Conceptualising airport digital maturity and dimensions of technological and organisational transformation

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Abstract
As airports undergo digital transformation, ie a paradigmatic shift in the way digital technologies are adopted and used, there is a need for actionable insights to ensure that airport digital maturity is achieved. Using an integrative review of literature, this paper develops an airport digital maturity model, focusing mainly on a passenger experience perspective. The paper then delineates two dimensions of digital transformation — technological and organisational. Subsequently, an airport digital transformation model is conceptualised to identify key factors that airports need to consider when transforming their business and interesting lines of enquiry for future research. Insights offered by the model are relevant to both practitioners and researchers interested in conducting future studies in this area.

Keywords
airports, maturity models, digital transformation, technology, organisation

INTRODUCTION
Modern society has been formed by three industrial revolutions: (1) the age of mechanical production, (2) the age of science and mass production and (3) the digital revolution. A fourth industrial revolution — the age of cyber–physical systems — is currently underway. It is commonly referred to as Industry 4.0 (or Airport 4.0 when mentioned in the context of airports). It builds on technologies developed during the digital revolution

but also uses smart systems to monitor, visualise and respond to digital processes in real-time, and as part of a wider ecosystem that connects all stakeholders. This is made possible by technologies and concepts associated with automation and data exchange such as the internet of things (IoT), Big Data analytics, cloud computing, cognitive computing (eg artificial intelligence and signal processing), additive manufacturing, blockchain, cybersecurity, virtual modelling and simulation, augmented reality and systems integration.

Digital transformation seeks to integrate technologies associated with Industry 4.0 into all areas of the business to fundamentally change how it operates and delivers value. It is therefore a process based on continuous improvement with the ultimate goal being to reach digital maturity — a point when smart systems are fully deployed and integrated. This level of transformation, however, does not happen by accident and rarely occurs organically. Instead, digital transformation is often seen as a journey that needs a strategic roadmap[1] and requires strong investment across the organisation, especially from a technology point of view. The disruptive potential of digital transformation also extends beyond merely implementing technology to address specific functional processes at an airport. Ultimately, it describes a paradigmatic shift in the way digital technologies are adopted and used, and from a strategic standpoint at an organisational level. How airports address organisational challenges associated with transforming their business will therefore go some way to determining their success in reaching digital maturity.

In terms of current literature, the concept of airport digital transformation is covered extensively in grey literature, with a range of publications by industry associations and management consultancy firms.[2–9] In addition, there are a growing number of academic papers that are focused on digitalisation, often regarding initiatives with specific technologies such as airport information systems,[10] augmented and virtual reality,[11] biometric systems,[12–15] digital channels,[16–23] people tracking,[24,25] queue prediction[26] and self-service technologies.[27–31] Airport digital transformation has, however, barely received any attention in the academic literature. One exception is Zaharia and Pietreanu[32] who examine challenges in airport digital transformation. As a result, there has been little attempt at developing key concepts and setting an agenda for future research on the subject, which is the main motivation for this paper.

Using an integrative review of literature, this paper applies the concept of maturity models to digital transformation at airports. The aim is two-fold: (1) to define key stages associated with airport digital maturity and (2) to identify key factors associated with airport digital transformation. In particular, two dimensions of digital transformation are delineated — technological and organisational readiness, and potential lines of enquiry for future research are identified. It is hoped that this paper will spur new academic research in what should be an area of growing interest and importance.

In terms of structure, this paper begins by providing background on the role of digital technologies at airports including benefits and challenges associated with investing in technology. Maturity models are then introduced, and key stages associated with airport digital maturity are defined in an integrated airport digital maturity model. Using the passenger journey as an example,

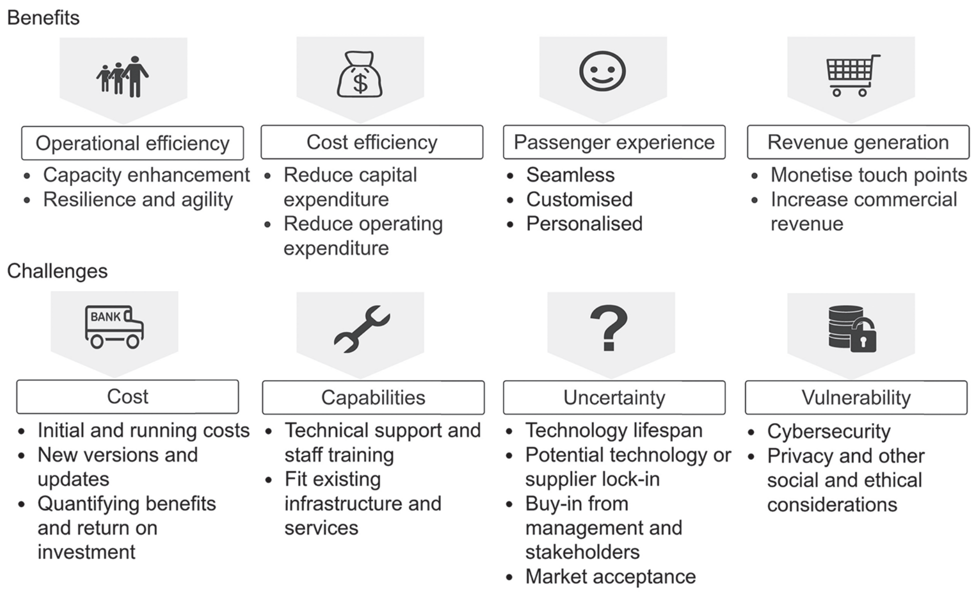

Figure 1 Benefits and challenges of investing in technology at airports
Source: Authors, based on reviewed literature.

the paper considers technological transformation required to reach maturity, including the importance of data. The paper also considers organisational transformation. Based on the topics discussed in this paper, an airport digital transformation model (ADTM) is presented to illustrate key factors that airports need to consider when digitally transforming their business. The model also provides a conceptual framework for researchers interested in conducting future studies in this area. The final section provides concluding remarks.

THE ROLE OF DIGITAL TECHNOLOGIES AT AIRPORTS

Airports invested approximately US$10bn on technology, in 2018, and have strong investment plans for Industry 4.0 technology, such as business intelligence (89 per cent of airports have plans to invest in this by 2022), biometrics for identity management (85 per cent), interactive navigation (77 per cent) and artificial intelligence (67 per cent, with focus areas being on predictive analytics and virtual agents and chatbots).[33] Expenditure on technology continues to grow. The US$10bn invested in 2018 is up from US$7bn in 2016, and technology spend as a proportion of total revenue at airports has more than doubled from 2.7 per cent in 2008 to 6.1 per cent in 2018.[34,35] The figures are based on a survey of senior IT (information technology) executives at airports worldwide. The 2018 figures are based on 101 respondents that represent 264 airports and 36 per cent of global passenger traffic. Weighting is then used to ensure that the sample is representative of airports worldwide. There is no comparison of investment by airport size or country, but it is likely to be the larger airports in more developed economies that invest most.

There are many reasons why airports are investing in technology (Figure 1). Based on interviews with about 15 major airports worldwide, Pell and Blondel[36] find the main reasons are to improve operational efficiency (by making better use of capacity and enhancing operational resilience and agility) and cost efficiency (by reducing capital expenditure requirements and operating expenditure). This reflects the fact that many major airports face capacity constraints and subsequent problems relating to delays, overcrowding and pressure on service levels in an industry that is capital intensive and increasingly competitive. The industry expects future growth. It is estimated that 8.8 billion passengers travelled through airports worldwide in 2018.[37] A compound annual growth rate of 3.5 per cent is forecast for the 2017–2040 period.[38] Such growth will create further challenges relating to capacity at many airports and further emphasise the need to invest in technologies that improve operational and cost efficiency of both landside and airside environments. For instance, investment in virtual modelling and simulation tools might enable airports to reduce capacity constraints in the terminal by better allocating resources and optimising passenger flows during peak times.[39]

Digital transformation is not only about creating value through efficiency gains. It is also about improving customer service by redesigning the customer experience and rethinking the purchasing process, and finding new sources of revenue. Gathering and analysing customer data allow businesses to know their clients better and help personalise their experience with the objective of creating value by reinforcing together the service and the core business of the organisation. For airports, simultaneously enhancing the passenger experience and generating additional revenue have become paramount, as passengers have high levels of technology adoption, and increasingly demand and expect digital interactions at all stages of their journey.[40,41] In addition, satisfaction rates with key airport processes are higher among passengers who use technologies vs those who do not.[42] This is important from a service quality perspective but also because studies suggest that happier passengers spend more.[43]

Despite the potential benefits, there are also many challenges associated with investing in technology (Figure 1). It can be costly to implement, and there may also be high running costs once implemented. It can be difficult to keep up with new versions and updates, which could potentially create system-level vulnerabilities, and there may be a need for additional technical support or staff training, especially if there are knowledge limitations of the workforce. As an example of the potential costs involved in staff training alone, Changi Airport Group (CAG) committed US$7.2m over two years, in 2019, to upskill 2,000 staff in adaptive, technological and technical skills needed to prepare for the digital transformation of the group.[44]

Ideally, new technologies should fit into existing infrastructure and services to keep costs down, especially early on before they can be scaled up with dedicated infrastructure and services. It may, however, be difficult to fit new initiatives into existing infrastructure and services. Technologies change rapidly so there is a great deal of uncertainty regarding their life span. There are also potential lock-in and risk effects, for instance, of being tied-in to a specific technology or supplier, which may be enhanced by the expected rapid change in technology — this is not necessarily a new phenomenon as technology lock-in has been described in the past (eg see Arthur[45]). Any new initiatives will need to receive support from senior managers but also from stakeholders including industry partners, such as airlines, border control, security and ground handlers and other stakeholders like investors, who may themselves have limitations. Airports will need to quantify potential benefits and returns on investment in order to get industry partners and other stakeholders to buy-in to any new technologies, which can be difficult, especially for new technologies that have not been trialled much before in an airport setting. There will of course also need to be acceptance of the market of new technologies. Increasingly, the implementation of new technologies is also challenged by concerns regarding data privacy and other ethical considerations. Despite the challenges, airports continue to respond to the increasingly digital world, and there is a growing interest in the digital transformation of airports with the ultimate goal being to reach digital maturity.

AIRPORT DIGITAL MATURITY

Extant maturity models

Maturity models are well established in management science. They can help to review current approaches and identify areas for improvement, benchmark against competitors, identify good practice from more advanced adopters, set targets and develop strategies for improving capabilities (eg by assessing resource needs and deployment) and create a roadmap of future improvements.[46] Indeed, the digital strategy roadmap drives digital maturity.[47] Models typically identify a series of levels that are passed as certain capabilities are reached. For instance, Nolan[48,49] presents some of the earliest models consisting of stages that an organisation can go through when planning, organising and controlling activities associated with managing computer resources and data processing within organisations.

One of the earliest conceptualisations of maturity models in management science was by Crosby.[50] His quality management maturity grid (QMMG) allows organisations to assess how mature their service or product quality-management processes are and how well those processes are embedded in the culture of the organisation. Crosby's work was popularised by the capability maturity model (CMM) that was developed by Carnegie Mellon University to improve software development processes and therefore also followed on from the computer resources and data processing models of Nolan.[51,52] See also Röglinger et al.[53] for an in-depth review of maturity model literature relating to business process management.

It is worth noting that there are several challenges associated with the use of maturity models. For instance, Mullaly[54] criticises their linear assumption that progression is sequential and results in improved performance. Also, that stages are characterised by practices based largely on anecdotal observations of what one would expect to see in a more mature company. This may be conceptually reasonable but not necessarily conducted rigorously.

Maturity models have been included in several airport digital transformation studies. For instance, Nau and Benoit[55] identify what they call four waves of digitisation at airports: Airport 1.0 where all processes are done manually; Airport 2.0 where some processes are automated for cost reduction; Airport 3.0 where automated processes are fully deployed and Airport 4.0 where airport systems are fully integrated within the airport ecosystem. Similarly, Pell and Blondel's[56] model identifies four stages: Airport 1.0, characterised by manual and analogic processes; Airport 2.0, characterised by the implementation of self-service thanks to the automation of some key flow processing tasks; Airport 3.0, characterised by several focused initiatives to leverage digitalisation and Airport 4.0, characterised by airports that are fully connected with all key stakeholders. Mohamed[57] applies a four-stage model to Kuala Lumpur International Airport (KLIA) that is similar to those of Nau and Benoit[58] and Pell and Blondel.[59] He states that KLIA has digitalised many key processes as part of their Airport 3.0 journey, for instance, by introducing self-service check-in and bag drop and digital wayfinding via their mobile application. The airport is now embarking on its Airport 4.0 journey to enable a fully integrated digital ecosystem that offers passengers a more seamless travel experience.

Although they do not refer specifically to digital maturity, ACI[60,61] describe three levels of a digital airport: (1) digitally enabled — the airport has the basics in order such as infrastructure and cyber-resilience to be able to become a digital airport in order to reach customers; (2) fully digital — the airport has implemented all the options that create a fully digital airport based on mainstream and commonly available technologies and (3) next-generation digital — the airport has implemented advanced digital concepts that are not commonly available and tested in the aviation industry such as seamless travel with single-token biometric touchpoints, new business models based on digital services such as blockchain, and personal and context-aware services for passengers.

An integrated airport digital maturity model

To provide a holistic perspective, this section presents an integrated airport digital maturity model (ADMM) that draws upon extant maturity models mentioned in the previous section. It consists of four levels (Figure 2). Airport 1.0 is the lowest level of digital maturity. In fact, it can be argued that Airport 1.0 is not at all digital. Key processes may, however, be supported by computers, for instance, at check-in and boarding, although it is likely that manual intervention is still required by staff. The ability to reach passengers (ie to communicate with specific individuals) is limited. There are likely to be delays in the time taken to use any electronic data that is collected.

Airports that have progressed to Airport 2.0 have begun to digitise by replacing key manual and analogue processes with automated and digital processes. This is supported by the initial deployment of self-service facilities and automated gates (ie at check-in and bag drop, security, passport control and departure gates), with the main focus being to reduce costs. There may also be an initial deployment of technologies that seek to enhance the passenger experience, for instance, with digital channels and free one-click wi-fi that provide several opportunities to reach the passenger. Electronic data may be captured and used retrospectively to inform decision-making, and there may also be several open data initiatives (eg using APIs [application programming interfaces]) to share data with key stakeholders.

Airports that have progressed to Airport 3.0 have begun to digitalise key processes. This involves using digital technologies to add value to existing processes. Self-service and automation are fully deployed, and all touchpoints are digitally enabled by a full range of mainstream technologies. The airport can now easily reach the passenger, for

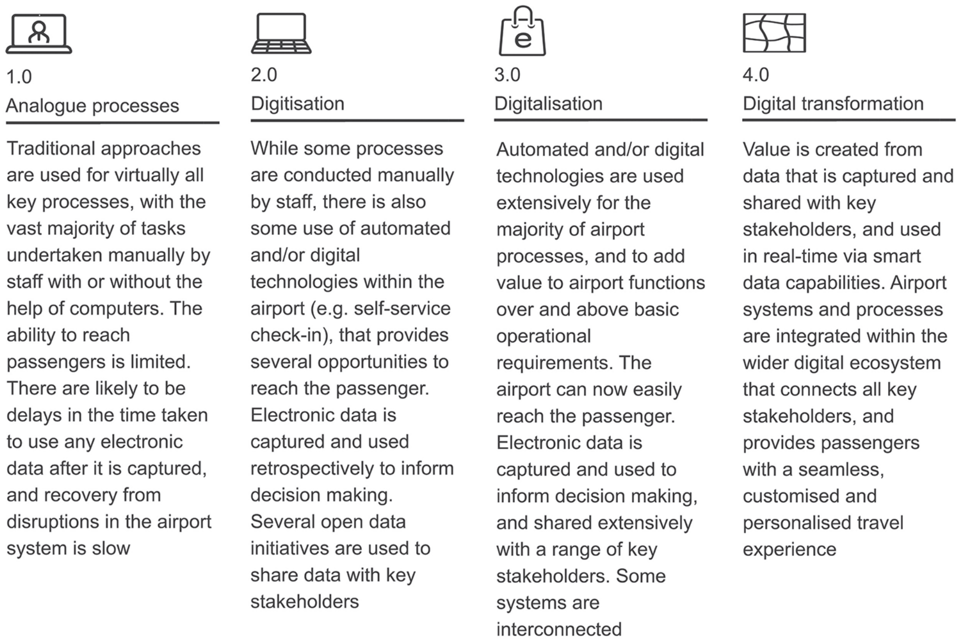

Figure 2 An integrated airport digital maturity model (ADMM)
Source: Authors, based on reviewed literature.

instance, via social media, a dedicated airport mobile application and/or a registered passenger profile or customer relationship management database. Data that is captured is used to inform decision-making, and there is extensive use of open data initiatives to share data with key stakeholders. There is still a focus on reducing costs but also on improving operational efficiency and the passenger experience (eg with location-based services and an omnichannel content strategy). There is also a focus on revenue generation (eg using the airport's own e-commerce platform).

Moving on to Airport 4.0 involves digital transformation. A paradigmatic shift in the way digital technologies are adopted and used. Value is created from data that is captured and shared with a range of key stakeholders in real-time using smart data capabilities. Airport systems and processes are integrated within the wider digital ecosystem that connects key stakeholders. Biometric touchpoints provide passengers with a seamless travel experience. The passenger is easily reached, and the airport is able to deliver customised notifications to passengers, along with personalised and context aware offerings. A range of Industry 4.0 technologies are used. The next section further explicates the concept of airport digital transformation.

AIRPORT DIGITAL TRANSFORMATION

Consistent with Vial's[62] definition of digital transformation, this paper considers digital transformation as a continuous improvement that triggers significant changes through the adoption and application of digital technologies. Therefore, rather than being static, digital transformation is a dynamic process that embodies both technological and organisational

Table 1 Example technologies deployed at different stages of the passenger journey

Stage	*Airport 1.0*	*Airport 2.0*	*Airport 3.0*	*Airport 4.0*
Airport car parking	Prebook by phone or book and pay on arrival or departure	Book online and pay on arrival or departure	Book and pay online	Book online and pay automatically via license plate recognition
Check-in	With staff at a check-in desk	Online or via a dedicated self-service check-in kiosk	Online or via a common-use self-service check-in kiosk	Register biometric and travel details at check-in or before arriving at the airport
Bag tag and drop	With staff at a check-in desk	Print the tag at a self-service check-in kiosk and deliver the bag to a staffed bag drop	Self-service bag tag and drop	Permanent digital bag tag with journey tracking via a mobile application
Security	Metal detectors and pat downs	X-ray scanners	Full body and computed tomography (CT) scanners	Biometric walk through (eg using highly sensitive infra-red cameras and facial recognition) without the need to remove items
Departure gate	Paper boarding pass checked by staff	Electronic boarding pass checked by staff	Self-scanned electronic boarding pass	Biometric single-token travel
Commercial	Information and services accessed physically at the airport	Digital information available about services at the airport	e-Commerce opportunities (eg pre-order car parking, click and collect retail)	Personalised / context-aware offerings
Information and wayfinding at the airport	Brochures, analogue signage and staffed information desks	Digital channels and digital signage	Digital self-service information and location-based services	Augmented and virtual reality experiences and personalised notifications
Contact the airport	Phone or post	E-mail or online feedback form	Messaging application or live chat service	Artificial intelligence (eg chatbot)

Source: Authors.

transformations, as explained in the following sections.

Technological transformation

Airport digital transformation is exemplified by the adoption of technologies that offer a vast range of opportunities for airports, industry partners and other stakeholders to innovate across the passenger journey. As an example of the role played by technologies at each stage of maturity, consider technologies used for several mandatory and optional touch-points during the passenger journey (Table 1).

There are a rapidly growing number of example Airport 4.0 initiatives. For instance, as of 2019, all 23,000 parking spaces at Oslo Gardermoen Airport are managed using an Autopay system, where cameras read the license plate of cars when entering and exiting the car park. Users have a selection of payment options — the easiest being to create an online profile with a credit card to drive in and out seamlessly.[63] At Lyon-Saint-Exupéry Airport, self-driving robot valets were launched in 2019. Drivers park in a hangar where the vehicle's details are scanned. A robot then slides a platform under the vehicle to lift it up and park it. The system optimises space utilisation by parking 50 per cent more cars into the same area due to precision parking and the ability to keep a record of when drivers will return — meaning it can park cars three or four deep.[64] In 2019, semi-autonomous and fully autonomous wheelchairs were trialled at Amsterdam Schiphol Airport, Tokyo Haneda Airport, Abu Dhabi Airport, Dallas/Fort Worth International Airport and Winnipeg Richardson International Airport for travellers with restricted mobility. The wheelchairs navigate or are self-driven around the terminal. Upon completion of the journey, the wheelchairs return autonomously to a docking station.[65]

Many airports have introduced or are trialling biometrics at one or more airport check point — the idea being to use facial recognition (or recognition via other personal features) to identify passengers and simplify their journey with a document-free experience. Hamad International Airport began testing several biometric projects under its Smart Airport programme in 2019, for instance, at check-in, bag drop, on entering security screening and at border control. The airport plans to create a single biometric system to manage the entire airport journey.[66]

Digital bag tags have been attracting attention in recent years. A company called BagID introduced a device that was used for the first time on a domestic flight in Norway in 2018.[67] The digital tag is attached to the passengers baggage and can be updated from an application on their mobile device each time they travel. They can then track their baggage throughout its journey. Additional features include the ability to report mishandled or lost baggage, activate an alarm in the case of theft and send notifications when the baggage is available for collection, and from which carousel.

In terms of context-aware offerings, many airports have launched their own dedicated and branded mobile applications,[68] and the number of features offered by them continues to grow. For instance, Miami International Airport's mobile application offers: mobile-based passport control; the ability to search or scan a boarding pass for information; notifications and updates for flight, gate and baggage carousel, and an option to share flight information; navigation maps that use blue dot beacon technology for added detail and accuracy; visual directions with walk times to find facilities and services; location-awareness to predict passenger location and anticipate their needs; geo-fencing to recognise and welcome passengers (eg when arriving at the airport); a customisable personal profile; weather information and real-time flight information and tracking; a 'near me' feature that provides the closest dining and shopping options. Forthcoming options will include push notifications for special offers from airport retailers, the ability to reserve parking and updated security wait times. In addition to mobile applications, airports increasingly seek to transform the ways they communicate with passengers, for instance, via chatbots on Facebook Messenger (introduced by Gatwick Airport[69]) or other applications.

A growing number of airports are experimenting with robots or intelligent machines. In 2016, Glasgow Airport introduced GLAdys — a robot that sang and danced to entertain passengers.[70] Also in 2016, Geneva Airport tested a robot called Leo that greeted passengers on the curbside as they arrived for their flights. They could then use Leo's touchscreen to scan their boarding pass, print their bag tag and receive gate information before Leo autonomously transports their baggage to the bag drop.[71] Incheon International Airport's second-generation robot called Airstar was introduced, in 2018, with improved

Table 2 Types of sensors used at airports

Category	*Examples*
Proximity	Parking space sensors, radio-frequency identification (RFID) smart baggage tracking, asset or workforce tracking, passenger tracking via beacons, Bluetooth, near field communications (NFC) or wi-fi
Pressure	Sensors for smart energy monitoring, building maintenance, waste management
Optical	Cameras or other sensors for biometrics, security screening, flow or throughput management or monitoring equipment such as kiosks and bag drop stations
Motion	Access control sensors for intrusion detection, video surveillance, automatic doors or barriers

Source: Authors, based on reviewed literature.

self-driving and voice recognition, speaking four languages and having the ability to express 14 different emotions. It can provide a range of passenger information and services including personalised information and escort travel after scanning passenger boarding passes.[72]

In the future, it may be common for passengers to check-in and access pre-trip information by having a two-way conversation with an artificial intelligence-powered Airport Assistant accessed via mobile or smart home devices. For getting to the airport, passengers may use automated (driverless and autonomous) transport systems. Instead of biometric identification, passengers may use body-embedded identification. For baggage, items may be collected and delivered to passenger homes by drones or robots. There may be ambient security scans on arrival at the airport instead of needing to go through security screening. When shopping, passengers may encounter robotic shop assistants, acceptance of virtual currencies (eg Bitcoin), personalised retail and nutrition options for food and drink based on passenger profiles, experimental food centres (eg with 3D printed food) and the 3D printing of goods. There may also be intelligent data mining to pre-empt passenger mood and behaviour at the airport. While some of these innovations may seem far off, the rapid pace of change and technology adoption in the sector mean that initiatives such as these may be closer to be being realised than one might think.

Despite the many opportunities for technological innovation, it should be recognised that technologies alone cannot create significant value; this happens only when there is an overall cohesive architecture — a smart airport, which is the key premise of Airport 4.0. Zmud et al.[73] refers to this as the Connected Airport, based largely on the concept of IoT. IoT can be defined as a system where a network of digitally connected physical objects (eg mobile devices of passengers or staff, baggage, cargo, aircraft or equipment such as vehicles, elevators, people movers, heating systems) generate digital information via sensors, such as those listed in Table 2. Information from sensors can then be communicated across the network to help aid decision-making.

In Zmud et al.,[74] IoT is regarded as the technology architecture for a digital airport future. It is based on five key stages of the information value loop (eg Holdowsky et al.[75]): (1) physical objects; (2) instrumentation, which is the sensor or smart component; (3) connectivity via a network that allows the digital interaction between objects; (4) aggregator that gathers and stores data, taking into account any standards and legal/regulatory or social and ethical requirements — collects related items of content and displays them or links to them and (5) analytics that provide actionable information from the data generated in order to improve performance.

Therefore, although based on the concept of IoT, the information value loop is dependent on a full range of Industry 4.0 technologies. For instance, data is collected from sensors and may be stored in the cloud using cloud technologies or some kind of unified digital platform. Here, Big Data analytics can be leveraged to drive Airport 4.0 initiatives, while artificial intelligence or machine learning can help to transform data into information that provides insights and allows for decisions and actions to be taken. The data also allows for modelling and simulation to be carried out (eg using Digital Twin technologies). There are a range of potential uses for Industry 4.0 technologies that often fall under clusters of solutions (Blondel et al.[76]). For instance, for passengers, key clusters include flow monitoring and management, process automation and customer engagement. Other solutions include intelligent building management (eg for energy management, preventative maintenance and asset management), predictive solutions (eg for the automated management of airport resources) and collaborative decision-making for air and ground operations (eg for operations management and total airport management). Regardless of which cluster is being addressed, digital transformation relies on the ability to use information in (near) real-time, and this typically requires integrating information feeds with key stakeholders.

Each stakeholder has their own responsibilities and priorities and is often inclined to protect their own information. There are also common goals that can, however, enhance the overall functioning and performance of an airport and subsequently enhance the passenger experience. Sharing data has therefore become one of the most important tools for digital transformation, and relies on having an effective stakeholder communication, coordination and engagement framework.[77] Increasingly, there are cybersecurity and ethical issues to take into account (eg regarding personal data privacy).

When considering data exchange, there needs to be a clear understanding of who the key stakeholders are (eg airport, airline, passenger, retailer, border control agency, security, ground handler) and what challenges they face.[78] For instance, most stakeholders need to achieve minimum service level agreements and seek to reduce operational costs, airports may additionally seek to increase non-aeronautical revenue while passengers may seek to find deals in retail. Each stakeholder then has certain data requirements. This includes data that they require themselves but also data that can be shared or come from shared sources. As an example, an airport may require passenger information in order to process them at each checkpoint. The airport may then access and share information with other stakeholders on the status and location of the passenger in the terminal, and status updates regarding terminal operations (eg in terms of any disruptions). Passengers may require travel updates (including live flight status), assistance with wayfinding and navigation and details of any retail offers, vouchers or competitions. They may then share information about themselves or their location in the terminal with the airport.

According to ACI Europe,[79] benefits of such data exchange include: passenger satisfaction increases because rather than being bounced between different stakeholders, services are more seamless; it might result in a reduction in the number of complaints, and a reduction in extra costs for airports and airlines because of less need for extra counters/desks, staff and overtime payments. Also, staff are likely to be under less pressure, and airports and airlines may be able to prevent and avoid poor service instead of working on service recovery because there will hopefully be less service failures. There might be greater revenue generation because a satisfied passenger spends more money (up to 45 per cent more than an unhappy passenger). It may also mean that staff are more free to provide assistance to those that need it, while those that do not need it can be in more control of their own journey.

Capturing and then leveraging useful passenger information are key to an Airport 4.0 philosophy. This information can be generated at different stages of the passenger journey. While currently this information may reside with different stakeholders in the value chain, sharing of this data in a secure, controlled and anonymous way is generally seen as being vital to addressing some of the challenges in the passenger journey.

Malaysia Airports Holdings Bhd (MAHB) allocated US$7.2m to their Airports 4.0 programme in 2018, and this provides a good example of how the Airport 4.0 philosophy, from a technological perspective, can be implemented in practice. According to Mohamed[80] (see also Huzaini[81]), MAHB's digital framework encompasses infrastructure enhancement, capacity development and digital innovation with aims to improve terminal optimisation, operational efficiency, revenue generation, regulatory compliance and the customer experience. Their framework comprises several main components including IoT, intelligent enterprise, cyber and information security, Big Data analytics and artificial intelligence, along with a unified digital platform that acts as a lifeline for the programme. With the main components in place, MAHB is focused on launching initiatives for solution clusters such as flow monitoring and management, process automation and customer engagement, for instance, with the introduction of single-token identity and the airport mobile application, MYairports. One of the most important initiatives for MAHB is to integrate data feeds with stakeholders to be able to provide real-time information about airport services and facilities, and allow airport systems and processes to be integrated within the wider airport digital ecosystem.

Organisational transformation

Digital transformation is as much about transforming the business as it is about transforming the way that technologies are adopted and used. Furthermore, although digital technologies offer opportunities for enhancing efficiency and customer experience, their full potential cannot be realised if organisational practices are flawed and people lack the right mindset.[82] This means that, in addition to the airport's adoption and use of emerging Industry 4.0 technologies, there are likely to be important organisational factors that affect the ability of an airport to transform. It is therefore important to understand the factors that determine or inhibit progression to Airport 4.0, and to establish effective monitoring and self-assessment procedures with regard to organisational readiness for digital transformation.

Pell and Blondel[83] identify four critical success factors for effective airport digital transformation. First, strategic clarity, which involves setting a clear yet concise digital strategy that is closely aligned to the airport's overall strategic priorities. It includes effective channelling of digital demand (ideas or requests) that may come from various stakeholders, to achieve a coherent overall approach. It involves having a clear view of who the ultimate target is for the digital strategy (eg passengers and/or airlines). It also involves having visible leadership support for the digital transformation agenda. The importance of strategy is supported by Kane et al.,[84] who state that 'strategy, not technology, drives digital transformation' (p. 1).

Secondly, there is a need for effective partnering and collaboration. This includes the ability to forge collaborative relationships across multiple interfaces including interairport collaboration (to take advantage of trickle-down proven solutions from more advanced to less advanced airports in terms of digital adoption). Partnering can accelerate the process of learning about new technologies, identify process-specific applications for the technologies and better manage implementation risks and costs.

Thirdly, there is a need for a digital mindset and culture. This includes the ability to identify, prioritise and implement solutions that are most relevant to the particular context of the airport (ie depending on if it is a large or small airport, or on the main type of traffic served). There should be a digital mindset with dynamic decision-making processes. There should also be trust between key airport stakeholder groups, and a move from department-driven initiatives to a more holistic approach because digital transformation touches all aspects of the organisation.[85]

Fourthly, there is a need for digital skills and resources. Airports should conduct a gap analysis to compare current skills and resources to those that are needed to meet the digital requirements of the future. This is because digital transformation requires strengthening the core and building for the future at the same time.[86] Airports need to understand key digital technologies and plan to develop internal capabilities in parallel to partnering with external service providers. Airports need to be able to clearly articulate how digital transformation can bring value to daily roles by focusing on simple and usable solutions that build trust. Business and operational readiness for change must be accompanied by required skills and resources to make the transformation a success.

The example of CAG's commitment to upskill its workforce was mentioned earlier in this paper and provides a good example of developing internal capabilities needed for digital transformation. The group's programme provides staff with adaptive, technological and technical skills that are likely to be needed for tasks and jobs created by digital transformation of the group, for instance, with training on employee readiness to embrace new technologies, and competencies with data, robotic process automation, programming and user interface/user experience (UI/UX) design. The importance of the programme is emphasised by the group's CEO, Lee Seow Hiang, who is quoted as saying: 'Digital transformation demands that workers today are upskilled to accelerate change and meet the challenges of tomorrow. With this investment in digital-focused training, we hope to establish a relevant, ready and resilient workforce'.[87]

At a cost of US$7.2m, CAG's programme shows that investing in people can be costly. Investing in people can also be a complex and long-term commitment (eg in terms of recruitment, training and retention of the correct skills). The organisational readiness that provides for digital transformation is likely to outweigh the effectiveness of alternative short-term responses to disruption such as cutting costs, streamlining supply chains or rebranding, especially when investments in people are closely aligned to the strategic objectives of the organisation.[88]

Similarly to Pell and Blondel[89], ACI[90,91] identify the need to engage airport leadership, identify and anticipate requirements, articulate strategy to engage and gain support from stakeholders, establish business cases that can be clearly communicated (especially regarding the benefits and added value of digital transformation — business cases supported by facts are of growing importance and can determine the success of the adoption processs[92]), join forces with industry partners and other stakeholders in the value chain, identify key digital talents to acquire and train while valuing and retaining existing internal resources with both business and digital competencies, develop an organisation-wide digital culture that promotes speed, risk-taking and experimentation, and a viable innovation governance that promotes, recognises and values internal ideas and initiatives for innovation.

In order to further encourage innovation, a growing number of airports have established innovation labs (sometimes called hubs, accelerators or incubators), for instance, Changi Airport Living Lab, San Diego International Airport Innovation Lab, ADP's Innovation Hub and Munich Airport's LabCampus. There is no standard format to the labs. They tend to, however, be in-house or collaboration efforts involving entrepreneurs, local businesses, research institutions, or other private or public sector organisations. The main objective tends to be to experiment with new technologies for different solution clusters. While the focus tends to be on technologies, the greatest impact that they have may well be on organisational transformation because they can create a culture for innovation, enhance organisational capabilities and encourage collaboration. They may also reinforce clarity if aligned closely with the strategic objectives of the airport. Despite the apparent benefits, the failure rate of such labs (not necessarily airport ones, but labs in general) is high.[93] There are likely to be several reasons for this. Ahuja[94] suggests it can be due to a lack of alignment with the business (and uncertainty over their purpose), lack of metrics to track success (especially regarding their financial return on investment) and lack of balance on the team (eg in terms of leadership, knowledge and skills). More research is therefore needed on how to develop successful labs including the measurement and evaluation of their value and effectiveness.

Further supporting the categories of organisational transformation in previous studies, Boutin et al.[95] suggest that there are five rules to follow for effective airport digital transformation: see the big picture (establish clear strategic goals), build and follow a business case (support each digital initiative with a business case), overinvest in buy-in (to build support for transformation from relevant stakeholders), be open to innovation that is not invented (and partner with technology and other companies that are introducing innovation) and invest in people, not just technology (to have the skills needed to succeed). There are therefore common

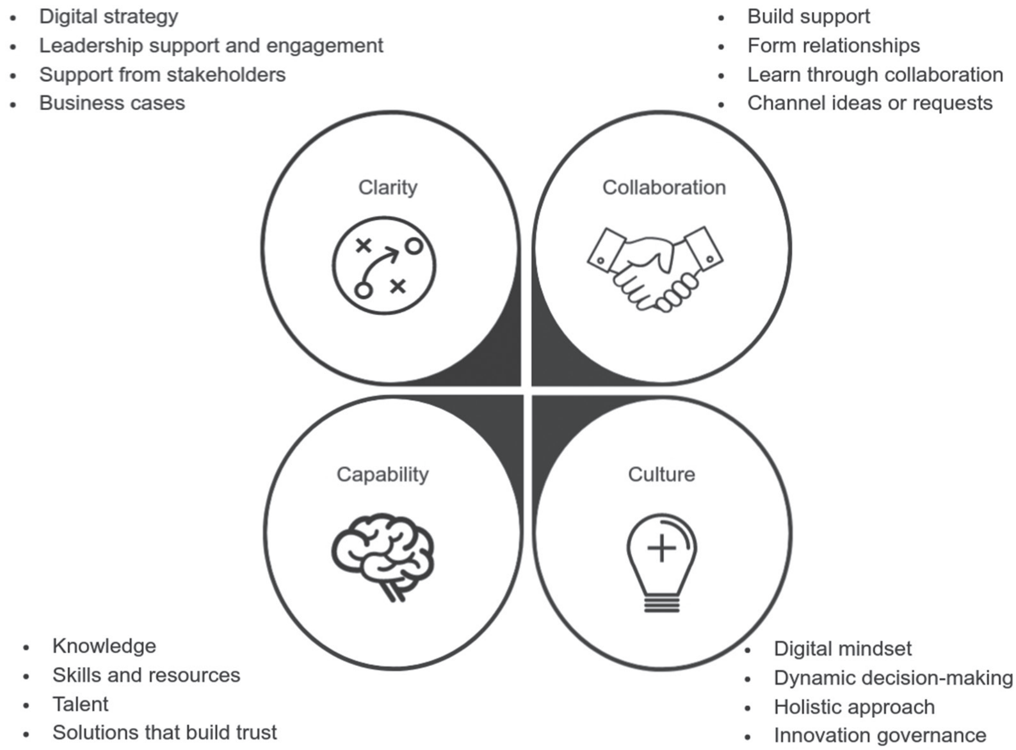

Figure 3 Organisational readiness for digital transformation
Source: Authors, based on reviewed literature with main categories adapted from Pell and Blondel.[96]

themes from the literature that can be grouped under four categories (Figure 3): clarity (incorporating strategy, leadership and business cases), collaboration (incorporating investment in building support, and forming and learning from collaborative relationships), culture (incorporating relevant solutions and a digital, dynamic, holistic and innovative approach), and capability (incorporating digital know-how, skills and resources, and solutions that build trust).

Airport digital transformation model and lines of enquiry for future research

Based on the topics discussed in this paper, an ADTM is conceptualised (Figure 4). The model includes a definition for airport digital maturity. It then identifies key factors that airports need to consider when transforming their business.

The ADTM suggests that airport digital transformation is reliant on organisational readiness, and this presents interesting opportunities for future research. For instance, survey items can be developed and used by researchers for each category (clarity, collaboration, capability and culture) to assess and benchmark the organisational readiness of airports. They can also be used by airport managers to assess the readiness of their own airport, and to identify areas in need of improvement. Additionally, they potentially represent latent factors whose structural relationship with other organisational and technological variables and outcomes such as the airport's level of digital maturity can be investigated.

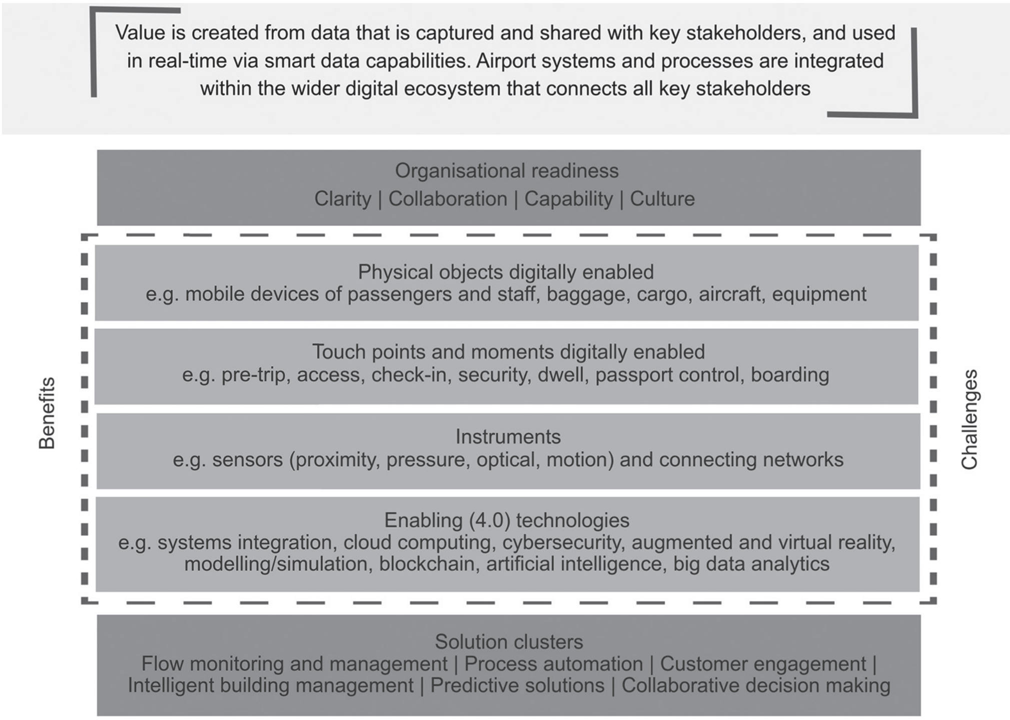

Figure 4 Airport digital transformation model (ADTM)
Source: Authors, based on reviewed literature.

The ADTM then considers technological transformation (surrounded by the dashed line in Figure 4). Based on the concept of IoT, it can be used to assess the way in which digital technologies are connected to people and processes within the airport system. Smart data capabilities play a pivotal role here because in order to create value, airports must capture and share data with key stakeholders, which requires an integration of systems and processes in the wider airport ecosystem. Through APIs, airports are able to connect their business processes, services, content and data with those of stakeholders in an easy and secure way. Interesting lines of enquiry for researchers or airports seeking to assess levels of airport digital maturity in this area are the extent to which people and physical objects and touch points and moments are digitally enabled (by people, we mean to what extent they carry and use devices that are digitally enabled); the extent to which different types of sensors are used; the extent to which data from sensors is analysed and used to inform real-time decision-making; the extent to which data from sensors is shared in real-time with stakeholders such as airlines, ground handlers, security and passport control and the extent to which airport systems and processes are integrated with those of key stakeholders. Data is at the heart of digital transformation, and more research is needed on issues associated with data, especially those related to the sharing of data between stakeholders. For instance, what are the interests that influence stakeholder decisions to protect or share data? As with organisational readiness, survey items on technological readiness can be developed and used by researchers or airport managers.

Enabling technologies, including those associated with Industry 4.0, can be used to securely store, analyse and act on data. Another interesting avenue for future research therefore is to explore which technologies airports are expected to focus on in the future, and how to exploit those technologies to address different solution clusters at airports. For instance, to what extent are airports likely to be focused on technologies, such as blockchain, biometrics, artificial intelligence or augmented and virtual reality, and what is the potential role that such technologies can play on the data-sharing ecosystem.

Taken together, different elements of the model in Figure 4 serve as the mechanism for becoming a transformed Airport 4.0. The model recognises that the adoption of technologies and organisational readiness presents both benefits and challenges. Transformation therefore requires careful alignment of technological and organisational transformation in order to fully leverage the benefits while addressing challenges associated with the transformation journey.

One aspect that is not covered so much in this paper, or in existing literature, is the potential adverse effects of digital transformation. For instance, on the standardisation or potential loss of jobs, reduced levels of human interaction and qualities such as personality, spirit and the ability to socialise, and concerns regarding data privacy. In addition, while there may be benefits of digital transformation from a passenger perspective, such as through customised notifications and personalised and context-aware offerings, airports also need to pay attention to the needs of passengers who are not familiar with or interested in using digital technologies. The number of people that fit into this category may be diminishing rapidly as we move towards a post-digital period whereby the use of digital technologies is second nature to airport passengers. This is, however, certainly not the case yet. Related to this, there may be equity issues associated with digital transformation at airports that do not appear to have been addressed in academic literature yet. Applying equity theory could be a useful way to determine the extent to which digital transformation is fair to both relational partners (in this case airports and their passengers), for instance, by comparing the ratio of costs and benefits of digital transformation for each partner.

CONCLUSION

Using an integrative review of literature, this paper applies the concept of maturity models to the digital transformation of airports. The paper considers the benefits and challenges associated with investing in technology. A conceptual framework — the ADMM is developed. This indentifies how airport digital maturity ranges from the mere replacement of analogue processes through to the more progressive and innovative adoption of digital technologies for adding value to specific processes. Ultimately, the industry is undergoing a progressive digital transformation, a paradigmatic shift in the way digital technologies are adopted and used but also in terms of how airports address organisational challenges associated with transforming their business. Following this, an ADTM is presented to illustrate key concepts discussed in the paper and help highlight possible lines of enquiry for future research.

In terms of technological transformation, this paper recognises the role that the concept of IoT plays on the digital transformation of airports. This involves using instruments (eg sensors) to generate data from digitally enabled objects at a range of mandatory and optional touchpoints or moments. Industry 4.0 technologies are then used to securely store, analyse and act on data for a range of solutions. As defined in the ADMM, value is created from data that is captured and shared with key stakeholders, and used in real-time. Sharing data therefore plays a key role in the digital transformation of airports, and several challenges and opportunities associated with data exchange are considered in this paper.

This paper recognises that digital transformation is as much about transforming the business as it is about transforming the way that technologies are adopted and used. Therefore, organisational transformation is also considered. Literature tends to recognise several main themes: clarity of digital strategy, leadership and business cases; a propensity to invest in collaboration and to partner with, and learn from other actors in the value chain; an appropriate organisational culture that is digitally minded and dynamic, and takes a holistic and innovative approach; capabilities such as digital know-how, skills and resources, and solutions that build trust.

Definitions and concepts presented in this paper can be refined through interviews with airports and key stakeholders, and investigated empirically by future research — the main area of interest being to assess and benchmark levels of digital maturity at airports and the respective importance of technological and organisational readiness.

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