges they will provide and if they are a feasible solution for airports to manage, communicate and optimize their operations.

1.1 Research objectives and research questions

Rising passenger numbers at airports and the need to cut carbon emissions create a need for more efficient ways to handle and optimize airport operations and the digitalization of the aviation field provides numerous new opportunities and technologies for just that. While a lot of research has been done on using Digital Twins, digitalization and airport operations separately, very little research has been done on exploring the usage of DTs in optimizing airport operations specifically, with only a few studies produced.

This thesis will examine existing literature, published studies and models on the subject as well as include a case study. The objective of this research is to create a thorough review on currently available literature on the possible applications of DTs in airports and to analyse the potential role and benefits of using a DT in making airport operations
more efficient, while adding to existing research with new information gained from the case study. With this, the following research questions should be answered:

i. Can Digital Twins be used to help optimize airport operations?
ii. What are the benefits of implementing a Digital Twin at an airport?
iii. What types of challenges does the implementation of a Digital Twin pose to an airport?

1.2 Scope of research

This paper will review and discuss research done on digital twins and their possibilities in optimizing airport operations. The theoretical background section of this thesis will cover DTs as a concept and the ongoing digitalization of the aviation field, which allows for new technology, such as the digital twin, to even be considered. The literature that is reviewed in this thesis aims to provide answers to the aforementioned research questions while giving the reader an understanding of current literature regarding DTs and their usage in optimizing airport operations. After the literature review, a case study in the form of an interview will be conducted and the results of that study will be discussed.

No empirical research on the usage of DTs in optimizing airport operations are included in this study, which results in no mathematical models or implementations being presented.

1.3 Methodology

This thesis will be completed as a literature review of the existing literature regarding the usage of DTs in the context of airport operations. All the materials for this thesis have been fetched from various scientific article databases, such as Elsevier’s Scopus, Clarivate’s Web of Science and Google Scholar. The literature has been searched by combining keywords Digital Twins, airport, aviation, aerospace, digitalization, digital transformation, turnaround operations, revenue, optimization, Internet of Things, IoT, and data-driven.

All the articles discussing digital twins were limited to having been published in the past 9 years, but most of the articles were published in the previous 5 years due to the quickly developing nature of the DT technology. Older publications were used only for defining background theory regarding the aviation industry and the developments within. The
source material was evaluated based on the number of citations and the publication forum’s citation ranking.

1.4 Structure of the research

The rest of the thesis will follow a structure as follows. The theoretical background for this thesis and the key concepts discussed will be defined in chapter 2. In it, the concept of the Digital Twin and the difference between a Digital Twin, a Digital Model and a Digital shadow will be defined first. Following that, the aviation field and its digitalization will be discussed.

Chapter 3 will focus on reviewing literature on using DTs in the context of airport operations. To begin, the amount of literature on the topic and its trend will be discussed. Next, the topic will be explored by reviewing and summarizing existing literature. After that, the challenges of implementing a DT at airports will be discussed. After that the literature and their findings will be discussed. Finally, a case study in the form of an interview will be presented.

Finally, in chapter 4, the thesis will be concluded with discussion and conclusions on the topic. The implications to research and to practice will be considered. Then, the possible limitations of this thesis and possible avenues for future research will be discussed.
2 Theoretical background

Airports need new ways of optimizing airport operations to keep up with future demand and to reduce carbon emissions. One of the main ways the aviation field is trying to keep itself future-proof is through digitalization and the leveraging of new technologies. This offers great opportunities, as replacing or expanding on previous systems with digital solutions generally helps increase efficiency and quality while reducing costs (Atalay et al., 2022). One way to approach this is via a digital twin, which has been characterised as one of the most important advancements in the field of technology (Barricelli et al., 2019). Despite a growth in interest regarding DTs, differing definitions remain in academia and across industries regarding the concept. The following chapter will aid in defining the concept as well as present background information on the digitalization of the aviation field.

2.1 Digital Twin

Artificial Intelligence (AI) has been around for decades, but the importance of it and the impact it has on our daily lives has increased exponentially. AI can be leveraged for its prescription, description and prediction capabilities, helping optimize many processes. While AI has advanced greatly, so has the spread of connectivity through technologies such as the Internet of Things (IoT) as well as the development of cloud computing and the processing of big data. One application which combines all the previous technologies is the Digital Twin (DT), which integrates AI models and big data analytics to process IoT data (Barricelli et al., 2019).

Depending on the source, the DT has many differing definitions. The term was first informally introduced by Michael Grieves in 2002 while discussing product life-cycle management, but the definition has changed over the years. One common definition sees the DT as a physical entity, a virtual equivalent and the data connections in between (Jones et al., 2020). The first application of a DT can be traced further back in history, to the 1970s, where the National Aeronautics and Space Administration (NASA) used the concept to help monitor the working status of their space vehicles. One was left on earth, which was used to map out the condition of the other one. (Xiong & Wang, 2022) When the Apollo 13 mission faced an unexpected explosion in its oxygen tank, pushing the spacecraft from its trajectory by approximately 400 miles a minute, the mission team back on earth guided the astronauts safely back to earth by modifying several high-
fidelity simulators to match the conditions of the damaged spacecraft (Neethirajan & Kemp, 2021).

This example serves as a great demonstration of a DTs capabilities, being used for both examining the current state of the system as well as predicting scenarios and evaluating different options to find the right solution to possible problems. They are self-learning systems that minimize failure rates, shorten development cycles, improve efficiency and open up innovative business opportunities (Bevilacqua et al., 2020). They have shown potential and are used in a plethora of fields, such as manufacturing (Atalay et al., 2022), healthcare (Liu et al., 2019), the building of smart cities (Francisco et al., 2020) and also aviation (Mendi et al., 2021).

However, these implementations differ in levels of data integration. Thus, it has been proposed that DTs be categorized based on the flow of data between the physical and virtual counterparts. Kritzinger et al. (2018) suggest that DTs be classified into three separate categories, the Digital Model, the Digital Shadow and the Digital Twin. In some cases, digital counterparts are created manually and cannot affect each other, while in some cases the flow of data is automatic and the two objects can make changes to each other autonomously. Next, the difference between the three DT types are explained as defined in the literature by Kritzinger et al. (2018).

Digital Models are representations of real world objects or processes where data flow is manual in both ways between the physical and digital objects. A change in state in one of the objects, physical or digital, has no direct effect on the other. All data exchange is done manually.

![Figure 1: Representation of a Digital Model's data flow (Kritzinger et al., 2018)](image)
In the case of Digital Shadows the data flows automatically from the physical object to the digital, but manually in the other direction. Thus, a change of state in the physical model automatically creates a change in the digital counterpart, but not the other way around.

![Figure 2: Representation of a Digital Shadow’s data flow (Kritzinger et al., 2018)](image)

Only when data flows automatically in both directions and the digital version can also make changes to the physical one, can the system be called a Digital Twin. A change in state in the digital object automatically leads to a change in state of the physical object and vice versa.

![Figure 3: Representation of a Digital Twin’s data flow (Kritzinger et al., 2018)](image)
The classification of DTs is deemed important by Kritzinger et al. (2018) due to the previous examples often being labelled simply as Digital Twins, while the differences are quite apparent.

### 2.2 Digitalization of the aviation field

Digitalization is changing the world we live in in such a way that some are even comparing it to a fourth industrial revolution or calling it Industry 4.0 (Krzywdzinski et al., 2016). Digitalization has many definitions, which have evolved with the development of technology. Eling and Lehmann (2018) provide a modern definition, which defines it as “the integration of the analogue and digital worlds with new technologies that enhance customer interactions, data availability and business process”.

The digitalization of the economy has accelerated greatly after the turn of the century with the development of IT technology, decline in price of ICT goods and the internet. In this new wave of industry, companies are integrating new technologies, such as IoT, cloud computing, analytics and AI to enhance decision making. With this, the volume of data is growing massively, and companies are harnessing the power of big data by adopting data-driven business models to gain a competitive edge (Tao et al., 2018). The advantages gained from embracing digitalization include increased cost savings through increased efficiency, increased revenue and operational agility as well as the possibility of differentiation (Vogelsang, 2009). These benefits are of special value to the aviation field, due to the intense level of competition, the cost structure and the need for efficiency in the industry (Wittmer et al., 2011).

The aviation field has always relied on collaboration to function. Just picture a regular flight – to get from A to B, the flight utilizes services provided by a multitude of different companies and governmental agencies. From baggage handling to air traffic control and weather services, all the pieces of the puzzle have to fit together to achieve the wanted outcome. In coordinating this effort, efficient communication and information exchange is of upmost importance. Despite this, data in the aviation industry has historically been very siloed and data sharing, especially in digital format, quite minimal. This lack of collaboration is expensive (Cruz, 2020). Information has travelled via outdated methods, such as in the case of weather data, via computer-generated audio distributed on VHF radio frequencies or using data cables. In some cases the only method of sharing
information between airport operators has been via telephone communications (Makhloof et al., 2014).

However, since the turn of the century governmental agencies have started to advocate data sharing and digitalization by changing regulation and starting initiatives and public-private partnerships such as the Federal Aviation Administration’s (FAA) System Wide Information Management (SWIM) in the US and the EU’s co-founded Single European Sky ATM Research (SESAR) in Europe. SESAR, for example, aims to digitalize the aviation field through innovation and research by radically transforming Europe’s aviation infrastructure. This will include cyber-secure data sharing, connectivity, virtualization of infrastructure and automation in air traffic management (ATM) (SESAR 3 Joint Undertaking, 2021). These developments offer opportunities to players in the aviation field, as digitalization is a key driver of innovation (Qi et al., 2021). As development advances, innovative solutions using technologies such as Blockchain (Ebarefimia, 2017), Augmented Reality (AR) (Palmarini et al., 2018) and 3D Printing (Berman, 2012), are being introduced to the field.
3 Digital Twins in Optimizing Airport Operations

The following section will examine, discuss and critically review literature regarding the optimization of airport operations with DTs. First, the quantity of existing literature and research will be analysed. Next follows a discussion and review of the theoretical literature on the subject. Afterwards, the challenges regarding DTs and their implementations will be discussed on a general level. Next, the general findings from the literature will be discussed. Finally, a case study in the form of an interview will be conducted.

3.1 Discussion about existing research on the usage of DTs in optimizing airport operations

DTs in the context of airport operations is a novel concept in terms of research. The very first article containing the keywords “Digital Twin” and “Airport” was published in 2020. As can be seen from Figure 4 below, the topic has since then started gaining interest, with 11 articles released on the topic thus far in 2022. Overall, research on the topic is in its infancy, with only 26 articles available in Elsevier’s Scopus database in total.

![Figure 4: Distribution of articles between the years 2015-2022 containing the keywords “Digital Twin” and “Airport” (Source: Scopus database. Retrieved 03.11.2022)](image-url)
In most cases, the research done is very hypothetical, with only a handful of case studies completed. However, research on using DTs generally in the field of aviation is slightly more mature, with the first articles in the Scopus database with keywords “Digital Twin” and “Aviation” being published in 2012. Interest in that has also grown in the past few years, with most of the articles being published between 2019 and 2022.

With the large spike of articles in the past few years, it would seem that Digital Twins are a topic of growing interest in the field, and that more research will be made in the coming years.

3.2 The role of DTs in optimizing airport operations

Airport operations are complex processes that involve a multitude of different actors and tasks. Historically, these processes have not been digitalized, and communication between these actors has been inefficient and made using outdated methods (Conde et al., 2022). This has created a lot of inefficiencies in the processes, with e.g. unreliable data and delays (Makhloof et al., 2014). When you add to that the need for airport operators to constantly adapt to changing circumstances, things get even more difficult. Thus, it is necessary to define data models and architectures to help manage and homogenise the data that is created. In this chapter, literature regarding the use of DTs in filling this need will be reviewed.

DTs of airports could help represent the state and processes of the physical airport, which would aid in the managing and overseeing of processes, and with the consumption of contextual information in multiple scenarios and applications (Conde et al., 2022). Using the DT in harmony with AI and ML (Machine Learning) methods to learn and perform adaptive control help manage the airport and take full advantage of the technology.

Saifutdinov et al. (2020) propose that DTs and ML can be combined in three ways. Firstly, the DT can be used to create training data for machine learning models. Secondly, the DT can be used to analyse the performance of ML models in novel scenarios. Lastly, the DT can be considered to be a learning environment for reinforcement learning agents.
The same study also discusses possible DT applications in the context of airport operations. The first would be to use the DT for passive observing purposes. In this monitoring mode the user could observe the movement of vehicles in 2D or 3D animation. Another possible application would be in recognizing critical situations. In this critical situations recognition mode, the program alerts the user when critical situations occur. In this model, the user would have to generate control commands purely heuristically.

Saifutdinov et al. (2020) go on to outline what these critical situations could typically be. The first situation that the DT could identify and alert of would be in regards to congestion and the accumulation of vehicles. As the speed, location and length of each vehicle is known, it is possible to identify situations where vehicles are moving slowly or even idling thus bringing insight into the level of congestion.

The next situation which could be recognised is a dangerously close proximity between vehicles and/or obstacles. Controlling the distance between vehicles and objects is of special value to aircraft, as collisions can lead to extremely negative and costly consequences. To avoid these, the researchers suggest forming an area around the vehicle that should not be entered by another. This control area would be visualized in the DT to help managers understand the amount of space different vehicles need, as seen in Figure 5 below.

![Figure 5: Control areas of moving objects in DT (Saifutdinov et al., 2020)](image-url)
The third situation the DT could recognize according to the study would be regarding the dangerous exceeding of speed limits. These situations could be e.g. that an aircraft does not slow down enough for corners or when approaching a parking spot. This could be due to human error or break failure. In these situations where a collision is imminent, the trajectory of one or more vehicles/aircraft should be changed urgently and new routes for all affected vehicles should be recalculated.

In addition to the aforementioned modes, Saifutdinov et al. (2020) recognize the potential of DTs being used as a learning tool. They propose that the risks of injury and property damage from training in the real world can be mitigated by practicing in dynamic virtual environments. This would have additional benefits as well, such as avoiding legislative issues and being able to run simulated environments in parallel, leading to an accelerated learning process.

Another study conducted in 2020 explored the idea of developing a DT for airport management. They found multiple reasons for adopting a Digital Twin. The first was to create a data-based model of processes and assets. This would pave the way towards more advanced techniques to find ways to improve performance and anticipate and prevent equipment failures. This would enable users to capture data from old technology which is still in use to find patterns and tendencies from it. (Cruz, 2020)

Secondly, Cruz (2020) found that using a DT would help in allocating scarce investments. The DT could be used to gain insight about large groups of key assets in complex systems to help use funds as efficiently as possible. DTs could also aid in decision making regarding whether to invest in upgrading existing assets or purchasing brand new assets. Using extensive graphics and dashboards with accurate and real-time data also helps reduce the total cost of assets by managing, making changes and obtaining accurate returns. This helps boost asset performance and return on investment (ROI).

Thirdly, the study proposed using a DT to perform predictive and condition-based maintenance, which would boost performance in the long term by reducing unscheduled downtime, improving safety and reliability while lowering costs. A DT with anomaly detection can help spot problems far earlier, which allows the airport to act preventatively rather than solely reactively. This proactive, insightful and data-based approach would also allow the prevention of some problems altogether.
This change in mindset towards a continuously developing business strategy that uses digital technologies as the main accelerators and facilitators that utilizing a DT brings is one of the key findings of the research done by Cruz (2020). The study proposes that it is necessary, for the benefit of business, the economy, the public good and the environment, that the aviation industry is able to break down information silos to obtain the right information at the right time.

An article published in 2022 discusses using a DT in managing information in turnaround event operations in commercial airports (Conde et al., 2022). Turnaround operations are defined as the set of activities conducted to prepare an aircraft that has arrived for the following scheduled departure of the same aircraft. These turnaround operations include all activities regarding the exchange of crew, passengers and cargo, baggage handling and catering services, both inbound and outbound (Makhloof et al., 2014).

Turnaround operations are a critical task for the functioning of airports, and having inefficiencies in them can cause a snowball effect on other functions. Just a 20% reduction in available personnel for turnaround operations has been found to cause nearly 50% of scheduled flights to depart late (Postorino et al., 2020). As these events require the coordination of many different actors, digitalizing these processes and communications between the different actors can help reduce delays in commercial flights (Conde et al., 2022).

Wong et al. (2021) suggest using a DT to assist in air cargo loading operations. Currently, cargo loading operations face many issues, such as dynamic loading considerations, which include the segregation of inherent lithium batteries and dangerous goods, which create a need for and boost the importance of loading optimization and real-time visualization. Additionally, planning for loading unit load devices (ULD) often happens just a few hours before flight departure. This leads to the planning and selection of cargo being executed based on merely feasibility considerations, rather than aiming for an optimized load.

Also, the size and shape of cargo is often misjudged, which affects its fitting and entry into the aircraft. Using a virtual reality (VR), IoT, real time sensor, and optimization simulation utilizing DT can aid in mitigating these issues by bridging the gap between
physical and digital operations. This in turn would help minimize loading time while improving safety and profitability (Wong et al., 2021).

3.3 Challenges in DT implementations

As the digital transformation of the aviation field is not fully mature yet, it is important to understand possible challenges of implementing a DT. Such new and developing technology must be understood thoroughly as they may require large investments to implement. Most of the literature reviewed in this thesis discuss the challenges of DT implementations at airports either in brief or not at all, thus leaving room for further research on this matter.

One of the biggest barriers to the implementation of DTs at airports is the capability of adopting it by airport operators (Conde et al., 2022). Security and reliability are two of the most important qualities in aviation, and they must be met by any new proposed solutions. This is also one of the main reasons why modernization initiatives, such as SWIM and SESAR, are long and difficult and why often data still travels via outdated methods at airports.

Xiong & Wang (2022) also raise the concern that a DT increases the control difficulty and risk of the digital process twin. They claim that if adequate attention is not paid and research isn't completed on improving the robustness of DT systems and reducing the uncertainty factors in the twin process, property losses and endangerment of life and safety may occur.

The other big challenge outlined by Conde et al. (2022) is the need for a comprehensive and correct sensorization of airports. Their whole concept is reliant on this as well as on the availability of services and APIs to acquire data on aircraft locations and turnaround operations.

Keskin et al. (2022) also discuss the possible challenges of implementing a DT at an airport. An airport is a highly dynamic and asset-intensive ecosystem, which leads to it including a large number of complex supply chain networks. This creates unique challenges in exchanging information and integrating and customizing digital solutions in a large network of stakeholders while still retaining user-friendliness and efficiency (Keskin et al., 2022). Also, many of these stakeholders may be unable or unwilling to
adapt to these new changes. Cruz (2020) finds that a big challenge in adopting a DT in an airport ecosystem will be the cultural change needed.

A case study on implementing a data-driven operation model for traffic at the Dallas Fort Worth International Airport (Lunacek et al., 2021) also raises the concern of adapting complex transportation networks, such as those at airports, to technology trends that are evolving rapidly. They note that inadequate planning and/or execution can lead to significant problems, such as increased costs, system inefficiencies and energy consumption.

3.4 Discussion about the literature

When going over the existing literature regarding the usage of DTs in optimizing airport operations, many similarities can be found. All of the literature discussed find the usage of DTs to bring benefits in the applications they discuss. The articles found advantages such as higher efficiency, lower costs, higher ROI on assets, improved safety, etc. Most of the articles stressed the urgency of adopting new digital technologies to combat rising passenger numbers. The articles were also very theoretical. Most of the research which included case studies did not go as far as to actually implementing a fully working digital twin, but rather used simulation models. This raises a few questions.

For instance, as some of the articles and cases utilize simulations rather than real data, they may not be accurately representative of real-life. For instance biases, bad data or erroneous assumptions may have been present. Also, the articles did not address the costs of implementing and operating a DT, thus there is still a lot of room to research the profitability of an airport digital twin. Furthermore, it would be interesting to learn more about the negative trade-offs of using a DT compared to traditional airport management methods. This would help in gaining a complete picture about the viability of the digital twin solution for airport operation optimization.

Many of the articles focused mainly on the technical aspects of the DTs, and the chapters describing their possible use cases were somewhat hollow. For example, in the study conducted by Saifutdinov et al (2020), the different applications are explained only in brief, with many questions remaining to the reader about their functionality. In many of
the critical situations that their DT can recognize, it remains unclear if the DT can predict them happening, or simply recognize them as they happen.

Either way, the DT would still be a big help to e.g. ground controllers. Even if the application only alerts the controller to a critical situation that is happening, they can still work to mitigate its effects. At large airports, distances can be substantial, such as at Denver International, where the control tower is over 5 kilometres away from the farthest taxiway. In such cases, it can be difficult to keep up situational awareness.

3.5 Findings

Overall, based on the existing literature, it would seem that in theory the usage of DTs in optimizing and managing airport operations could be a beneficial solution for companies. Combining the added visibility and technology, such AI and ML, that come with the DT solution bring more efficiency and resilience to airport operations. The system would allow airport operators to better visualize airport processes and pain points while being able to leverage the technology to avoid disruptions to minimize delays and cancellations.

The different studies discussed in this thesis observed different airport processes and functions, and benefits of implementing a DT were found in many business aspects. More optimized operations could help airports facilitate growing passenger numbers while boosting safety and ROI of assets all the while minimizing energy consumption and the need for maintenance. These findings can offer airports major benefits but the challenges of implementing a DT need to be noted. For example the cost, security, reliability and possible disadvantages of DT implementations at airports need to be researched further to better understand if the benefits of DTs outweigh the challenges and limitations.

3.6 Case study - Nordcloud

3.6.1 Overview

Nordcloud, an IBM Company is a European leader in cloud implementation, application development, managed services and training. They are triple certified and were positioned in Gartner’s Magic Quadrant for Public Cloud Infrastructure Professional and
Managed Services, Worldwide. IBM utilize Nordcloud for their hybrid cloud consulting capability.

According to a report by Everest Group (Mittal et al., 2022), IBM was named a leader in their Digital Twin Services PEAK Matrix® Assessment, receiving high marks for both their impact created in the market as well as their vision and capability do deliver services successfully.

3.6.2 Interview with Cormac Walsh

The interview with Cormac Walsh, the aviation industry head at Nordcloud, an IBM company, was conducted via Google Meet on the 23rd of November, 2022. Mr. Walsh currently works on providing digital transformation and cloud solutions for the aviation industry. The purpose of the interview was to uncover new possible benefits and challenges of an airport DT.

According to Mr. Walsh, an airport digital twin is an excellent concept. He sees airports as a fulfilment centre for a product, with the product being getting people onboard airplanes. As such, the airport ecosystem is a prime candidate for utilizing the DT technology, as DTs are currently used to optimize complex fulfilment centre operations (NVIDIA, 2022).

Mr. Walsh also states that the foremost adversary that airports have are delays, and DTs have great potential in helping mitigate them and their effects. The FAA has estimated that the total cost of delays in the U.S. in 2019 was $33.0 billion (Federal Aviation Administration, 2019). Airlines for America (A4A), an American trade association, calculated the direct aircraft operating cost per block minute based on data from the U.S. Department of Transportation. According to them, the effect on the total direct operating costs is $80.52 per block minute (Airlines for America, 2022). This figure does not include indirect costs faced by airlines and airports, such as reputational damage, customer satisfaction decreases and rerouting costs, which can be significant.

One of the main ways that a DT can help in achieving reductions in delays at airports, according to Mr. Walsh, is the increased visibility into processes. Using the DT in conjunction with AI and ML can make information available to different actors faster than is currently available. It can also unlock new pieces of information altogether. For example, utilizing computer vision with existing gate cameras can give pilots or ground staff more information as to the progression of underwing operations. By squeezing out the small micro-delays that snowball rapidly into larger delays, this technology can help
expedite aircraft departures. This also has financial benefits, as those micro-delays have a direct monetary value, as discussed earlier.

Mr. Walsh addresses concerns regarding safety and reliability by stressing that the technology should be used alongside current practices, meaning that AI would not be the arbiter of decisions, it would rather aid in making the process more efficient without removing human oversight. This would in fact add an extra element of safety. Another way that a DT would help enhance safety at airports by helping optimize the safety protocols in place.

Another way in which DTs can be utilized by airports is to cut carbon emissions. DTs could be set up to by their implementers to reduce CO2 emissions by e.g. optimizing vehicle traffic to avoid unnecessary movement alongside the inherent CO2 decreases from optimized operations.

In Mr. Walsh’s experience, the biggest challenge that airport digital twins face is the sharing of data and coordination of collaboration. Airports are complex ecosystems, and getting everyone to collaborate on such a large project is very difficult and sometimes there are actors or companies that do not want to partake. However, in these situations, airports should not be discouraged. According to Mr. Walsh, you should always assume that there is a way around challenges and you can e.g. work around some actors not collaborating by leveraging new technologies, such as the aforementioned computer vision. You can also craft your use cases to avoid the usage of difficult or privileged data sources.

Another problem that DT implementations face at airports relates to the understanding of the scope of the project. Many people envision DTs as an all or nothing solution, with e.g. the twin encompassing the whole airport and all its operations. Mr. Walsh suggests that this is not an ideal outlook, and that prospective DT implementers should rather consider a snacking method. This means starting by deploying a DT at a smaller scale and then expanding. You could start by first building e.g. a DT of your security control area, using the twin to optimize your security check processes. From there, you can expand the twin to cover a larger portion of your processes, reducing the initial investment needed. You should start with the data sources you have, and then use the funds you save into implementing further. This also reflects the way that most companies are currently buying their DTs.

A few other things that airports looking to implement DTs should keep in mind include being technologically honest as to what you can do. You can never capture everything,
so the ambition needs to be sober and clear-eyed. Also, the culture prevalent at the airport is a very important factor, and Mr. Walsh suggests involving the end users as much as possible. The users should understand that they are an important part of the ecosystem and they should be made aware just how big of an impact their actions have.
4 Discussion and conclusions

The growing interest towards airport digital twins and the findings of studies indicate that DTs have potential to aid in answering the needs of different actors in the aviation field, their customers and governmental agencies. There exists a large amount of research completed on DTs in general, but the research on DTs in the context of airport operations remains fairly novel and limited. More research is needed to fully validate the concept of using a DT in airport operations. The goal of this thesis was to find answers to the following research questions on DTs and their usage in managing and optimizing airport operations via a literature review and a case study:

i. Can Digital Twins be used to help optimize airport operations?
ii. What are the benefits of implementing a Digital Twin at an airport?
iii. What types of challenges does the implementation of a Digital Twin pose to an airport?

These questions were addressed by completing a thorough review of existing literature on the topic and with a case study. The following section will assess and summarise the findings of this thesis while discussing possible topics for future research and practical implications.

4.1 Findings and their implications to practice

Existing literature on the topic was identified and reviewed to aid in answering the research questions. A case study was then conducted, where these findings were verified and new benefits and challenges were identified. Also, an approach to airport DT deployments, snacking, was introduced.

The background theory indicates that airports are facing challenges with rising passenger numbers and pressure to lower emissions while being presented with opportunities via emerging technologies. The literature and case study suggest that using current methods, inefficiencies occur in the processes due to e.g. lack of communication and visibility, and these inefficiencies can lead to very costly delays. With advances in technology and cultural climate, historical data siloes are being torn down and live data can and is being shared and consumed for more accurate analyses.
The reviewed literature suggests that applying the DT technology to optimize airport operations can be highly valuable, and that Digital Twins can be used to help optimize airport operations. The literature also found DTs to bring such benefits as increased visibility into processes, better information management and communication, predictive and proactive maintenance, turnaround operation optimization, predictive event and disaster recognition, asset management and mitigated risk of injury and property damage in training. (Cruz, 2020; Conde et al., 2022; Saifutdinov et al., 2020) Challenges relating to the implementation of DTs at airports were also identified. These concerns related to security and reliability, the retention of user-friendliness, the prevalent culture at airports, the need for large infrastructural investments and the consequences of lack of proper planning and execution. (Conde et al., 2022; Keskin et al., 2022; Cruz, 2020; Lunacek et al., 2021)

The case study completed in this thesis also provides new benefits of an airport DT, such as CO2 emission reductions, and offers recommendations to actors working in airport ecosystems on how to proceed with developing a DT. The snacking method alongside the suggestions on managing the scope of the project with sober ambition and involving the end users are a good starting point for any prospective DT implementer.

4.2 Implications to research

This thesis provides an early qualitative look into the benefits and challenges of implementing an airport digital twin. As research on the topic is very limited, this thesis will help form a basis on which further research can be built upon.

Ultimately, the findings of this thesis corroborate the findings of previous research done on the topic. The case study conducted confirms the suggested benefits of previous literature, while suggesting novel benefits not discussed before.

This thesis also introduces a new concept to airport DT implementations, the snacking model. Previous literature has suggested that large investments into infrastructure may be needed for DT implementations at airports. However this thesis suggests an approach of building a DT of an airport gradually, shaping the use cases to match the digital maturity of the airport.
4.3 Limitations and future research

As the reviewed literature indicates, the DT shows great potential in helping airports handle rising passenger numbers in the future by optimizing their operations. However, the topic is very new and the number of research done on the topic is still quite low. This means that more studies, especially empirical ones, need to be conducted to understand the topic fully. For instance, more studies with real-life cases are needed to obtain a more accurate and well-rounded framework.

This thesis was carried out as a literature review and a case study, but without any practical or empirical analysis. Thus no profitability or financial analysis was conducted on airport DTs, as the costs are difficult to estimate, and the existing literature did not contain financial information regarding DT implementations. Real-life business cases would be a valuable topic to research in the future so that financial and performance data can be analysed, thus offering a deeper understanding of the feasibility of DTs in optimizing airport operations.
References


