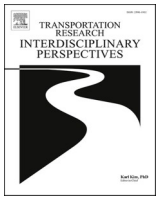
Transportation Research Interdisciplinary Perspectives 27 (2024) 101182



Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.sciencedirect.com/journal/transportation-research-interdisciplinary-perspectives



The impacts of shock events on airport management and operations: A systematic literature review

Yue Gu [a,*], Mirjam Wiedemann [b], Robert Freestone [c], Henrik Rothe [d], Nicholas Stevens [e]

[a] School of Engineering and Technology, Central Queensland University, Rockhampton 4701, Australia
[b] School of Aviation, The University of New South Wales, Sydney 2052, Australia
[c] School of Built Environment, The University of New South Wales, Sydney 2052, Australia
[d] Centre for Air Transport Management, School of Aerospace, Manufacturing and Transport, Cranfield University, Cranfield MK43 0AL, UK
[e] Centre for Human Factors and Sociotechnical System, School of Law and Society, University of the Sunshine Coast, Maroochydore 4556, Australia

ARTICLE INFO

Keywords:
Shock events
Airport planning
Airport operations
Resilience
Airport strategy
Airport business model

ABSTRACT

Unpredictable shock events have disruptive and long-lasting impacts on the aviation industry. However, the scale and type of impact of different shock events on airport operations and planning have been unevenly surveyed. A better understanding can help airports to improve their risk mitigation and develop more resilient operations and management. Through a systematic literature review of peer-reviewed research, we summarise shock events into four categories based on the cause of the shock: economic recessions, infectious disease pandemics, terrorist attacks, and natural disasters. The major impacts are identified as a reduction in air travel demand, interruptions in operations, modified operating procedures, and changes in facilities and infrastructure. We further bring these together into a conceptual typology of event-impact interactions. This longitudinal overview may assist airport managers in better understanding the impacts of shock events and taking further steps in developing more resilient airport infrastructure and associated business models.

1. Introduction

Since 2000 the aviation industry has been impacted by an unpredictable sequence of major events which have caused significant disruptions for airports including dramatic decline in operations and even closure. These events include the September 11 terrorist attacks, the global financial crisis of 2007–2009, periodic volcanic eruptions, and several infectious disease outbreaks such as COVID-19, SARS and Ebola. The impacts and consequences of these kinds of shock events are significant, potentially severe, and long-lasting. For instance, the pandemic of COVID-19 resulted in a passenger drop from 4.5 billion passengers in 2019 to 1.8 billion in 2020 (ICAO, 2021). The pandemic caused airlines alone an estimated loss of $180 billion USD from 2020 to 2022 (IATA, 2022).

Facing sharply fallen demand, airlines have often grounded their fleet to cut costs. On the other hand, airports must maintain their operations to facilitate essential movements for repatriation, disaster relief and air cargo, incurring substantial ongoing operating costs. These outgoings can make up almost 65 % of total airport costs and are incurred regardless of traffic levels (Twinn et al., 2020). The collapse of revenue and high fixed costs can cause significant financial problems for airports and, further, for the entities that own them (Forsyth et al., 2020). Many airports can struggle financially long-term, even after short-term upheavals (Njegovan, 2006).

Airlines generally possess the adaptive capacity to make changes to resourcing and schedules to remain resilient to changes brought by shocks and ultimately continue to grow (Oxley and Jain, 2015). Airports must consider ways to better adapt their operations and business models to prepare for and respond to potential external shocks in the future. At present, airport planning based on long-term trends, assuming gradual and incremental change, does not always consider the possibility of unpredictable exogenous events, although business diversification is a recognised risk mitigation strategy.

Various terms describe low-probability and high-impact events that can threaten an organization's profitability and existence, such as crises, disasters, disruptive events and shock events (Faulkner, 2001; Janić, 2015; Pearson and Clair, 1998). Prideaux, Laws, and Faulkner (2003) argued that shocks are unlikely to be anticipated. For this paper, the term "shock event" refers *to an external, sudden and unexpected event that may cause significant disruption in operations, further challenging an*

* Corresponding author.
E-mail address: y.gu@cqu.edu.au (Y. Gu).

https://doi.org/10.1016/j.trip.2024.101182
Received 8 November 2023; Received in revised form 25 March 2024; Accepted 30 July 2024
Available online 10 August 2024
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airport's viability and survival. These events are assumed to have profound and large-scale impacts on global air travel potentially.

From 2001 to 2020, global air passenger traffic increased at an average 2.45 % annual rate, while the world economy expanded at an average 2.92 % over the same period. The growth of global air passenger traffic, however, was subject to notable fluctuations, as shown in Fig. 1. Some unanticipated shocks contributed to these fluctuations, such as the combined 2000–2001 shock of the dot-com bust and 9/11 terrorist attacks and the 2008 global financial crisis.

Table 1 lists some of the major exogenous shocks that impacted global air transportation between 2000 and 2020. During this twenty-one-year period, negative growth of global annual air passenger traffic was experienced three times: in 2001, 2002, and 2020. The first two occasions coincided with a combined shock event of the dot-com bust and the 9/11 terrorist attacks in the US, which was the worst crisis in the aviation industry before COVID-19. The third negative growth in 2020 coincided with COVID-19. There were also other exogenous shocks in the years when growth was below or equal to the average growth rate for the whole period but not negative, namely: the second Gulf War and SARS in 2003, and the combined global financial crisis and H1N1 pandemic in 2008 and 2009.

Furthermore, some shocks that happened between 2000 and 2020 had a substantial impact on air traffic in particular regions or for a brief period, such as Iceland's Eyjafjallajökull Volcano Eruption in 2010, the Tohoku-Pacific Ocean Earthquake in 2011, the Middle East respiratory syndrome (MERS) Outbreak in 2012, H7N9 in 2013, and the Ebola outbreak in West Africa in 2014.

1.1. Shock events and airports

The implications of shock events for airports are different from those of the airline industry. Airports seemingly have much less adaptive capacity via their necessity to be locationally and geographically fixed in place. They are grounded to their urban settings, and this has resulted in their emergent and symbiotic reliance on surrounding regional and metropolitan catchments (Stevens et al., 2010). The risk profile of airports is different to that of the airline industry, and the ways in which adaptability and thus resilience can be planned for requires more specific investigation.

In recent years the airport industry has taken notice of the challenges associated with operational disruption via shock events. For example, the National Academies of Sciences, Engineering, and Medicine (2021) report on *Airport Collaborative Decision Making (ACDM) to Manage Adverse Conditions* identifies a continuum of disruptions to airports, including 'crisis' that would represent the global scale shock events of interest here. It acknowledges the benefits of ACDM as offering early warning and anticipation, operations resilience, predictability, and resource management benefits. Indeed, the notion of airport resilience to disruption and shock events – absorb, recover, and adapt – is an important focus of ongoing airport industry literature and risk profile investigation (Airport Cooperative Research Program (ACRP), 2021; ENAC Alumni, 2023; Environmental Science Associates (ESA), 2022).

Table 1
Shocks in global air passenger traffic from 2000 to 2020.

Year	Annual change (%)	Shock events
2001	−0.6 %	9/11 Attack & dot-com bust
2002	−1.81 %	9/11 Attack & dot-com bust
2003	2.45 %	9/11 Attack, SARS, and dot-com bust
2008	0 %	Global Financial Crisis
2009	1.81 %	Global Financial Crisis & H1N1 Pandemic
2020	−60.31 %	COVID-19 pandemic

Note: The data used for calculating the annual changes are from the World Bank (2023).

This study employs a systematic literature review to underpin a conceptual overview of shock events, impacts and responses to build a broader appreciation of what airports have done and can do to better withstand future disruptive shock events and improve business resilience. Scholarly research on the direct impacts of shock events on airports and their adaptive capacity to respond is surprisingly limited and furthermore our review addresses a research gap with few studies considering the types of impacts of shock events on airports.

Our key research question is thus: *What are the impacts of shock events on airports?* In the following section, we outline the review methodology employed. The results section presents key findings for the different types of shock events based on the cause of the shock and elaborates on their various impacts. We then present a typology of events and impacts, discuss their scale, and consider implications for airport resilience planning. The paper concludes with some ideas for future research.

2. Research methodology

A systematic literature review (SLR) of the scholarly literature was conducted to comprehensively search for peer-reviewed journal articles that focus on the impact of shock events on airports. The Scopus database was employed since it contains a larger and more comprehensive number of publications than other databases (Abduljabbar et al., 2022). The database was accessed from 28 February 2023 to 12 March 2024.

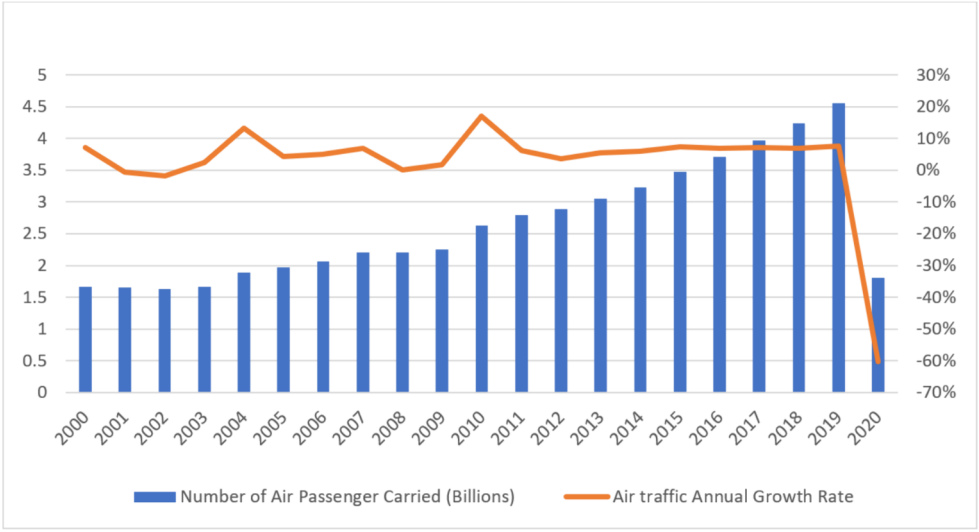


Fig. 1. Global annual passengers numbers and air traffic annual growth rate from 2000 to 2020 (Based on World Bank, 2023).

The SLR process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009), shown in Fig. 2.

Based on the definition of shock event in this study and the shocks that affected global air travel as discussed above, the search used 19 keywords: "airport" coupled with "shock", "disruptive", "crisis", "recession", economic crisis", "terrorism", "geopolitical", "military conflict", "pandemic", "covid", "corona", "SARS", "natural disaster", "cyclone", "hurricane", "volcano", "tsunami", "earthquake", and "flood". Despite no substantial fluctuations in global air travel coinciding with natural disasters because of their limited duration, it was decided to include natural disasters as a shock event as natural disasters always have impacts on aviation. Natural disasters are, in fact, one of the most destructive shock events for airports, as noted below.

The abovementioned keywords appeared in the titles, keywords or abstracts of 4219 journal articles, conference papers and reviews published from 2001 to 2023 and written in English.

The first screening removed duplicates, most deriving from the search results of "airport" with "pandemic" and "airport" with "covid." to 2732. The second screening excluded articles that were clearly outside the focus of this study. These articles included one of the keywords, such as "airport", in the abstracts, but their content was not relevant to our review. In addition, studies that were purely scientific rather than policy-oriented, such as disease detection technologies, were excluded. This process resulted in 132 journal articles. By reading through these articles, 91 articles were further removed from the list as they mainly focused on the impacts of shocks on air travel or other aviation industry sectors instead of airports. A total of 41 core (SLR) articles that directly discussed the impacts of shock events on airports remained after the screening process.

To contextualise the impacts of shock events on airports, our discussion below also draws on studies outside of the SLR inclusion criteria (including studies eliminated in the final phase of screening) that acknowledge impacts of shock events on air traffic volumes, airlines, and the broader aviation industry, as well as some industry reports and other grey literature. The core contributions are summarised and categorised in Tables 2-5, as elaborated in the next section.

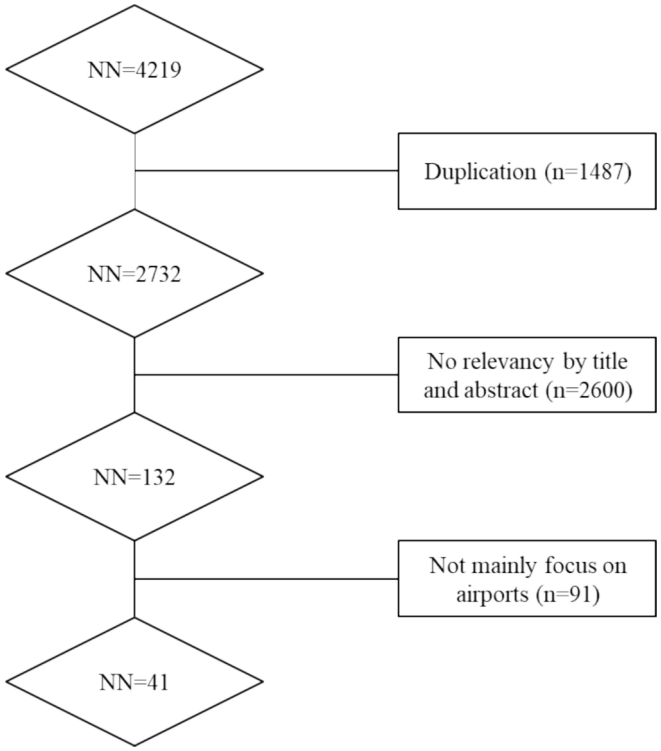


Fig. 2. Article selection process.

3. Literature on the impact of shock events on airports

While the general impact of shock events on air traffic has been acknowledged (e.g., Blalock et al., 2007; Reichardt et al., 2019; Rose et al., 2017), the analytical literature on direct impacts on airports is surprisingly sparse. As noted, the SLR identified 41 articles published between 2001 and 2023 of relevance. Based on the cause of the shock, all the external events that may cause significant disruption in operations and challenge an airport's viability and survival are summarised into four categories: Economic Recessions, Infectious Disease Pandemics, Terrorist Attacks, and Natural Disasters. The specific impacts of the four types of shocks are presented in this section. The scale of impacts and implications for airport resilience planning are discussed in the following section.

The body of published scholarly knowledge on this topic is modest perhaps because shock events can be widely perceived as "one-offs" rather than systemic threats. Most studies are of a theoretical nature or use a case study or recent examples to demonstrate impacts. While the COVID-19 shock event is more visible in the literature, the impacts of events of the last 20 years are less well covered. However, the COVID-19 pandemic has only reemphasised the need to understand the spectrum of shock events and their impacts for more resilient airport planning.

3.1. Economic recessions

Core articles on the impacts of economic downturns on airports identified in the systematic review are summarized in Table 2. The major effect of economic recessions on airports is the reduction in air travel demand and damage to airport revenue. The air transportation industry is a strongly cyclical business, fluctuating with the global economy. Negative growth of global air passenger traffic due to economic recession was experienced twice: in 2001–2002, coinciding with the dot-com bust, and in 2008 with the global financial crisis (Franke and John, 2011).

The dot-com bust in 2000 triggered an economic downturn which contracted air travel demand, while the 9/11 terrorist attacks exacerbated the impact of the economic downturn after a short cessation of all commercial aviation in US airspace by producing a fear of flying in the public with new restrictions being introduced globally. The global financial crisis in 2008–2009 was different. There were no additional factors that overlapped with the plummeting global economy (Franke and John, 2011). But not only did the number of air travellers decline, the total metric tonnage of air cargo also dropped by 3.7 % in 2008 and 7.9 % in 2009 (ACI, 2011).

During economic recessions, airlines cut flight capacity and eliminate non-profitable routes to reduce potential loss (ATA, 2010; Franke and John, 2011; Pearce, 2012). Airports are less able to flexibly change their operational costs (Forsyth et al., 2020; Serrano and Kazda, 2020).

Table 2
Core literature of impacts of economic recessions on airports.

Study	Major results	Geographical scope
Kim (2016)	The recession had a negative impact on demand and airport throughput performance.	United States
Martín et al. (2013)	Higher outsourcing levels decrease cost flexibility, while rising low-cost traffic increases airports' ability to control costs.	Worldwide
Ripoll-Zarraga et al. (2023)	The study analysed Spanish airports' efficiency from 2004 to 2013, highlighting changes in efficiency priorities before and after the economic crisis.	Spain
Voltes-Dorta and Pagliari (2012)	Airport efficiency dropped during the recession between 2007 and 2009.	Worldwide

Table 3
Core literature of impacts of infectious diseases pandemics on airports.

Study	Major results	Geographical scope
Alonso Tabares (2021)	Methods for infectious diseases detection at the airport are presented, including allocation of screening, facilitation requirements, and delegation of responsibilities.	Worldwide
Arora et al. (2021)	Operational, economic and environmental impacts are discussed from the global aviation industry perspective with a pandemic response matrix proposed.	Worldwide
Ayers and Crawley (2020)	The COVID-19 pandemic impacted airport staff, operations and the image of the airport.	Hartsfield-Jackson Atlanta International Airport, USA
Barczak (2021)	Polish airports faced a 70 % drop in passengers in 2020 due to the pandemic, with travel restrictions and revenue losses contributing significantly.	Poland
Choi (2021)	Business diversification, strategic non-aviation revenue enhancement and new business model strategies to mitigate risk are discussed.	Incheon International Airport, South Korea
Chung (2015)	A streamlined approach for improving pandemic control is proposed to maximise screening effectiveness and ensure airport efficiency	Worldwide
Colak et al. (2023)	The COVID-19 pandemic stimulated airports to introduce more flexibility into their cost base and diversify their revenue streams.	United Kingdom
Findley et al. (2021)	Airports located in areas with smaller populations recovered faster than those located in more populous areas.	United States
Forsyth et al. (2020)	Examines airport price responses during crises like COVID-19, emphasizing the importance of maintaining viability without resorting to price increases.	Worldwide
Gao (2022)	Investigates the travel demand recovery pattern for US airports with geographic location and hub status playing significant roles in speed of recovery.	United States
Gold et al. (2019)	Simulation experiments evaluated health screening strategies for air travellers during epidemics, recommending prioritizing exit screening and conducting cost-benefit analyses for additional screening resources.	Worldwide
Hassert et al. (2021)	Airports can invest in organizational growth to recover from the crisis and increase resilience for future shocks.	Worldwide
Hotle and Mumbower (2021)	Travel at large airports and airports in multi-airport cities decreased the greatest during the first year of the pandemic.	United States
Hou et al. (2021)	Need for governments to liberalise airport slot allocations to speed up airport traffic recovery.	China
Hovanec et al. (2023)	The COVID-19 pandemic led to major disruptions in airport operations, causing significant declines in passenger traffic and flight frequencies.	Slovakia
Kazda et al. (2022)	Post-pandemic challenges for airports include flight delays and operational disruptions due to a shortage of trained staff, particularly affecting ground handling and security.	Worldwide
Lopez-Valpuesta and Casas-Albala (2023)	The COVID-19 pandemic had a negative impact on passenger satisfaction.	Seville Airport, Spain
Okulicz and Rutkowska (2021)	The study suggests using the Airport Collaborative Decision-Making (ACDM) system to enhance efficiency and continuity during the suspension and resumption of air traffic.	Warsaw Chopin Airport, Poland
Rozenberg et al. (2022)	The Wien Group including Schwechat Airport faced challenges of significant passenger declines during the pandemic.	Vienna International Airport, Austria
Serrano and Kazda (2020)	Estimates the changes in future airport operations as airports seek alternative sources of non-passenger revenue.	Worldwide
Tidhar (2022)	Challenges and lessons learned for airport screening during the COVID-19 pandemic are reviewed.	Worldwide
Vogel (2020)	Privately owned airport operators were more negatively affected on bond financing during the COVID-19 pandemic.	Worldwide

The combination of the reduction in airport aeronautical revenues and the high fixed costs leads to an inevitably negative impact on airports' performance during economic recessions. Ripoll-Zarraga et al. (2023) found that small and medium sized airports in Spain suffered a more significant reduction in air traffic compared to large airports. In 2012, Voltes-Dorta and Pagliari identified numerous studies on cost and output efficiency of particular airports. They investigated the impact of the global financial crisis on 194 airports and found that cost efficiency dropped over-proportionally to the loss of revenue. Similar findings were also acknowledged in the studies of Martín et al. (2013) and Kim (2016). The airport industry is estimated to have lost approximately $3.5 billion USD worldwide from the global financial crisis (ACI, 2011).

3.2. *Infectious diseases and pandemics*

Since the start of the 21st century, several infectious diseases escalating into global epidemics or pandemics have shocked the international air transport sector. These events include the SARS outbreak in 2003, the outbreaks of avian influenza H5N1 in 2005 and 2013, the Swine influenza H1N1 pandemic in 2009, the African Ebola outbreak in 2014, the 2015 MERS outbreak in the Republic of Korea, as well as the Coronavirus disease (COVID-19) from 2019. These events resulted in a considerable reduction in air travel demand and changes in operating procedures but, at the same time, also required new infrastructure investments for airports. The articles which addressed the impact of infectious diseases pandemics on airports are listed in Table 3.

SARS, the most severe disease outbreak before COVID-19, hit the Asia-Pacific and North America markets with passenger traffic decreases of 22.0 % in April and 41.3 % in May of 2003. Despite returning to positive traffic growth late in the year, hub airports in the Asia-Pacific region experienced a devastating decline in passenger flow (IATA, 2020). The fear of SARS, coupled with travel restrictions, contributed to these significant losses. The 2005 and 2013 outbreaks of Avian Flu (H5N1) had a much "milder and short-lived impact" on air travel (IATA, 2020), although Avian Flu had an exceedingly high mortality rate of 64

Table 4
Core literature of impacts of terrorist attacks on airports.

Study	Major results	Geographical scope
Akhtar et al. (2010)	Discusses challenges in economic assessment of countermeasures against terrorist attacks, suggesting an inverse ex post analysis for evaluating implemented security measures at Norwegian air and seaports.	Norway
Blalock et al. (2007)	New baggage screening regulations were associated with a 6 % reduction in US air traveller volume and increased security screening costs.	United States
Blunk et al. (2006)	The US airline industry, despite its initial profitability in 2001, experienced a substantial and lasting decline in domestic air travel following the 9/11 terrorist attacks.	United States
Goodrich (2002)	The 9/11 attacks led to significant security measures affecting travel, tourism, and the economy, highlighting the importance of security in the tourism industry.	United States
Herbelles and Lawrence (2023)	Highlights the need for a risk-based approach and collaboration with stakeholders to enhance resilience and preparedness for future crises.	Worldwide
Ito and Lee (2005)	The 9/11 attacks led to a substantial and enduring decline in U.S. airline demand, unexplained by economic or seasonal factors.	United States
Rose et al. (2017)	New baggage screening regulations were associated with a reduction in air passenger volume.	United States
Stewart and Mueller (2014)	Discusses a risk and cost-benefit analysis of airport security measures, suggesting that current measures may be excessive and questioning the need for further enhancements.	Worldwide
Zatopek and Mandle (2002)	Outlines security measures implemented at U.S. airports, including planning considerations, changes in parking revenues, and experiences with curbside enforcement policies.	United States

Table 5
Core literature of impacts of natural disasters on airports.

Study	Major results	Geographical scope
Grogan and Vallerga (2000)	Analyses damage to Metropolitan Oakland International Airport's runway caused by liquefaction during the Loma Prieta earthquake.	Oakland Airport, USA
Herqutanto et al. (2022)	The 2018 Palu earthquake exposed the airport's limited disaster management capacity due to discontinued training and unclear management systems, impacting both airport operations and the local community.	Indonesia
Polater (2018)	Systematically analyses recent literature on airport disaster management for non-aviation events, identifying key research areas and gaps.	Worldwide
Saputra and Veronica (2017)	Proposes a comprehensive Airport Disaster Management Plan using lessons from the Mount Agung (Indonesia) eruption to enhance airport resilience.	Indonesia
Wibowo et al. (2021)	Analyses the impact of earthquakes on airline passenger traffic in West Nusa Tenggara Province, Indonesia, highlighting significant negative effects.	Indonesia
Yang et al. (2021)	Investigates earthquake risks and economic losses in airport transportation systems using HAZUS and FMEA models for assessment and mitigation.	China

%. A likely reason for the limited impact was the low transmissibility of the disease between humans (Chung, 2015). The 2015 outbreak of MERS only caused a 12 % decline in the air traffic flow in South Korea in the first month of the outbreak (IATA, 2020). Before COVID-19, the effects of recent epidemics or pandemics largely disappeared within six months (IATA, 2020).

The outbreak of COVID-19 brought the impact of infectious diseases to a level surpassing previous shock events. The pandemic caused a decline in air passenger travel of over 60 % in 2020 (ICAO, 2021). The sudden drop in air traffic was caused by the fear of flying and draconian travel restrictions, such as travel bans, border closures, and quarantine for arriving passengers (Lamb et al., 2020; Suau-Sanchez et al., 2020). Moreover, the lockdowns and other COVID-19 restrictions themselves undermined the global economy and further damaged air travel demand for business, family and leisure travel (Abate et al., 2020; Arora et al., 2021; Barczak, 2021; Hovanec et al., 2023; Oxford Analytica, 2020; Rozenberg et al., 2022; Shibata, 2021).

Outbreaks of infectious diseases have seen investments in new airport infrastructure and passenger protocols such as utilising touchless technologies and disinfecting and health screening equipment (Amankwah-Amoah, 2021; Alonso Tabares, 2021; Choi, 2021). Health screening takes different forms at airports to control the spread of infectious diseases. Temperature checks are common for determining passengers who are febrile. Antigen tests were widely used in airports for COVID-19. Some countries, such as China, required all international travellers to obtain a COVID-19 negative test certificate before arriving in the country (Warnock-Smith et al., 2021). After vaccination rates reached a certain level, a COVID-19 vaccination certificate was required for international travel in many countries. Changed procedures always convert to higher costs for airports and their users (Suau-Sanchez et al., 2020). As Gold et al. (2019) discussed, health screening instruments vary in cost implications, although this investment can increase airports' resilience and capability (Hassert et al., 2021). Normally, the instruments with low initial cost, such as ear thermometers, are inefficient, while those with higher initial cost, such as non-contact infrared thermal cameras, are more effective and less intrusive. The nowadays high volume of passengers requires more efficient equipment and procedures as otherwise the time taken for health screening can reduce the operating efficiency of airports as some airports experienced in 2003 during the SARS outbreak (Li et al., 2020; Tuchen et al., 2020).

During the COVID pandemic, airport staff were asked to work from home where feasible, switch to online rather than face-to-face meetings and, when working on-site, go through COVID-19 safety training, including wearing masks, having their temperature taken and adhering to social distancing rules as outlined by Ayers and Crawley (2020). The social distancing rule significantly changed operational procedures such as passenger boarding with implications for airport profitability. For instance, airports may have had to limit the number of passengers in their terminals and accordingly reconfigured layouts to comply with regulations (Dabachine et al., 2020; Okulicz and Rutkowska, 2021; Suau-Sanchez et al., 2020). The concessions at airports were also hit by drops in customer throughput, culminating in aggregate losses of non-aeronautical revenues for airports (Ayers and Crawley, 2020). Vogel (2020) highlights the increased capital costs for airports because of the increased risk profile during prolonged shock events. Post-pandemic, airports also face challenges from flight delays and operational disruptions due to a shortage of trained staff, particularly affecting ground handling and security (Kazda et al., 2022).

3.3. Terrorist attacks

The Global Terrorism Database produced by the University of Maryland recorded more than 200,000 terrorist attacks globally between 1970 and 2020. Of these, a total of 1,430 targeted airports and aircraft (The National, 2021). These are assaults on high-value facilities and equipment and are calculated to impact the economy adversely and

people's preparedness to fly (Rose et al., 2017). In the aftermath of terrorist attacks, the potential impacts on airports include a decline in air travel demand, changes in operating procedures, and unavoidable investments in new facilities and equipment. Table 4 lists the core papers for the impacts of terrorist attacks on airports identified in the SLR.

Terrorist attacks impact airports in diverse ways. Direct losses in deaths and injuries (both passengers and airport staff) and property damage including facilities, equipment, and infrastructure in airports are well known (Rose et al., 2017). Operating disruption from flight cancellations and airport shutdowns also results in losses for airport business. For example, the 9/11 terrorist attacks caused the US commercial aviation system to be shut down for two and a half days. Thousands of flights were cancelled, and all international flights were diverted to Canada and Mexico. As one of the targets of the Brussels bombings in 2016, the city's airport was shut down for more than one week. A profound negative effect on airports' economic performance is evident (Blunk et al., 2006). Air travel demand transitorily decreased by 30 % in the first four months after 9/11 in 2001 and experienced an ongoing decline of roughly 7.4 % to November 2003 (Ito and Lee, 2005). This reduction was attributed to potential air travellers choosing alternative transportation modes where possible, such as road or rail. Rose et al. (2017) found that the behavioural economic impacts of airport attacks was almost two orders of magnitude higher than immediate effects such as property damage and airport shutdown.

As Blalock et al. (2007) discuss, the 9/11 terrorist attacks fundamentally changed airport security procedures and facility requirements. Before, only 5 % of checked-in bags were screened in the US. Thereafter, the US Federal government established the Transportation Security Administration to take over security for commercial aviation. It required all checked bags to be screened for explosives, with airlines matching checked bags to their passenger lists (Goodrich, 2002; Zatopek and Mandle, 2002). By January 2004, more than 8,300 explosion detection systems (EDS) or explosion trace detection (ETD) machines were installed at US airports. After another failed bombing attempt in December 2001, passengers were asked to remove their shoes when passing through security checkpoints. The changes in airport security procedures require more input in money, time, and workforces. Blalock et al. (2007) and Rose et al. (2017) both reported that the new baggage screening regulations were associated with a 6 % reduction in US air passenger volume. Akhtar et al. (2010) estimated the annual cost of security measures for Norwegian airports at $165 million USD. Stewart and Mueller (2014) argued that the current measures may be excessive and questioning the need for further enhancements.

3.4. Natural disasters

Despite no substantial fluctuations in global air travel coinciding with natural disasters because of their limited duration in the last two decades, natural disasters always have impacts on aviation, including the airport industry (Polater, 2018). Natural disasters are, in fact, one of the most destructive shock events for airports since they can disrupt air travel immediately after happening and physically damage airport facilities (Herqutanto et al., 2022; Saputra and Veronica, 2017; Wibowo et al., 2021). Natural disasters do not necessarily cause lasting changes in airport operating procedures but may require considerable investment for replacing or repairing infrastructure (Saputra and Veronica, 2017). Table 5 lists the core articles on natural disaster impacts.

Earthquakes near airports threaten significant damage on infrastructure and facilities, and cause millions of dollars of direct loss (Grogan and Vallerga, 2000; Herqutanto et al., 2022; Yang et al., 2021). Earthquakes, sometimes coupled with tsunamis, can quickly destroy airport infrastructure. The Tohoku-Pacific Ocean Earthquake in 2011 devastated Sendai Airport near the coast of Miyagi Prefecture in Japan. The tsunami flooded the buildings and airside of the airport and damaged air-to-ground (A/G) and RADAR systems and aeronautical ground lights. The airport was taken out of service for one month and only fully recovered after 100 days (Yukinobu, 2011). Volcanic eruptions can impact airports in a broader region than earthquakes since atmospheric volcanic ash can spread over large distances and pose threats to aircraft engines. The 2010 eruption of Eyjafjallajökull in Iceland was a typical example of the impact of volcanic eruptions, with many European civil aviation authorities temporarily having to close their airspace. Thousands of flights at airports were cancelled worldwide, not only in Europe, and caused an estimated loss of £95.6 million pounds for airports over one week (Jamieson, 2010).

Other weather-related disasters, such as cyclones and hurricanes, can significantly disrupt airport operations (Rose, 2021). Hurricane Katrina in 2005, one of the deadliest natural disasters in the United States, caused $55 million USD in damages to facilities and $170,000 daily losses in revenues for Louis Armstrong New Orleans International Airport (The New Orleans Experience, 2005).

4. Discussion

This section provides a categorisation of the impacts of different types of shock events, considers the scale of impacts, and then discusses the implications for airport resilience and planning.

4.1. Types of impact of shock events on airports

Shocks have significant, sometimes profound, impacts on airports. The most direct impact is a considerable reduction in air passenger demand that hits airport revenue in terms of reduced income from airline and passenger charges. The other typical impacts include interruptions in operations, increased costs and/or reduction in efficiency, and changes in operating procedures and facility requirements. These impacts are not uniform in all airports, varying in nature, severity and duration. Surfacing from the literature review, the identified major shock events commonly affecting the operation and performance of airports can be categorized in four main ways:

1. *Reduction in air travel demand*: passengers' behavioural changes to shocks.
2. *Interruption in operations*: air traffic or airport shut down and possibly increased operating costs and reduction in efficiency.
3. *Changes in operating procedures*: the policy or regulation changes in response to new situations during or after shock events.
4. *Change in facilities and infrastructure*: provision or replacement of new facilities and changes in airport infrastructure to meet new regulations and operating environments.

Economic recessions have a prolonged effect on air travel demand. While they do not necessarily change airport operation procedures and facilities, they can culminate in delayed investment in infrastructure and decrease operational efficiency (Voltes-Dorta and Pagliari, 2012). In comparison, infectious diseases that result in epidemics or pandemics have a tremendous effect on airports in all four aspects. The severity of the impact of pandemics on air travel demand is highly related to the duration of a disease outbreak. When the active outbreak subsides, air travel demand generally rebounds quickly (IATA, 2020). Natural disasters can destructively disrupt airport operations and directly destroy facilities and infrastructure at airports. Compared to the other types of shock events, the impact of natural disasters is intense but short-lived unless the potential passengers' behaviour is changed due to damages to the local economy. While natural disasters usually do not cause operational changes, terrorist attacks may introduce new regulations that cause changes in operating procedures and new facility requirements (Zatopek and Mandle, 2002). Terrorist attacks can have a long-term effect on air travel demand due to the fear of flying caused by the attacks, and the potential for passengers to substitute other transport modes.

All four types of impacts of shock events translate into negative

effects on the economic performance of an airport. Table 6 brings together the typologies of major shock events with the types of impact of airports.

4.2. The scale of impacts

The scale of the impact of shock events depends on their severity, duration, and geographical scope. The severity of shock events is unpredictable and varies from case to case. For example, while COVID-19 largely shut down global air travel, the impact of the 2015 outbreak of MERS was mainly limited to South Korea (IATA, 2020). Jackson and Frelinger (2012) found that more than half of the terrorist attacks that targeted airports and aircraft did not cause fatality or injury. In comparison, 9/11 changed the course of the aviation industry.

The duration of shock events is another factor that can determine the scale of impacts and is related to induced behavioural changes. Economic recessions have a prolonged impact because it can take years for economies to fully recover. Oxley and Jain (2015) found that global air travel demand reached its pre-shock level only four years after both the dot-com bust in 2000 and the global financial crisis in 2008. However, based on previous experience, the fear of flying caused by infectious diseases reduces quickly after the outbreak is over (Lamb et al., 2020). As highlighted earlier, before COVID-19, the effects of recent epidemics or pandemics disappeared six months after the first outbreaks (IATA, 2020). There is a lack of data to conclude how long the impact of a terrorist attack can last. One possible hypothesis is that the duration of the impact of a terrorist attack may be correlated with the severity of the attack. Natural disasters are short-lived and intense, even though they may have a long-term impact on air travel demand due to their damage to the local economy, reduced tourist numbers and damage to air travel infrastructure.

In terms of geographical scope, economic recessions normally have a broad impact through disruptions to global economic connectivity. The effects of the other three types of shock events are more intense on airport operations but usually have geographical limitations (9/11 and COVID-19 are two exceptions), especially natural disasters. For example, the outbreak of SARS primarily affected air travel demand in Asia (IATA, 2020), and the Tohoku-Pacific Ocean Earthquake in 2011 primarily hit air travel in the Japanese realm (Yukinobu, 2011).

4.3. The implications for airport resilience and business model

Traditionally, airport resilience planning is regarded as a process by which an airport identifies and assesses the risk of extreme weather and climate change to help prioritise preparedness, mitigation, response, and recovery strategies (Baglin, 2012; Smith et al., 2015). However, airport resilience planning should not be limited to addressing such emergencies. Shock events have profound temporal impacts on air travel demand and airports' financial situations. In these cases, airport resilience relies upon non-aeronautical and other revenues and the airport's integration into the supportive infrastructure of local communities (Horton et al., 2022; Linkov et al., 2021).

As seen in this paper, the airport industry has experienced significant impacts from many more external shocks than extreme weather. COVID-19 is solid evidence with major implications and lessons evident. For example, airports needed to coordinate with airlines and authorities to adopt new health and safety routines to reduce interactions between people, apply advanced technologies to improve testing accuracy and efficiency, and rearrange terminals to ensure passengers had enough space to keep social distancing. The case for airports to increase their non-aeronautical revenues in a way that includes regional integration is strengthened to help survive major aviation downturns. To take this strategy even further, airports' business models are already changing. Diversified revenue streams balance not only losses from aviation in case of any shock events – but also conceptually reduce the dependency of airports on purely aviation revenues (Choi, 2021; Colak et al., 2023).

It is widely agreed that a steady increase in passenger numbers in the decade before COVID-19 hit, liberalisation, deregulation of air traffic, and airport privatisation are three key factors that have driven non-aeronautical revenues at airports (Chen et al., 2020). In the past, airports were mainly public entities, and therefore financial performance was a secondary concern (Gillen, 2011; Gillen and Mantin, 2014). In recent decades airports have been increasingly privatised or restructured as government trading enterprises and consequently must look more closely at financial bottom lines and financial sustainability. Maintenance of airport infrastructure and high capital investments driving the airport balance sheet on the costs side become more demanding during shock events. On the revenue side, the split between aeronautical revenues, such as landing and passenger fees, and non-aeronautical revenues from retail and property is brought into sharp relief (Nunez-Sanchez et al., 2020). The more non-aviation revenues contribute to airports' income, the less they will suffer from any of the four types of shock events assessed in this paper. In case of economic recessions and infectious disease pandemics, airports might compensate for losses from reduced air traffic by being a multi-modal transport and business hub of the region. Also, the effects of terrorist attacks and natural disasters can be better compensated by multi-purpose, multi-modality infrastructure. Consequently, non-aviation revenues at airports worldwide have grown significantly over the last two decades, with non-aviation revenues at major airports being more than 50 % of total revenues (D'Alfonso et al., 2017).

However, the analysis of shock events has shown that non-aeronautical revenues can also decline during a shock event. During the height of the COVID-19 pandemic, retail outlets in terminals on both airside and landside closed. Airports tried desperately to stimulate non-aviation revenues, often in novel ways, for example, by using airport parking areas as drive-in movie theatres (Einhorn and Whitley, 2020). While some highly diversified airports seemed to have done better during the COVID-19 crisis than airports with a traditional business model (Einhorn and Whitley, 2020; Lukin, 2021), airports globally struggled to stay afloat (Twinn et al., 2020). Out of the attempt to increase non-aviation revenues, new business models such as the Airport City and Aerotropolis have been popularised for airports involving building and managing city-like developments such as retail, residential, commercial, and leisure facilities at and around the airport (Freestone, 2011). The new models need to go through an evolutionary process from bi-polar business (aviation + non-aviation) towards multi-modal, multi-purpose businesses as to increase the level of resilience in cases of longer air traffic disruption to create genuinely resilient business models for the future (Wiedemann, 2021). Creating regionally integrated airports that embrace progressive urban development, capitalising on airport ground and air accessibility with a focus on increasing revenues through regional, if not international, economic cooperation and collaboration could go a long way in this respect. For example, the Sydney

Table 6
Types of impact of shock events on airports.

	Reduction in air travel demand	Interruptions in operations	Changes in operating procedures	Changes in facilities and infrastructure
Economic recessions	Tremendous and profound	Minor	None	None or delayed investment
Infectious diseases	Tremendous and profound	Intense	Yes	Yes
Terrorist attacks	Tremendous but short-lived	Destructive	Yes	Yes
Natural disasters	Possible, but short-lived	Destructive	None	Replacement

Aerotropolis development based around a second international airport exemplifies this approach (Australian and NSW Government, 2018).

5. Conclusion

Various shock events of the last two decades have cumulatively made significant impacts on the aviation industry, indicating the necessity for airports to adapt their operations and business models to prepare and respond to potential external shocks in the future. The systematic literature review helps fill a significant gap in knowledge in the broader area of impacts on shock events on airports. To answer what are the impacts of shock events, this study identified four types of events that have had noticeable effects on the global aviation industry over the last two decades, namely: economic recessions, infectious diseases pandemics, terrorist attacks, and natural disasters. Together they have, in turn, four typical impacts: reduction in air travel demand, interruption of operations, changes in operating procedures and changes in airport facilities and infrastructure. We bring these together into a conceptual typology of event-impact interactions (Table 6). All four types of effects contribute to the economic performance of airports within a specific spatial and operational structure. As a result – considering shock events appearing in alarming sequence every 4–5 years – it is necessary to think about resilience strategies to enhance revenues and reduce costs on an ongoing basis via technological adaption, comprehensive airport and regional risk planning and analyses, and exploration of new business models. Larger and long-range implications come into play.

Future airports are exposed to extreme challenges with the entire aviation industry striving for zero-carbon emissions by 2050 whilst at the same time satisfying an ever-more expansive technology-driven passenger experience. Substantial investment in physical infrastructure and coordination between stakeholders – including existing airport surface access systems and related terrestrial micro-transport networks and yet to be established and implemented Advanced Air Mobility (AAM) – is required. In this context shock events are not only a threat to airports causing loss of revenues, they can also support or even trigger disruption of old habits and silo thinking and accelerate the implementation of progressive changes. Simplified and integrated operational protocols can ultimately liberate the design of airport infrastructure from traditional constraints towards more efficiently used space and resources. For example, recent terminal design propositions indicate shifts towards smaller human-scale indoor and outdoor spaces, transforming the airport into a more resilient multifunctional urban environment. In this respect airports can accelerate the sustainability transformation of urban and transport infrastructure.

We acknowledge that our study has some limitations with the core review restricted to a single commercial database for scholarly research and selective search terms. However, after multiple rounds of adding more search terms, we found that findings of different papers were in essence identical especially considering that most papers in this field are of theoretical nature. Also, we defined a shock event as '*an external, sudden and unexpected event that may cause significant disruption in operations, further challenging an airport's viability and survival*'. Therefore, the ongoing disruptive threat to the aviation industry caused by climate change was not part of this investigation. However, it is clear that many so-called natural calamities can also be linked to global climate change. These limitations can be answered in future studies.

Also, there are many different types of airports, from large commercial complexes through to general aviation airports. The same type of shock events may have varied impacts on different types of airports. Future studies could expand on our findings by taking the type of airport into consideration. Future research might also explore resilience strategies, with an emphasis on innovation, sustainability and risk management approaches that ensure a holistic view of the enduring complexity of airport operations and planning. Such approaches have been explored in a range of complex and safety–critical domains, such as disaster management and urban development. Their use could add significant insight and value for a comprehensive airport business model review that is more resilient to shock events of the future and stimulates not only the business side of airports but contributes to the quality of life of the airport transient and local communities as a major driver for any airport development at times of no disruption.

CRediT authorship contribution statement

Yue Gu: Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Mirjam Wiedemann:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing. **Robert Freestone:** Conceptualization, Methodology, Validation, Writing – review & editing. **Henrik Rothe:** Validation, Writing – original draft, Writing – review & editing. **Nicholas Stevens:** Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Gu, Yue; Wiedemann, Mirjam; Freestone, Robert; Rothe, Henrik; Stevens, Nicholas

2024-09-01
Elsevier
https://doi.org/10.1016/j.trip.2024.101182
Gu Y, Wiedemann M, Freestone R, et al., (2024) The impacts of shock events on airport management and operations: a systematic literature review. Transportation Research Interdisciplinary Perspectives, Volume 27, September 2024, Article number 101182

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