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Full Research Papers should contain original research not previously published elsewhere. They should normally be between 4,000 and 7,000 words although shorter or lengthier articles could be considered for publication if they are of merit. The first page of the papers should contain the title and the authors' affiliations, contact details and brief vitae (of about 50 words). Regarding the following pages, papers should generally have the following structure: a) title, abstract (of about 150 words) and six keywords, b) introduction, c) literature review, d) theoretical and/or empirical contribution, e) summary and conclusions, f) acknowledgements, g) references and h) appendices. Tables, figures and illustrations should be included within the text (not at the end), bear a title and be numbered consecutively. Regarding the referencing style, standard academic format should be consistently followed. Examples are given below:

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- Forsyth P. (2002a), 'Privatization and Regulation of Australian and New Zealand Airports', *Journal of Air Transport Management*, 8, 19-28.
- Papatheodorou, A. (2008) The Impact of Civil Aviation Regimes on Leisure Market. In Graham, A., Papatheodorou, A. and Forsyth, P. (ed) *Aviation and Tourism: Implications for Leisure Travel*, Aldershot: Ashgate, 49-57.
- Skycontrol (2007) *easyJet welcomes European Commission's decision to limit PSO abuse in Italy*. 23rd April. Available from: http://www.skycontrol.net/airlines/easyjet-welcomes-european-commissions-decision-to-limit-pso-abuse-in-italy/ (accessed on 22/08/2008).

Industry Perspectives are usually shorter than full research papers and should provide a practitioner's point of view on contemporary developments in the air transport industry. Contributors should explicitly specify whether their views are espoused by their organization or not.

Conference Reports should be between 1,000 and 1,500 words. They should provide factual information (e.g. conference venue, details of the conference organizers), present the various programme sessions and summarize the key research findings.

Book Reviews should be between 1,000 and 1,500 words. They should provide factual information (e.g. book publisher, number of pages and ISBN, price on the publisher's website) and critically discuss the contents of a book mainly in terms of its strengths and weaknesses.

TABLE OF CONTENTS

The aviation industry has experienced many crises, out of which it usually departed with a strong rebound. Looking at the timescale, it is justified to argue that about every 10 years, a major crisis occurs. While this frequency appears to be rather stable, the severity of the downturn differs in magnitude. Thereby, general economic development and air traffic development are connected, with the later one being more volatile. This volatility, however, is not just true for the downturn, but also for the rebound following the crisis. Taking a close look at the temporal sequence of past crises like e.g. 9/11 or the Global Financial Crisis a clear pattern can be identified. The recovery of the aviation industry lags behind the recovery of the general economy, but rebounds stronger. To determine a quantitative relation of how much stronger the aviation industry recovers compared to the general economy, a model was developed based on the data of past crises. With a detailed focus on the recovery phase, this paper gives a forecast on how the rebound following the COVID-19 pandemic is likely to develop.

Fatigue poses an important safety risk to aviation, while it has been suggested as a key human factor which influences crew's working ability and flight safety. Flight attendants are in the first line to serve customers and also play an important role in flight safety. Thus, the modified Delphi method and grey correlation analysis are used to find the influential factors of the fatigue. Furthermore, the weight analysis and ranking of the fatigue factors of the flight attendants are discussed in the study context of the analytic hierarchy process. The results show that the company's planning and scheduling have the highest weight of fatigue. Furthermore, a load factor of 80% appears tiring for the crew, despite the fact that the number of flight attendants meets the legal requirements. In fact, this has the highest weight of fatigue in short-haul flights, unlike long-haul flights where the weight differs. Research findings may have managerial implications to airlines and relevant government agencies towards fatigue's reduction and improvement of flight attendants' working life.

Significant changes have taken place at airports due to market liberalization, airport privatization and growing competition. The growing demand and evolving expectations of passengers, require new ways of using technologies, to enhance operational processes and the whole travel experience. The digital era is transforming the aviation industry and has a significant impact on its future. The aim of this study is to assess the benefits of applying digital technologies to airports and airlines and their inseparable connection with innovative services provision to passengers, while it describes how to create a seamless end to end experience at the airport, maintaining a high level of security. Moreover, the study underlines the contribution of digital technologies to aviation industry, focusing on the organizational integration and passenger experience optimization. Reference is made to the pandemic, of COVID-19 and its impact on air travel. Primary research methodology is qualitative, with structured personal interviews, while the main findings indicated that through digital technologies and innovative services, the benefits for airports, airlines and passengers are increasing. Finally, this paper discusses a benefit model approach, based on the literature review and the research findings, with theoretical and practical implications.

This paper analyses the impact of aircraft noise on community around Podgorica Airport, Montenegro. The airport is located 12 km from the city centre of the Montenegro capital, Podgorica. It served 1.3 million passengers and 7.5 thousand operations in 2019. The noise impact assessment is conducted in IMPACT web-based modelling platform using the distribution of operations by aircraft types, time of the day, and radar tracks for the busiest day (August 15) in 2019. Noise contours are assessed for Lden and Lnight indicators. They were merged with the Global Human Settlement Layer to assess the number of people exposed to different noise levels. In addition, based on the World Health Organization recommended exposure levels related to their health implications, the percentages of the population highly annoyed and highly sleep-disturbed are estimated. Furthermore, facilities of public importance (schools, hospitals, churches, etc.) are assessed against compatibility with the requirements set for the Zones with increased noise protection in national regulations. The results show that the exposure of community around Podgorica Airport to aircraft noise is still not a serious issue. The near vicinity of the airport is industrial zone and the number of people highly annoyed by noise is approximately 3.2% of the total city population. Nevertheless, it is crucial to draw attention to planners to preserve airport neighbourhood from potential inhabiting, to avoid problems that some airports in the region are facing nowadays.

There is a growing movement in the U.S. (e.g., airports) to obtaining LEED (Leadership in Energy and Environmental Design) certification to reduce energy use. LEED advocates assert, on average, 25% less energy used by LEED-certified buildings compared to conventional commercial buildings. In the absence of studies regarding large U.S. LEED commercial airport buildings, a systematic quantitative review, content analysis and SWOT was performed to determine the economic feasibility of reducing energy use in airport buildings. A systematic quantitative literature review, combined with a comparison of LEED cost-benefit studies, and LEED certification objectives - to - airport facility energy requirements and U.S. government energy reduction initiatives was performed. Positive and negative (Pro/Cons) energy reduction findings were catalogued, charted, and analyzed. The findings from 1) LEED commercial building studies, 2) the LEED cost-benefit studies, and 3) the comparison of LEED certification program to large commercial U.S. airport energy requirements and trends were synthesized using a SWOT analysis. In aggregate, there was negligible correlation between commercial U.S. building LEED certification levels and energy use reduction. In spite of noteworthy findings regarding on-site energy reductions, there was insufficient evidence to suggest LEED reduced overall (site and source) energy use. Therefore, little evidence supports the cost-effectiveness and economic feasibility to reducing energy use simply through the LEED certification process. This study presents the pros and cons in applying LEED certification to reducing energy use in commercial airport buildings.

EDITORIAL

This issue collects five papers focusing on a variety of topics related with the contemporary air transport environment.

In the first paper, **Jorgen von der Brelie** and **Axel Lemke** investigate the recovery of aviation industry focusing on past crises. In fact, taking a close look at the temporal sequence of past crises like e.g. 9/11 or the Global Financial Crisis, the authors observe a clear pattern showing that the recovery of the aviation industry lags behind the recovery of the general economy, but rebounds stronger. Therefore, the authors tried to determine a quantitative relation between aviation industry and general economy in terms of recovery strength, by developing a model based on the data of past crises. With a detailed focus on the recovery phase, this paper gives a forecast on how the rebound following the COVID-19 pandemic is likely to develop.

Chao-Hung Chiang, in the second paper, driven by the fact that fatigue, a key human factor which influences crew's working ability, poses an important safety risk to aviation and flight safety, uses the modified Delphi method and grey correlation analysis to find the influential factors of the fatigue, ranking them and discuss them upon analytic hierarchy process. The results show that the company's planning and scheduling have the highest weight of fatigue, while the findings may have managerial implications to airlines and relevant government agencies towards fatigue's reduction and improvement of flight attendants' working life.

The significant changes that have taken place at airports due to market liberalization, airport privatization and growing competition are discussed, in the third paper, by **Ioulia Poulaki, Elen Paraskevi Paraschi, Konstantinos Marinakos, Avraam Avramopoulos** and **Sevasti Makrygianni**. The authors assert that the growing demand and evolving expectations of passengers, require new ways of using technologies, to enhance operational processes and the whole travel experience. Given the digital transformation of the industry and the tremendous impact of COVID-19 pandemic on air travel, this study aims to assess the benefits of applying digital technologies to airports and airlines and their inseparable connection with innovative services provision to passengers. Research findings indicated that through digital technologies and innovative services, the benefits for airports, airlines and passengers are increasing. Therefore, the authors discuss a benefit model approach, with theoretical and practical implications.

The fourth paper analyses the impact of aircraft noise on community around Podgorica Airport, Montenegro, while the noise impact assessment is conducted in IMPACT web-based modelling platform using the distribution of operations by aircraft types, time of the day, and radar tracks for the busiest day of the year. **Nikola Lukačević, Emir Ganić** and **Bojana Mirković** assert that the exposure of community around Podgorica Airport to aircraft noise is still not a serious issue and crucial to draw attention to planners to preserve airport neighbourhood from potential inhabiting, to avoid problems that some airports in the region are facing nowadays. In the fifth and last paper **John F. Kauffman**, driven by the growing movement in the U.S. to obtaining LEED (Leadership in Energy and Environmental Design) certification to reduce energy use, performs systematic quantitative review, content analysis and SWOT to determine the economic feasibility of reducing energy use in airport buildings, providing noteworthy findings when it comes to on-site energy reductions, while there was insufficient evidence to suggest that LEED reduced overall (site and source) energy use. Nonetheless, the pros and cons in applying LEED certification to reducing energy use in commercial airport buildings are presented and discussed.

We would like to extend our thanks to all these authors and all the reviewers for their hard work and contribution to this issue of Journal of Air Transport Studies. We believe that these works are providing a valuable contribution to the aviation practitioners as well as encouraging further research on the respective topics.

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MODELLING AVIATION INDUSTRY'S RECOVERY FROM COVID-19 BASED ON PAST CRISES EXPERIENCE

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ABSTRACT

The aviation industry has experienced many crises, out of which it usually departed with a strong rebound. Looking at the timescale, it is justified to argue that about every 10 years, a major crisis occurs. While this frequency appears to be rather stable, the severity of the downturn differs in magnitude. Thereby, general economic development and air traffic development are connected, with the later one being more volatile. This volatility, however, is not just true for the downturn, but also for the rebound following the crisis.

Taking a close look at the temporal sequence of past crises like e.g. 9/11 or the Global Financial Crisis a clear pattern can be identified. The recovery of the aviation industry lags behind the recovery of the general economy, but rebounds stronger. To determine a quantitative relation of how much stronger the aviation industry recovers compared to the general economy, a model was developed based on the data of past crises. With a detailed focus on the recovery phase, this paper gives a forecast on how the rebound following the COVID-19 pandemic is likely to develop.

KEYWORDS: aviation crises, recovery, COVID-19, air traffic volume, economic development, air traffic and economic correlation

1. INTRODUCTION

In the first step, this paper describes the general correlation between air traffic and economic growth, which are usually measured in RPK (Revenue Passenger Kilometres) and GDP (Gross Domestic Product). The correlation of RPK and GDP over time is analysed, and also geographical variations are considered. Especially interesting, however, are times of crises, where the volatility of the two main indicators further increases. Consequently, the second step is to "zoom in" on the crises and to identify typical patterns. Resulting from that very detailed analysis, a model for crises will be developed. This model helps to understand the temporal sequence of crises. By using this model and further focusing on the rebound after a crisis, it is finally attempted to give an outlook on how the current situation of the aviation industry is likely to develop in 2022 and onward.

2. LITERATURE REVIEW

Over the past decades, global RPK growth has been strongly driven by GDP, establishing a close relationship between the two indicators. According to the International Air Transport Association (IATA, 2008), growth in GDP was consistently replicated by RPK, with a growth rate double as high. Likewise, Rigas Doganis (2010) observes a strong correlation, in which RPK grows by a factor of 2 compared to GDP. This relevant figure has been used by airlines in 2009 as a tool for predicting the drop in demand following the outbreak of the Financial Crisis. Publications by Belobaba, Odoni, Barnhardt (2009) closely relate economic growth to a rise in air travel demand, too. Macroeconomic fluctuations are perceived to be the main threat to air traffic growth (Snyder, KPMG, 2019). Following that a reference factor of 2 and the relationship between RPK and GDP growth is widely recognised for characterising RPK growth progressions as data from a number of reports, for example from the European Commission (2016), IATA (2008) and Zock (2008) demonstrate. The close relationship between the indicators in the past give reason to use GDP as a tool for a quantitative data analysis to forecast developments in aviation (Yao et.al., 2014).

However, it is precisely in crisis years when IATA questions the applicability of this factor (IATA, 2008), without establishing a different, specific factor for these particular years. Instead, IATA's release briefly comments that RPK declines at a faster rate than GDP in specific crisis years, without showing deeper quantitative analysis on that observation.

The general study of online literature available delivers a number of papers, mainly from IATA, in which predictions are made for the time necessary for RPK to recover to levels of demand prior to a crisis. IATA's 2015 study on crisis times in aviation substantiates, that generally, even after up to five years following a shock, 20% of the impact of a crisis is still noticeable. Nevertheless, IATA notes that every crisis is different, and that recoveries of some shock periods occurred in shorter periods of time, too. Therefore, the often so called "resilient" industry of aviation (Adepalli, S., Pagalday, G., Salonitis, K. & Roy, R., 2017), (IATA 2015), (Airbus, 2019), (PWC, 2014) is characterised by literature to have a consistent capacity to bounce back to an underlying growth path after disturbances in growth. However, IATA suggests that this resilience does not come automatically, and that a major influence of the outcome after a crisis is the regulatory environment. In light of the current pandemic, this point seems to have explicit relevance, as the international patchwork of regulations and restrictions imposed to tackle COVID-19 is limiting the industry's capacity to regain momentum. Yet, restrictions to air travel should be temporary and therefore, assuming aviation to have regained a reasonable level of freedom by the end of 2022, this paper studies how the initial stages of recovery could look like under the major influence of economic growth. As some literature points out, using a ratio between GDP and RPK might give the impression that the economy is the only driver of aviation (Bourguignon, F., Darpeix, P., 2016). Clearly, this is not true, as there are many factors, external and internal, affecting growth, such as resources available, infrastructure capacity and taxes. However, as mentioned above, the progression of the general economy is the most influential, as it bears a deeper insight into the spending potential of people and therefore demand for travel. There is little literature analysing the RPK data of recovery periods, as most studies have a holistic approach to a crisis, focusing on the new state of the industry after the recovery, rather than on the developments observed during the recovery. In the current situation, where managers have to focus much more on short term than usual, the result of this particular paper might turn useful to navigate through the next two years.

3. CORRELATION OF AIR TRAFFIC AND ECONOMIC DEVELOPMENT

3.1 Correlation Ratio

There has been a clear correlation between air traffic volume measured in RPK and GDP in the years between 1990 and 2019. In Figure 2 it can be seen that RPK and GDP growth followed a similar course, sharing a cyclical growth development, in which RPK appears to follow the trends of GDP growth. However, RPK has had higher levels of volatility, most notable in downturn periods, as can be seen after the 9/11 attacks or the Global Financial Crisis (GFC) of 2008 (Figure 2). It is evident that RPK is more prone to suffer higher levels of fluctuation and to slide into recession, as seen in Figure 2, where RPK adopted negative growth during all major periods of crises, which are the 1991 Oil Shock, 9/11 and the GFC. For GDP, this only occurred in 2008. However, the RPK growth recovery of a crisis period is characterised by a strong rebound outpacing GDP, visible in Fig for the years 2004 and 2010, where RPK reached factors of growth well above 2.

Table 3.1: Worldwide average RPK and GDP growth rates with calculated factors of growth, decades between 1990 and 2019

Decade	**Ø GDP growth**	**Ø RPK growth**	**Factor**
1990-1999	2.65	4.64	1.75
2000-2009	2.87	4.65	1.62
2010-2019	3.03	7.35	2.47
Overall growth factor			**1.95**

Source: World Bank, ICAO (own elaboration)

Following the development observed in Figure 2 a widely accepted hypothesis suggests a growth-ratio of 2:1 between RPK and GDP at a worldwide level (Doganis, 2010; Belobaba, et al., 2009, p. 2.; IATA Economic Briefing, 2008). Table *3.1* illustrates the evidence found to support this hypothesis by illustrating the factors of growth in each decade to calculate an average factor of growth between GDP and RPK from 1990 to 2019. The result demonstrates some variation in the factors of growth. The period between 2000 and 2009 was particularly marked by years of strong downturns closely following each other (9/11 and GFC 2008) leading to a lower factor than the preceding decade, while the most recent decade developed more stably, resulting in a higher factor compared to the previous decades. However, overall a factor of 1.95 is delivered for the long term, which is very close to the factor of 2 assumed by industry organisations and specialists (Doganis, 2010; Belobaba, et al., 2009, p. 2.; IATA Economic Briefing, 2008).

It was also analysed if the 2:1 relation exists during periods of downturn. However, there have been few years in which both indicators slid into recession at the same time, leading to an inconclusive analysis for years of recession. Nevertheless, for the year of 2009, a negative growth factor of 2.25 can be calculated after both indicators slid into recession, providing some evidence that the factor of 2 between RPK and GDP growth also exists during years of negative growth (Fig).

A good example to visualise the relationship between RPK and GDP is delivered by Fig, in which the worldwide cyclical development of RPK and GDP can be seen in detail. The start of the decade saw a booming GDP and an RPK growth double as strong. However, the burst of the Dotcom bubble paired with the tragic events of 9/11 in 2001 caused a considerable slowdown in GDP and particularly strained the air transport industry, which slid into unprecedented recessive growth.

In 2004, after SARS and the Iraq war, along with a booming Chinese economy and increased momentum of developing countries a strong upturn of the global GDP (UN, 2004) developed, boosting the recovery of RPK after 9/11, which had a remarkable impact on global traffic numbers and in particular on the North American air travel. Following two years of weak growth in 2002 and 2003, RPK growth peaked in 2004 at +14%, initiating a streak of outstanding growth lasting until 2007. RPK generally grew visibly above the factor of 2 compared to GDP, which showed an average annual growth of about 4%. This was a relatively high rate of growth at worldwide level resulting from higher productivity levels in Europe, whilst RPK mostly scored growth rates above 10% over the same period. Therefore, the rebound after the early shocks was of considerable vigour. The main factors driving RPK growth were market liberalisation and globalisation, most notably in China, India and Europe, along with the mentioned strong growth in GDP (IATA, 2008; IATA, 2007; UN, 2005; ICAO, 2003).

The IATA Annual Report of 2008 predicted a looming economic downturn in the USA between 2007 and 2008, with the potential to spread to other parts of the world. As the GFC broke out in the second half of 2008, the air traffic industry faced a new significant downturn, with the strongest impact felt in 2009, when the RPK were reduced by -3.77%. The fall in global trade also caused GDP to decline -1.67%, roughly half as much as RPK. However, following the crash of 2009, 2010 showed a significant rebound of +10.53% in RPK growth. GDP reacted similarly, but to a lesser degree, showing an increment of +4.3%. Both indicators reverted from negative to positive growth from 2009 to 2010 strongly.

For the decade between 2000 and 2009 RPK grew at a factor of 1.62 compared to GDP, while being heavily affected by two major crisis periods following each other. It is clear that in both occasions the impact was much stronger on RPK, which slid into recession twice. The strong rebound following the crisis periods and the solid growth recorded in the middle years of the decade, with growth factors above 2, led to a higher level of volatility.

RPK growth is driven by a number of economic, social and demographic factors such as increasing levels of urbanisation, a growing middle class worldwide, globalisation and the irruption of the Internet, increasing the propensity of people to travel by air (Adepalli, et al., 2017), (Airbus, 2016). Aviation has shown a high degree of resilience to external shocks and changes in geo-economics, leading to exceptional development in the past decades despite the shocks of 1991, 2001 and 2008. This resilience was in most occasions a reflection of the economic rebound after a shock period and the improvement of quality of life, especially in emerging countries (Oxley & Jain, 2015). Global aviation organisations such as IATA acknowledge the relevance of economic cycles to the development of air traffic and also identify a correlation factor of 2 between these indicators throughout their growth cycles (IATA, 2008).

The global economic improvement and its effect on RPK in the past three decades is best illustrated by the fact that the global amount of RPK flown has quadrupled since 1990, reaching 8.7 trillion RPKs worldwide in 2019 (Figure 1).

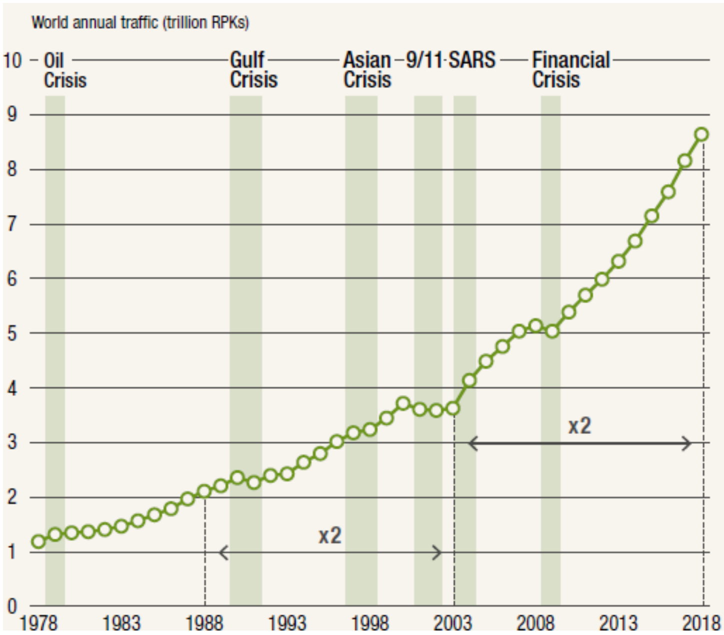

Figure 1: Absolute RPK (trillions) worldwide, major crises periods highlighted, doubling of worldwide RPK every 15 years, (Airbus, 2019).

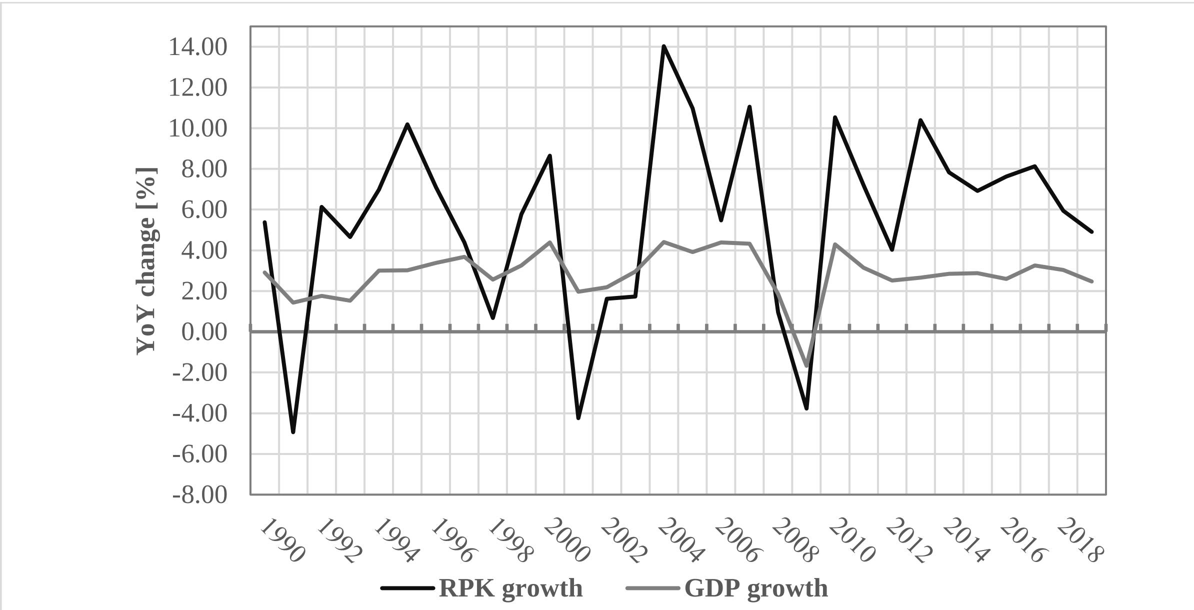

Figure 2: Correlation of RPK and GDP, 1990-2019 (ICAO Data+, World Bank)

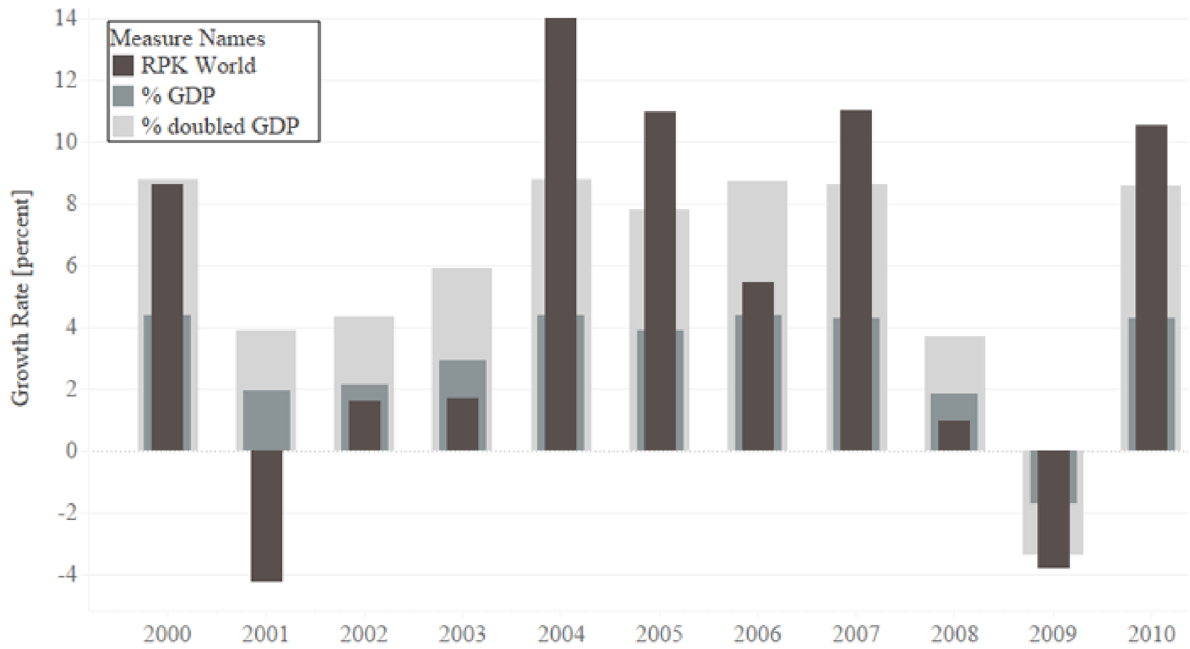

Figure 3: Worldwide RPK annual growth against single and doubled GDP growth (const. 2010$), 2000-2009 (ICAO, World Bank)

3.2 Geographical Variations

The relation between RPK and GDP has also been analysed for other relevant regions, namely the USA and the EU27 (comprising the member countries as of 1st of February 2020) in order to discern if the factor of 2 can be assumed for them, too.

Observations of RPK and GDP growth developments of these regions reflect specific characteristics and events of their local markets. For example, in the USA, the air travel industry witnessed high levels of airline consolidation following the liberalisation process in the early 90s, reducing over-competition between airlines (Koenig & Mayerowitz, 2014). This, combined with steady levels of demand, resulted in fairly moderate RPK growth rates in a country with historically solid GDP growth, leading to comparatively lower growth factors (Table *3.2*).

In contrast, the liberalisation of air travel within the EU27 enabled the development of LCCs across Europe, creating a boom in the industry within this region (Burghouwt et al., 2015). Dozens of airlines competing within a small geographic area, combined with high levels of demand for short haul transport, resulted in particularly high RPK growth rates in this region. The disparity of GDP growth rates among EU countries and its political complexity leading to lower GDP growth rates than seen in other regions led to fairly higher growth factors between the indicators, even when compared to worldwide figures (UN, 2012) (Table 3.3).

Table 3.2: USA average RPK and GDP growth rates with calculated factors of growth, decades between 1990 and 2019

Decade	Ø GDP growth	Ø RPK growth	Factor
1990-1999	3.22	4.56	1.41
2000-2009	1.91	1.71	0.89
2010-2019	2.23	3.23	1.43
Overall growth factor			**1.24**

Source: World Bank, ICAO (own elaboration)

Table 3.3: EU27 average RPK and GDP growth rates with calculated factors of growth, decades between 1990 and 2019

Decade	Ø GDP growth	Ø RPK growth	Factor
1990-1999	2.16	8.56	3.96
2000-2009	1.56	4.68	2.99
2010-2019	1.56	6.18	3.96
Overall growth factor			**3.64**

Source: World Bank, ICAO (own elaboration)

Table *3.2* and Table 3.3 illustrate the relationship between RPK and GDP in these two regions more detailed. The USA saw an overall factor of 1.24, well below the worldwide level. In contrast to that stands the EU27, displaying very strong growth factors consistently above 2, even in the weaker decade between 2000 and 2009. Overall, a factor of 3.64 resulted for the last three decades.

It is clear in all cases, both worldwide and at a more regionalised level, that RPK generally follows the trend of GDP but is more volatile (same tendency, larger amplitude). In sum, the average relation of RPK and GDP growth is close to a factor of two on a worldwide level, while in the EU the factor is higher and in the USA the factor is lower.

4. CHRONOLOGICAL SEQUENCE OF EVENTS DURING CRISES

After analysing the relationship between RPK and GDP in magnitude, it shall now be focused on the temporal sequence of changes of RPK and GDP, especially in crisis periods. Coming from the general perspective, it is now zoomed in on three crises: 9/11, the GFC of 2008 and the COVID-19 Pandemic.

This is relevant to discern the level of sensitivity of the air transport industry compared to the wider economy, across three different crises events: terrorism, financial and health. In order to have an illustration as detailed as possible, quarterly data were used for the G20, representing around 85% of the global economy. Several common developments across all the regions can be seen between the selected events.

4.1 Initial Slowdown

Prior to the occurrence of each downturn event, a 'pre-crisis' slowdown in GDP was generally recorded in all three cases, as a result of a cyclical economic slowdown. In the case of 9/11 this was due to the bursting of the Dotcom Bubble in the USA, which also caused a general reduction of GDP growth in the EU and G20. GDP begun to record reducing quarterly growth in Q4 2000, one quarter ahead of RPK. The 2008 GFC was preceded by a general cyclical slowdown which was then accelerated by events such as the crash of Lehman Brothers, while COVID-19 also saw signs of economic decline across all three regions from the start of 2019. In the case of 9/11 and COVID-19, these economic slowdowns were unrelated to the shock events, however, they were still relevant in terms of how they exacerbated the cyclical downturns. Nevertheless, in the case of the 2008 GFC, this pre-crisis slowdown was the start of a sequence of spiralling events that eventually resulted in a deep economic recession. The shock events mentioned above (9/11, bankruptcy of Lehman Brothers as well as the imposition of the US travel ban) marked the tipping point in the growth development and led to a dramatic exacerbation of the impact caused by the economic cycles.

4.2 Recession

After the slowdown, RPK slid into recession earlier than GDP. This sequence was seen consistently in all regions and all crises selected. The rapid slump into negative growth was caused primarily by the specific shock event: the 9/11 attacks (Q3 2001, Figure 4), the bankruptcy of Lehman Brothers (Q3 2008, Figure 5) and the imposition of hard international travel restrictions (Q1 2020, Figure 6).

It can be seen that RPK consistently fell into negative growth in the quarters listed above as a direct consequence of the impact caused by these events. In contrast to that, GDP continued to show a deceleration process for a few quarters before reaching the point of the lowest growth. During the 9/11 crisis, GDP did not record any negative growth, while it certainly did in the GFC, reaching the highest negative growth in the first quarter of 2009.

A further commonality between RPK and GDP can be seen by observing the low points, which occur in the same quarter (Q4 2001, Q1 2009 and Q2 2020 in Figs. 4, 5 and 6).

4.3 Recovery

After several quarters of deep decline, the recovery to a positive growth trend by RPK was remarkably more vigorous compared to the GDP trend after 9/11 and in the GFC. In Figure 4 and Figure 5 it can be seen that the first quarter of positive RPK growth displayed much higher growth values than GDP in each region. The factors calculated for the quarters of peak RPK growth after each crisis are for example about 4 at G20 level (Figure 4) and up to 14 at EU27 level in Q1 2010 (Figure 5). Nevertheless, it is also true that GDP was consistently developing positively earlier than RPK. Thereby, the recovery was initiated first by GDP, then followed by RPK. In the case of the GFC, where both indicators recovered from recession, RPK regained positive growth delayed by one quarter. A similar sequence was seen for the EU27 and the USA, which support the hypothesis of a strong recovery of RPK.

Therefore, it can be said that RPK generally follows the 'First In Last Out' logic. RPK usually experiences decline first, and its recovery lags behind the GDP.

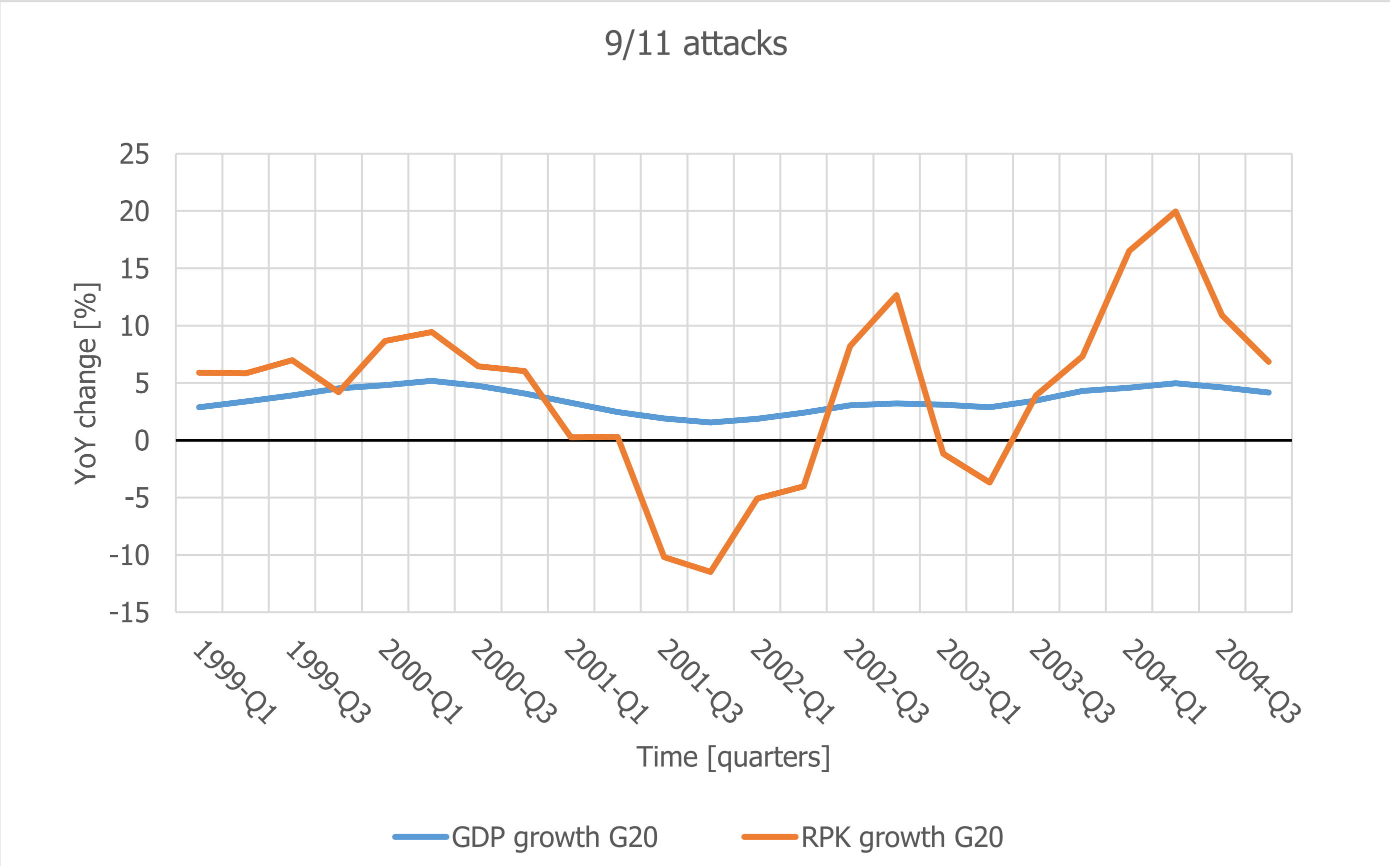

Figure 3: Detailed development of the GDP and RPK quarter growth rate on the G20 level before, during and after the 9/11 crisis, 1999-Q1 – 2004-Q4 (ICAO Data+, OECD)

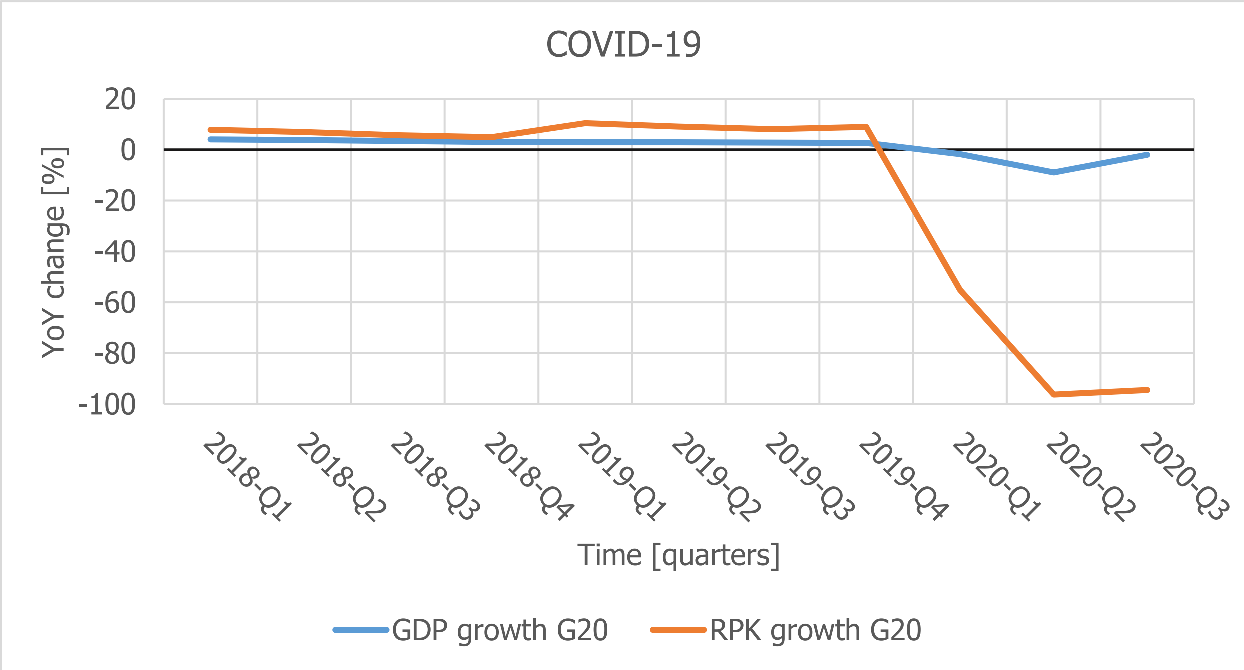

Figure 4: Detailed development of the GDP and RPK quarter growth rate on the EU27 level before, during and after the Global Financial Crisis, 2006-Q1 – 2011-Q4 (ICAO Data+, OECD)

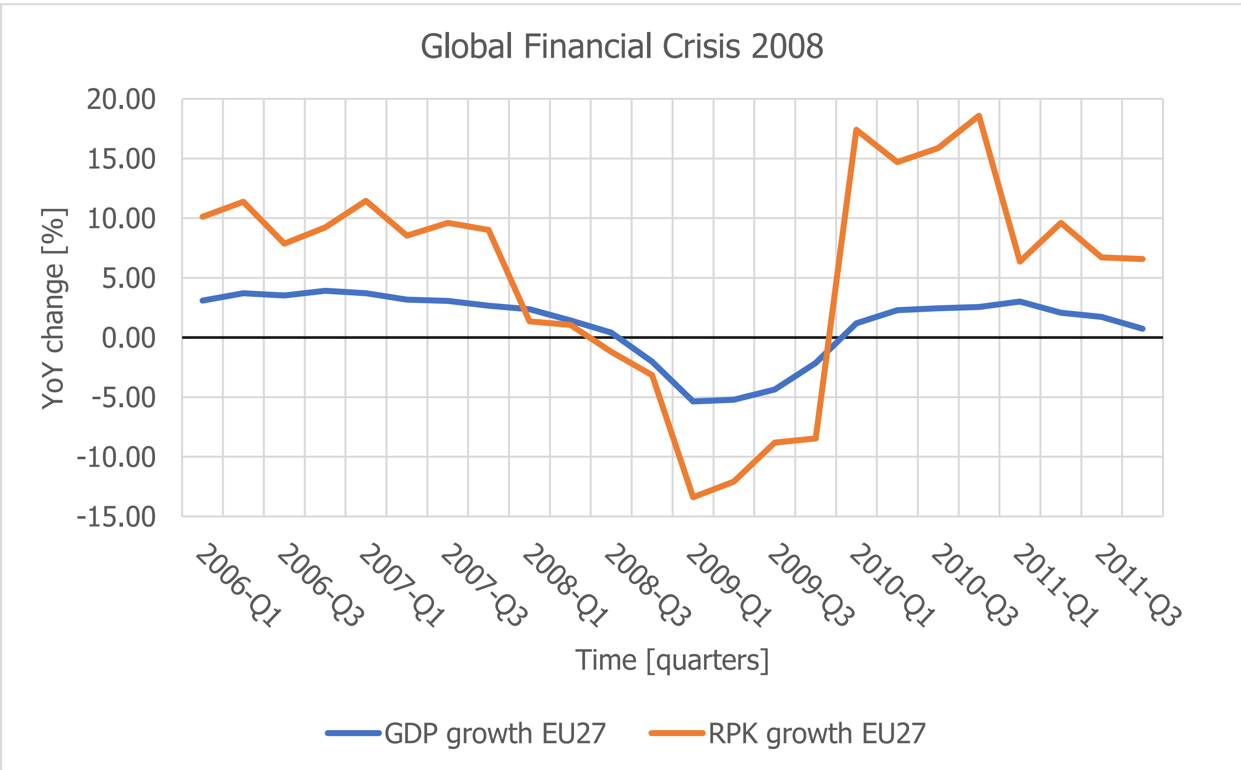

Figure 5: Detailed development of the GDP and RPK quarter growth rate on the G20 level before and during the COVID pandemic, 2018-Q1 – 2020-Q3 (ICAO Data+, OECD)

DISCUSSION

5.1 Development of A Model Derived from the Analyzed Data

The previous Figure 4, Figure 5 and Figure 6 are exemplary for the recurring phases of an aviation crisis. Although the crises occurred due to different reasons (economical, terror attack etc.) it is clear that a certain pattern reoccurs. This finding lead to further research, validation and finally to the development of the A-CRM – the Aviation-Crises Recurring Model.

The A-CRM consists of three main phases, all of which can be identified in all crises and in all regions (

Figure 6). However, the phases do vary in magnitude.

The first phase of the A-CRM begins with the steady state condition and a factor between GDP and RPK as described in chapter 3.

Usually, a rather unapparent slight decrease in GDP comes first, when suddenly the "shock event" kicks off the real crisis. The shock event can therefore be seen as the trigger. It usually can be associated with a specific date, and it originates from various areas (9/11, Lehman Brothers, closing of the US for foreigners).

This shows how vulnerable especially aviation in a globalized world is. Aviation is influenced by all kinds of crises and as it is so far globalized and interconnected it is also prone to rather regional events like the SARS outbreak or the Eyjafjallajokull volcanic eruption.

After the shock event the GDP and RPK indicator decrease with RPK taking a sharp downward tendency and reaching the negative growth first. This marks the end of the first phase and the beginning of the second phase.

In the second phase, the RPK value shows its volatility and reaches multiples of the negative value of GDP. The factor between GDP and RPK is at least as large as in the steady state condition, but this time in negative direction.

Sometimes the GDP only reaches very small negative numbers or no negative numbers at all, while RPK shows large negative growth rates (e.g. 9/11 in Figure 4). In these special quarters, the factor might reach very high values, which are due to the low denominator GDP.

Interestingly, both indicators reach the turning point at the same time. The trend reversal always occurred in the same quarter, but positive growth rates were reached by GDP first. The recovery of RPK lags behind the GDP recovery.

This recovery marks the beginning of the third phase – the rebound.

Once the RPK value turns positive again, it outperforms the GDP by multiples larger than the average factor. These rebounds can again be identified in all crises and in all regions, but with varying magnitude.

To get a better understanding of the rebound, it was defined as the time period after a negative RPK growth during which the factor between RPK and GDP exceeds the long-time average and/or the RPK growth exceeds the long-time average RPK growth. This last aspect is important, because, there have been regions with particular high GDP rebounds and although there was a clear RPK rebound the high GDP growth rate lead to a smaller RPK/GDP factor.

Sometimes even two rebounds can be observed (Figure 4) before the system again reaches a steady state condition. A mass-spring system seems an appropriate analogy. Out of a steady state condition, an exogenous shock displaces the mass (RPK), which is thereafter pulled back by the spring (rising demand) and oscillates around the steady state condition. With a strong damping of the system, it finally reaches the steady state condition again. This concludes the phases of the A-CRM model.

As for the current situation the forecast of the rebound phase is particularly interesting, it shall be further described in the following. In Figure 4 and Figure 5, the rebound phases can be clearly identified in Q3/Q4-2002, Q1/Q2-2004 and from Q1-2010 until Q4-2010.

5.2 Can the A-CRM be used to Forecast Future Demand?

In the current situation, airline managers are faced with the challenge of allocating resources and setting up budgets for the near future. Due to the dynamic development of the pandemic, a reliable forecast – for the next flight plan period or even just the next months – seems more unpredictable than ever before. However, the decisions to be taken have a huge economic impact. Allocating too many resources (e.g. taking aircraft out of the deep storage, re-certifying crews etc.) will cost a lot of money, while allocating too few resources will cost the airlines a lot of business and puts them in a poor position compared to the competitors.

Using the A-CRM model (

Figure 6) helps to provide an educated estimate. Using the definition of a rebound from above, the quarters belonging to phase 3 of the A-CRM model are identified. In order to get more specific results, this has to be calculated for each region separately. In a first step, this leads to an average length of the rebound phases. Thereafter, the relation of GDP and RPK (rebound factor) only during the phase 3 (the recovery) of the A-CRM model is calculated.

These resulting factors of phase 3 are shown in Table 5.2.1 and compared to the steady state condition factors. As expected, the factors for phase 3 exceed the steady state condition factors in all regions. This was expected as all regions experience a rebound. The EU has the highest rebound factor of 7.5 (more than double), while the world rebound factor increases by 50% to 3.0 and the US rebound factor reaches 2.8. It has to be mentioned that the high EU rebound factor is based not only on a strong air traffic recovery, which certainly exists, but also based on the comparatively lower GDP. Therefore, even average rebounds of air traffic lead to higher factors.

Table 5.2.1: Calculated factors between GDP and RPK growth in various phases of the A-CRM Model

Region	Steady State Condition	Phase 3
World	2.0	3.0
USA	1.2	2.8
EU	3.6	7.5

Once the rebound factors for each region are determined, it is then possible to use forecasts of the GDP from large organizations (like OECD, IMF, WTO) to estimate the development of the RPK value. The result of cause depends on the correctness of the GDP forecast and additionally assumes that RPK and GDP during the recovery of these crises are likewise interdependent compared to previous crises. This is not certain so far, however, this methodology at least provides results that promise to be more accurate than just taking the long-term average.

Table 5.2.2: Forecast GDP growth values from various international organisation, October 2021 (WTO, 2021; OECD, 2021; IMF, 2021)

Organisation	2022
WTO	4.1
OECD	4.5
IMF	4.9

Table 5.2.2 shows recent worldwide GDP forecasts from the mentioned organizations. According to the A-CRM air traffic grows globally with a factor of three during a rebound. An average GDP growth of ~4.5% in 2022 would therefore lead to a growth of air traffic of

approximately 13% in the same year on a global scale. For the EU, the air traffic rebound will be even higher, but again uncertainty is larger on a regional level and the rebound phase is not synchronized between all regions. Large domestic markets, for example, experience a much earlier recovery than international regions. This is why no specific forecast will be given for the EU, USA or even smaller regions. But the rebound factors at least will provide a qualitative estimate.

In summary, 13% worldwide air traffic growth for 2022 is the forecast according to the A-CRM. Obviously, there remains a large amount of uncertainty, which cannot be eliminated.

When markets open up again and travel restrictions fall, an immediate surge in demand is expected (IATA, 2021). This indicates a certain pressure on the demand side and a willingness to travel again. Once travel restrictions are abandoned on a large scale, there will be a rebound – the question is for how long and with which magnitude. The methodology described before and the A-CRM model provides an educated estimate for this question and provides airline managers, industry professionals and researchers with a helpful tool.

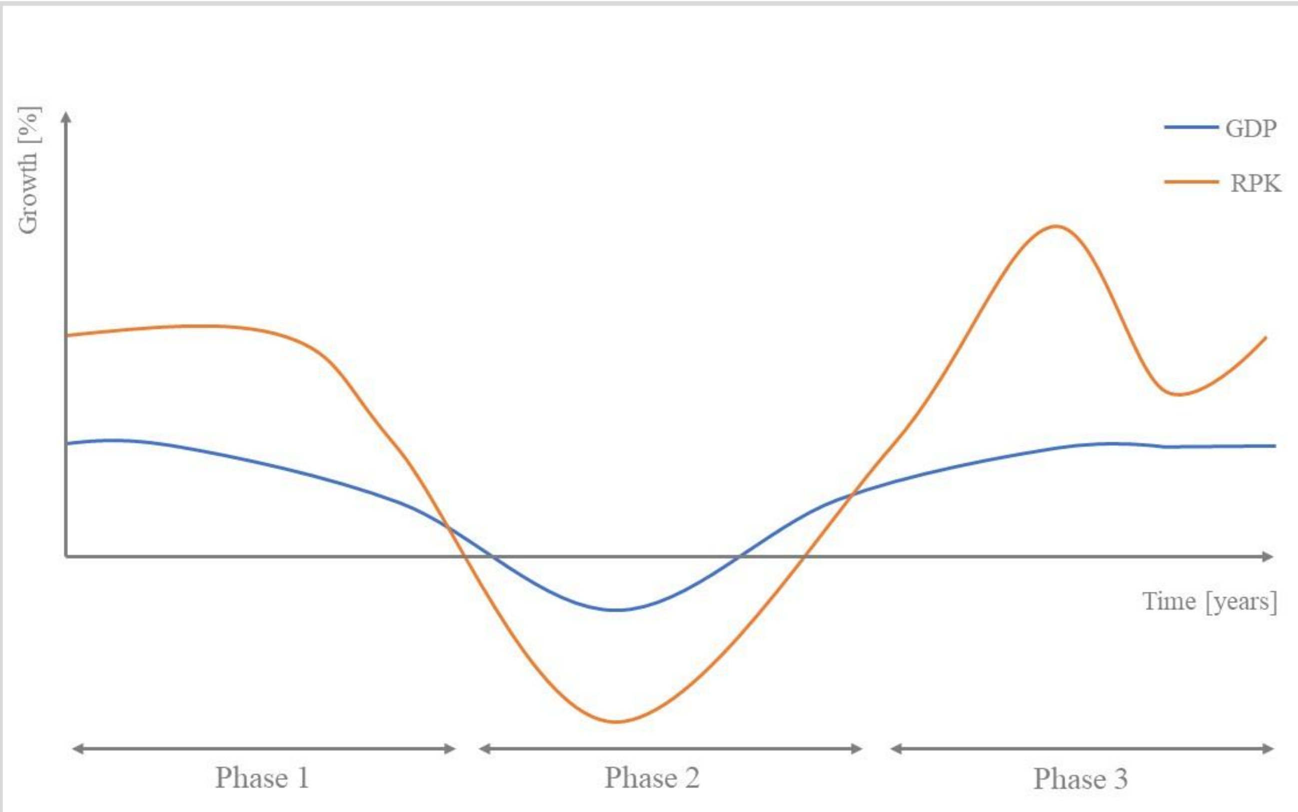

Figure 6: The Aviation - Crises Recurring Model (A-CRM)

6 CONCLUSION

The A-CRM (

Figure 6) describes the relationship between RPK and GDP for steady state conditions as well as for crises. With its focus on crises, however, the A-CRM model provides a conclusive description of the pattern, which GDP and RPK usually take once a shock event deflects these parameters out of their steady state condition. However, it has to be mentioned that, first, every impact of a crisis is different and secondly disruptive developments leading to an infinite change of a system can only be modelled with limited predictive capability. The A-CRM uses the in-depth analysis of patterns of past crises to make a prediction of the most likely development of air traffic in the future. This gives a powerful argumentation for example to the management, especially during crises, when investors, employees or other stakeholders may lose confidence in the future success of the industry. The knowledge of these typical developments may also be an advantage in negotiations with business partners; e.g. airlines may achieve further discounts from their suppliers or manufacturers (like Boeing or Airbus) during Phase 2 of the A-CRM.

Decisions, however, should always be taken in accordance to the specific development of the company's main business region. It is a fact that single events (like the bankruptcy of a competitor) have a stronger effect on regional level than globally. The A-CRM therefore provides the best predictions on a global level, as local events are balanced out on a higher level. Once a solid forecast for the GDP growth is received, a prediction of the RPK development can be deducted using the rebound factors. As a result, the development of air traffic after the crisis (Phase 3) and its rebound can be approximated.

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INFLUENTIAL FACTORS OF FLIGHT ATTENDANTS' FATIGUE – EVIDENCE FROM AIRLINE COMPANIES IN TAIWAN

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ABSTRACT

Fatigue poses an important safety risk to aviation, while it has been suggested as a key human factor which influences crew's working ability and flight safety. Flight attendants are in the first line to serve customers and also play an important role in flight safety. Thus, the modified Delphi method and grey correlation analysis are used to find the influential factors of the fatigue. Furthermore, the weight analysis and ranking of the fatigue factors of the flight attendants are discussed in the study context of the analytic hierarchy process. The results show that the company's planning and scheduling have the highest weight of fatigue. Furthermore, a load factor of 80% appears tiring for the crew, despite the fact that the number of flight attendants meets the legal requirements. In fact, this has the highest weight of fatigue in short-haul flights, unlike long-haul flights where the weight differs. Research findings may have managerial implications to airlines and relevant government agencies towards fatigue's reduction and improvement of flight attendants' working life.

KEY WORDS: Flight attendants; Fatigue; Short-haul flights; Long-haul flights

1. INTRODUCTION

Unlike other industries, flights are across the meridian and cabin crew often experience jet lags. When cabin crew worked in high altitude, some of the more common signs and symptoms of hypoxia are dizziness, fatigue, difficulty in processing visual information, and impaired judgment due to the lack of adequate oxygen supply (Federal Aviation Administration, 2008). The physical and mental load of the cabin crew is greater than that of the ground worker. Furthermore, as the aviation industry makes changes, such as longer flight times, shorter turnaround times, polar routes, increased passenger capacity, greater passenger numbers, and new safety procedures, the workload of cabin crew is also increased (McNeely et al., 2014).

According to the International Air Transport Association (IATA), the International Civil Aviation Organization (ICAO), and the International Federation of Air Line Pilots' Associations (IFALPA), fatigue is a major risk in terms of human factors. As it affects the work ability of cabin crew in various aspects, it poses risks to aircraft safety. Cabin crew's fatigue is a potential risk factor for flight safety (IATA, ICAO and IFALPA, 2011).

Over the years, international organizations have paid attention to and improved the research on fatigue management in the aviation industry. Fatigue is a type of body defense mechanism but extra accumulation of fatigue can change into a harmful and damaging event (Mahdavi et al., 2020). Research by the Civil Aeronautics Medical Institute, part of the Federal Aviation Administration (FAA), has found that disrupted sleep among cabin crew when they are on duty leads to common chronic sleep deprivation, fatigue, and declined performance in cognitive performance tests (FAA, 2013). Predictably, fatigue can lead to a decline in all types of human performance and a rise in aviation accidents or other accidents (ICAO, 2016). Therefore, it is necessary to identify the causes of fatigue among cabin crew, and implement effective fatigue management measures. It is the fact that no single strategy will fully eliminate fatigue and the aim must to promote and optimize alertness (Flower, 2001). That's the reason why need to find the factors which cause the fatigue.

Based on the above, this study invited experts from the civil aviation authority and flight attendants with management and training qualifications in the survey, in order to discuss the causes and degree of fatigue from the aspects of company planning, passengers, and individuals. The purposes of the study are: (1) a literature review and interviews with managers and also senior flight attendants to summarize the possible causes of flight attendant fatigue; (2) to acquire the influential factors of the fatigue by flight attendants using the Modified Delphi Method (MDM) and Grey Relational Analysis (GRA); and (3) to estimate the degree of influence of each factor on fatigue based on the Analytic Hierarchy Process (AHP). In addition, fatigue caused by several scheduling methods is also discussed in this study. Finally, based on the analysis results, conclusions and suggestions are proposed for reference to airlines or relevant government agencies in attempts to control or relieve flight attendants' fatigue.

2. LITERATURE REVIEW

2.1 Definition and Measurement of Fatigue

FAA (2007) defined fatigue as a kind of fuzzy multi-dimensional structure that can be explained in various ways, mostly used to reflect drowsiness/fatigue caused by a prolonged waking state, lack of sleep, and desynchrony of day and night. The cause of fatigue is deprivation of two factors, which are the circadian rhythm (circadian clock) and a stable sleep process (sleep and wakefulness). ICAO (2011) defines fatigue as a physiological condition in which mental or physical performance is impaired by loss of sleep or prolonged waking state, circadian effect, or workload (mental and/or physical activity), which result in decreased alertness of crew members, and the impairment of the ability to safely operate the aircraft. Phillips (2015) pointed that a few broad definitions of fatigue which are included the aspects of experiential, physiological and performance. Moreover, fatigue is also a dynamic multidimensional concept. The traditional approach to managing crew fatigue is to limit the maximum number of flight days and duty hours per day, month, or year, and forest the minimum rest time while on duty (IATA, ICAO and IFALPA, 2011).

Moreover, fatigue is estimated in different measurements at different fields. Maslach Burnout Inventory (MBI) conceptualizes pointed "fatigue" into three aspects: emotional exhaustion, depersonalization, and reduced personal accomplishment (Maslach and Jackson, 1980). Copenhagen burnout Inventory (CBI) was developed by Kristensen, Borritz, Villadsen and Christensen (2005), and included three sub-scales: personal or generic burnout scale, work-related burnout scale and client-related burnout scale (Kristensen et al., 2005). Brief Fatigue Inventory (BFI) is also used to measure the severity and impact of fatigue (Mendoza et al., 1999). Fatigue Severity Scale (FSS) is a unidimensional scale on the physical focus and the Modified Fatigue Impact Scale (MFIS) is a multidimensional scale including physical, psychological and cognitive aspects of fatigue (Learmonth et al., 2013). The domain of the CBI assesses the exhaustion originating from people centered professions and can link the fatigue with their work (Kristensen et al., 2005; Kováč and Halamová, 2022).

2.2 Influence Factors of Flight Attendants' Fatigue

In the past, studies on fatigues are contributed to multi-dimensional factors, and the nature of work usually is shift work and/or long working hours. Most studies on crew fatigue of airline companies were based on pilots' fatigue. The influencing factors of flight attendants' fatigue were rarely discussed in literatures. Therefore, it is going to collect factors related to flight attendants' fatigue in this study.

Among the causes of fatigue, the most common factors are scheduling, sleeping, and working conditions, which were match the three aspects of CBI. Therefore, literature reviews were stated according these three facets, i.e., company planning, work-related and personal factors as follow, respectively.

2.2.1 Factors in company planning

Arrangements of airline operations play an important role in fatigue management. IATA, ICAO and IFALPA (2015) mentioned that proactive fatigue monitoring processes such as to obtain experience of fatigue and the effectiveness of different mitigation strategies from scheduling, in-flight rest facilities, layover hotels, etc. The increase in the number of duty shifts would lead to fatigue. Moreover, FAA (2007) pointed that aircraft factors also caused fatigue, such as airlines, aircraft factors.

Circadian rhythm was also the great impact on flight to cause fatigue, including number of trips across time zones, illumination (seasonality), direction of flight, departure and return and duration of stay (FAA, 2007; Flower, 2001). As to flight length, long-haul operations (i.e. flights ≥ 8h in length) and short-haul operations (i.e. flights <8h in length) has differences from a fatigue perspective (Roach et al.,2012). The causes of fatigue risk of short-haul flights include scheduling early in the morning or late at night, early duty reporting time, frequent taking off and landing, multiple flight routes in a day, high-density airspace, consecutive shifts over several days, and many days on duty (IATA, ICAO, IFALPA, 2011; Roach et al., 2012). Widyanti and Firdaus (2019) collected the complained factors of flight attendants were included duration of rest period, jet lag, scheduling, duration of work and management such as management support which related with company planning.

2.2.2 Factors in work-related

Related studies of fatigue are found that fatigue is highly exist among workers (Mahdavi et al., 2020). Influential factors of fatigue might come from communication overload (Lee et al., 2016), workload (IATA, ICAO, IFALPA, 2011; Van Den Berg et al., 2019; Yilmaz et al., 2022) and working environment (University of Illinois at Chicago, 2014; Mahdavi et al., 2020) which would impact the fatigue significantly. It is the fact that flight attendants need to deal directly with passengers, answer questions about flights, take care of passengers with special needs, help others in need, and assist all passengers accordingly and usually worked at multiple high workloads which might cause fatigue.

When flight attendants had long contact with passengers, the emotional labor required will increase (Anderson, 1993). Working conditions, emotional exhaustion, and intense interpersonal relationships with customers would increase the fatigue of flight attendants' (Yilmaz et al., 2022). FAA (2007) also classified the factors to cause fatigue of crew including length of service hours, heavy workload, duty time (short or long route), amount of walking demand, service class (economy class or first class and business class)

2.2.3 Factors in personal

The International Federation of Airworthiness (IFA) has stated that responsibility for control fatigue does not solely rest with the company and individuals have to use the opportunities and facilities for rest periods provided (SKYbrary, 2019). Li et al (2018) also pointed that fatigue caused by a prolonged period of exposure to task-related stimuli and the effects would be aggregated or mediated by individual resilience. The flight attendants tend to suffer from work fatigue after enduring high work pressure and emotional load for a long time and those are psychological factors which caused by the external effect. Thus, fatigue may be induced by physical, physiological and psychological causes (Kennedy, 1988) and it can be used for various conditions including lack of sleep, tiredness, mental fatigue/exhaustion and so on (Mahdavi et al., 2020).

FAA (2007) classified the sleep factors, such as sleep quality and sleep length; and medical, physical, or psychological conditions related to fatigue or insomnia: various physical problems (sinus problems, dehydration, headaches, and muscle cramps), personal problems, local conditions, emotional stress, sick leave and absenteeism, and post-traumatic stress syndrome. Insufficient or disrupted sleep will cause fatigue (Caldwell et al., 2019; Van Den Berg et al., 2019; Bendak and Rashid, 2020). Especially for shift work, it would interrupt workers sleep-wake cycle and degrades sleep conditions resulting in a high potential of human fatigue (Jones et al., 2005). As for personal factors caused fatigue, such as age, gender, morning-night type, personality (extrovert-introvert personality), degree of fatigue before execution, and eating habits (FAA, 2007).

Finally, it was summarized as three facets which to cause fatigue of flight attendants in the studies. Frist is the factor of company planning, which refers to the fatigue caused by the resources provided by the company due to scheduling. Second is the factor of work-related, which refers to cause by resulting from interactions between flight attendants and passengers. Third is personal factor, which refers to the physical and psychological factors of the flight attendants in response to their duties.

This study summarized the fatigue factors mentioned in previous literature into the above three aspects for subsequent research and evaluation. The aspects and factors related to fatigue factors are listed in Table 1.

Table 1 : Literature reviews of the criteria influence on fatigue

Criteria	Sub-Criteria	Relative Literature
Company Planning	duty time (short or long route) , circadian rhythm(time zones, jet lag), company's policy, schedule arrangement, flight day, work environment, onboard crew rest facilities, layover hotel, airlines, aircraft, rest time, number of trips across	Flower (2001); FAA (2007); IATA,ICAO and IFALPA(2011); Roach et al.(2012); IATA, ICAO and IFALPA (2015); Widyanti and Firdaus (2019); VAN DEN Berg et al. (2019); Mahdavi et al.(2020)
Work-related Factors	length of service hours , experience, amounts of walking demand, work environment/ service class, workload, physical workload, multiple high workloads, passenger services, passengers' requests, passenger interaction, work pressure	FAA(2007); Anderson(1993); Lee et al.(2006);IATA, ICAO, IFALPA(2011); Damos (2013); Phillips (2015) ;Lee et al. (2016) ; VAN DEN Berg et al. (2019); Yilmaz et al.(2022)
Personal Factors	sleep factors, fatigue before execution, related to fatigue or insomnia issues, condition of mental and/or physical, emotional stress, sickness absences, personal status / personality, age, gender, morning-night type, eating habits	Kennedy (1988); Jones et al. (2005); FAA (2007); ICAO (2011) ;Li et al (2018) ; Caldwell et al.(2019); VAN DEN Berg et al. (2019); SKYbrary (2019); Mahdavi et al.(2020); Bendak and Rashid(2020)

3. METHODS

3.1 Questionnaire design and survey

Two national airlines were mainly used in the study. An airline company has about 4,200 flight attendants with an average seniority of 6 to 7 years, while B airline company has about 3,700 flight attendants with an average seniority about 12 years. The seniority between two airlines has a great gap which also showed high flow rate of flight attendants.

In this study, it used CBI which consisted of three main criteria, namely fatigue caused by company planning, fatigue caused by work related factors, and fatigue caused by personal factors. Based on literature review and interviews, 14 sub-criteria of fatigue were summarized in Table 2.

The expert and professor questionnaire survey of MDM were included professors, officials of civil aeronautics administration and airline companies. Flight attendant managers are more than 15 years of experience or/and with management or educational training qualifications from two major airline companies in Taiwan as Table 3.

Each group was 3 experts and total 12 people were participated in the MDM survey. The effective questionnaire recovery rate was 100%. As to AHP survey, 48 questionnaires were distributed to flight attendants who has a management qualification or/and work experience at least 5 years. After eliminating 13 invalid questionnaires, the effective questionnaire recovery rate was 73% as Table 4.

Table 2: Main criteria and sub-criteria of factors affecting flight attendants' fatigue

Main criteria/code	Sub-criteria/code
Company Planning Factors (C)	scheduling arrangement (C1); complex meals, or meals need to be reprocessed (C2); with 80% of passengers on board, the crew is tired even with legal flight attendants (C3); poor aircraft layout, unfriendly working environment, such as high refrigerator, uncomfortable sleeping area(C4); distance between the hotel and airport (C5)
Work-related Factors (P)	continuous and excessive service requests (P1); passengers that need special care, such as physically handicapped or disabled people (P2); poor communication with passengers (P3); additional needs of passengers (e.g. taking care of elderly/infants, chatting, and taking care of passengers in case of illness) (P4)
Personal Factors (S)	insufficient rest before flight (S1); physiological factors (e.g. low physical strength) (S2); psychological factors (e.g. poor mood) (S3); sleep disorders, such as shallow sleep (S4); physical discomfort, but not taking leave (S5)

Table 3: Respondents Profile of MDM

Item	A Airline Company	B Airline Company	Civil Aeronautics Administration	Professor
Top managers	2	1	2	3
Instructors	1	2	1	

Table 4: Respondents Profile of AHP

	Item	Number		Item	Number
Age (years old)	25-29	9	**Gender**	Male	13
	30-34	7		Female	22
	35-39	6	**Education**	Collage	24
	40-44	8		Above Mater	11
	Above 45	5	**Job Title**	Flight Attendant J Class/Deputy Purser	16
Seniority (years)	A t least 5	9		Cabin Chief / Chief Purser/ Inflight Service Manager	19
	6-10	12	**Flight Route**	Regional Routes	15
	Above 11	14		International Routes	20

3.2 Research Process

First, the MDM was used to estimate three main criteria and 14 sub-criteria based on literature review and expert interviews with senior flight attendants. Next, GRA was applied to evaluate indicates correlation among the factor. Finally, AHP was used to conduct pairwise comparison on the importance and weight of each factor and discuss the degree of influence of each factor on fatigue. The research framework was shown in Figure 1, which divided into three stages, to describe as follows.

1. Stage 1: Selection of main criteria and sub-criteria. According to Hill and Fowles (1975), the MDM is a structured questionnaire developed based on literature review and expert interviews. Therefore, based on literature review and interviews with senior cabin crews, and 3 main criteria and 14 sub-criteria were proposed in the study.

In the first round of expert survey, experts anonymously reached consensus by combining the knowledge and opinions of experts. The seniority of experts, i.e. senior flight attendants had more than 15 years of work experience.

2. Stage 2: Selecting criteria. The steps are as follows.

(1) As for the verification of the MDM, this study took the average as the basis for selecting and evaluating sub-criteria. According to an inter-quartile-range (IQR), if the IQR is below or equal to 0.60, the expert opinions can be regarded as being highly

consistent. When IQR in the range from 0.60 to 1.00, it means medium level consistency. When the IQR greater than 1.00, it means that no consensus has been reached (Fahety, 1979; Hollden and Wedman, 1993).

(2) GRA was used to assess the independence of the criteria for the results of first round expert questionnaire. GRA can determine the degree of correlation between factors according to the similarity or difference in the development trend of each factor, and is measured by the Grey Relational Grade. The study used the Grey Relational Grade of 0.75 as the threshold to find the sub-criteria group of correlation, and extracted the representative criteria of this group with the consent of experts.

(3) In the second round of expert survey, using the results from the GRA, namely, correlation among factors that could be replaced, were provided to 12 experts, before obtaining the written consents from the experts to confirm these criteria. And the results of the second round, all of the criteria have high degree of consistency was considered to be the final criterion with a high degree of consensus.

3. Stage 3: AHP construction. Based on the results of the second round of expert survey, AHP was used to explore the weights of the criteria, and then the weights and ranking of factors affecting fatigue were obtained. The findings on the factors causing fatigue of flight attendants and the degree of fatigue could serve as a reference for future fatigue review and improvement.

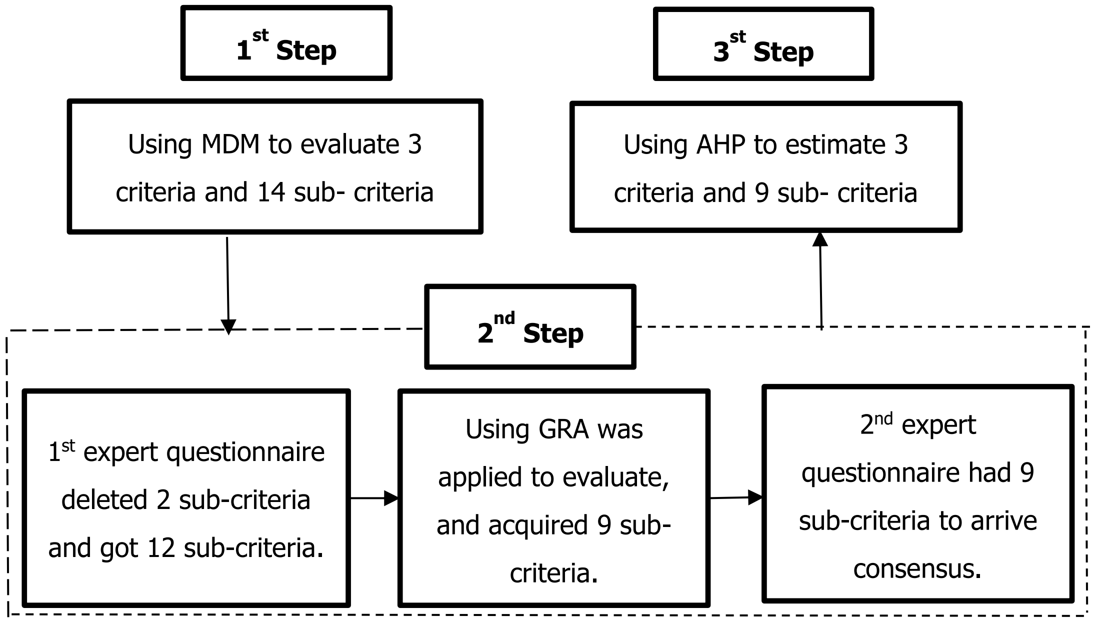

Figure 1: Research process

4. EMPIRICAL ANALYSIS

4.1 Results of the Modified Delphi Method

In Table 6, the results of the first round of expert survey showed that among the 14 sub-criteria, 12 of item reached the consensus level of above 86% (the average was higher than 4.24) and passed the consistency test. Because the expert opinions on items C4 and S5 varied, and the average score was below the threshold and without passing the consistency test, were removed from the questionnaire. After the GRA evaluated, there are 9 criteria used in second round of expert survey. The results showed that all criteria reached consensus of 100% (the average is higher than 4.92), indicating a high degree of consistency. The final criteria were thus regarded to have reached a high degree of consensus, and two rounds of expert questionnaires were concluded.

4.2 Results of the Grey Relational Analysis

GRA was performed based on the results of the first round of expert survey, and revealed that the Grey Relational Grade was higher than 0.75, and there were 6 sub-criteria in 3 groups in total. This indicates that the development trends among the criteria were similar, and it can use one of the indices to evaluate. The representative sub-criteria of each group selected in this study were scheduling arrangement (C1), passengers that need special care, such as physically handicapped or disabled people (P2), and insufficient rest before flight (S1) in Table 5.

Table 5: Results of Grey Relation Analysis

Criteria within each group	Grey relational grade	Representative Index of group
scheduling arrangement (C1), distance between the hotel and airport (C5)	0.76	scheduling arrangement (C1)
passengers that need special care, such as physically handicapped or disabled people (P2), additional needs of passengers (e.g. taking care of elderly/infants, chatting, and taking care of passengers in case of illness) (P4)	0.78	passengers that need special care, such as physically handicapped or disabled people (P2)
insufficient rest before flight (S1), physiological factors (e.g. low physical strength) (S2)	0.78	insufficient rest before flight (S1)

After the GRA results were respectively presented to the experts, they agree to replace distance between the hotel and airport (C5) with scheduling arrangement (C1) fully. As the Labor Standards Act and Aircraft Flight Operation Regulations on working hours, flying time, and rest time, airline companies tend to choose rest places for air crews near the airports despite cost considerations. As for the second group, since both sub-criteria are related to the additional requests of passengers, passengers that need special care, such as physically handicapped or disabled people (P2) was chosen to be the representative sub-criterion of this group. For the third group, the experts agree to choose insufficient rest before flight (S1) as the representative sub-criterion of this group. Thus, the remaining 9 indicators were used for the second round of expert survey. Finally, the results of selecting sub-criteria by using MDM and GRA are evaluated in Table 6. Hierarchy of the study is showed in Figure 2.

Table 6: Results of using MDM and GRA

Main criteria	Sub-criteria	1st Expert questionnaire				Expert Suggestion after GRA Results	2nd Expert questionnaire				The Final Results
		Average Score	Quartile Deviation	Consistence Test	Selection Results		Average Score	Quartile Deviation	Consistence Test	Selection Results	
Company Planning Factors (C)	scheduling arrangement (C1)	4.75	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	complex meals, or meals need to be reprocessed (C2)	4.75	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	with 80% of passengers on board, the crew is tired even with legal flight attendants (C3)	4.75	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	poor aircraft layout, unfriendly working environment, such as high refrigerator, uncomfortable sleeping area(C4)	2.17	2	no consensus	Not Adopt	--	--	--	--	--	--
	distance between the hotel and airport (C5)	4.25	0.25	highly consistent	Adopt	Replaced by C1	--	--	--	All experts agree replaced	--
Work Related Factors (P)	Continuous and excessive service requests (P1)	4.75	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	passengers that need special care, such as physically handicapped or disabled people (P2)	4.25	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	poor communication with passengers (P3)	4.83	0	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	additional needs of passengers (e.g. taking care of elderly/infants, chatting, and taking care of passengers in case of illness) (P4)	4.25	0.25	highly consistent	Adopt	Replaced by P2	--	--	--	All experts agree replaced	--
Personal Factors (S)	Insufficient rest before flight (S1)	4.75	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	physiological factors (e.g. low physical strength) (S2)	4.25	0.25	medium consistency	Adopt	Replaced by S1	--	--	--	All experts agree replaced	--
	psychological factors (e.g. poor mood) (S3)	4.67	0.25	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	sleep disorders, such as shallow sleep (S4)	4.83	0	highly consistent	Adopt	--	4.92	0	highly consistent	Adopt	Adopt
	physical discomfort, but not taking leave (S5)	2.17	1	no consensus	Not Adopt	--	--	--	--	--	--

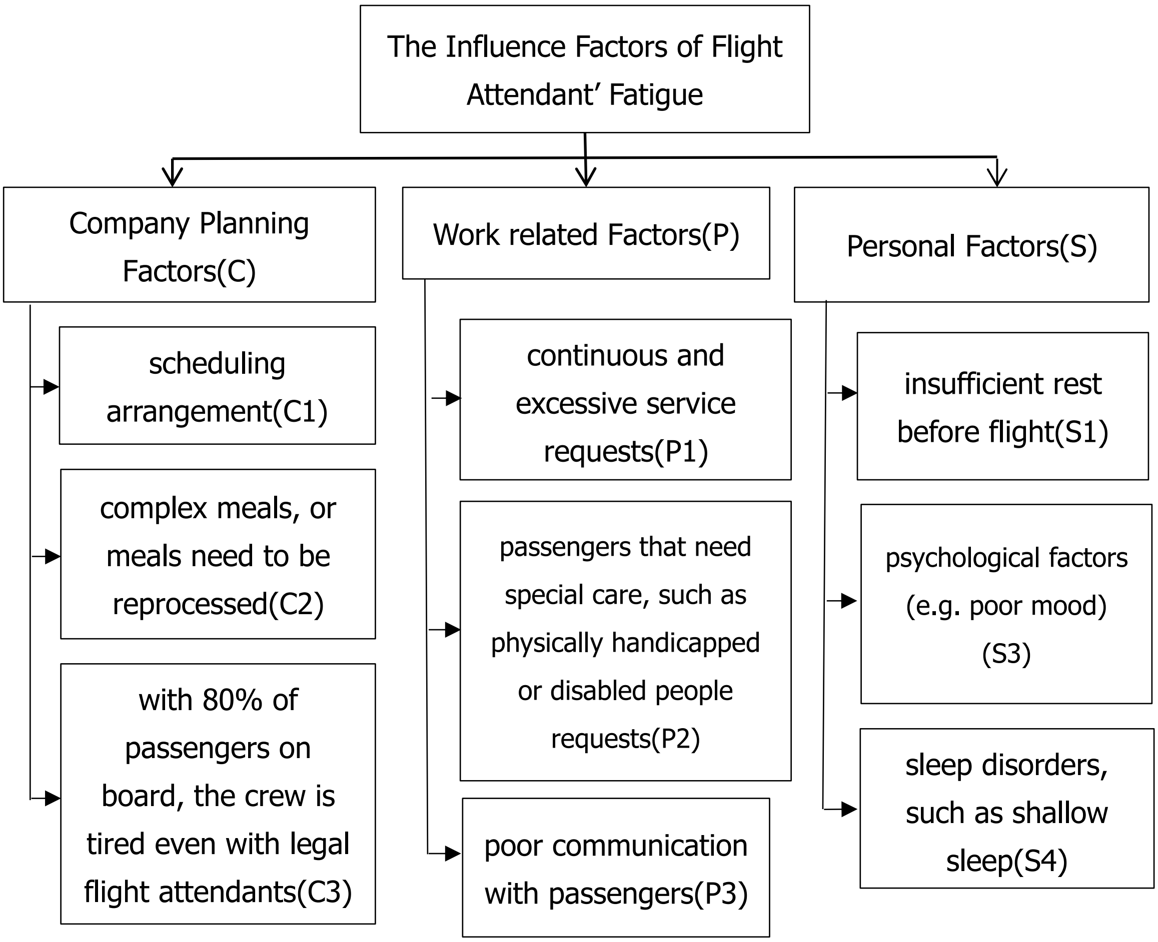

Figure 2: Hierarchy of the influence factors of flight attendant' fatigue

4.3 Results of the Analytic Hierarchy Process

Previous literature has suggested that gender, age, seniority, and long- or short-haul flights have different effects on fatigue. Therefore, this study analyzed and compared expert questionnaires based on various groups and overall results. The results show that the C.I. value is less than 0.1, indicating that although the judgments are not completely consistent, they are within the permissible error range. The value of C.R. is also less than 0.1, indicating that the consistency of the matrix is satisfactory. The results of the study are showed in Table 7.

Table 7: Weight of each group indicators influence on the fatigue of flight attendants

Groups		Main Criteria			Sub-Criteria								
		C	P	S	C1	C2	C3	P1	P2	P3	S1	S3	S4
Gender (Female)	Weight	0.568	0.272	0.159	0.434	0.272	0.294	0.493	0.191	0.316	0.48	0.308	0.212
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.247	0.155	0.167	0.134	0.052	0.086	0.076	0.049	0.034
	Rank	--	--	--	1	3	2	4	7	5	6	8	9
Gender (Male)	Weight	0.463	0.301	0.237	0.434	0.156	0.411	0.493	0.191	0.316	0.507	0.217	0.276
	Rank	1	2	3	1	2	3	1	3	2	1	3	2
	Total Weight	--	--	--	0.201	0.072	0.097	0.148	0.058	0.095	0.120	0.051	0.065
	Rank	--	--	--	1	6	4	2	8	5	3	9	7
Age (Below 35)	Weight	0.652	0.22	0.128	0.476	0.261	0.263	0.493	0.191	0.316	0.41	0.301	0.289
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.310	0.170	0.171	0.109	0.042	0.07	0.053	0.039	0.037
	Rank	--	--	--	1	3	2	4	7	5	6	8	9
Age (Under 36)	Weight	0.459	0.33	0.211	0.402	0.236	0.362	0.497	0.214	0.290	0.549	0.28	0.171
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.185	0.108	0.166	0.164	0.071	0.096	0.116	0.059	0.036
	Rank	--	--	--	1	5	2	3	7	6	4	8	9
Seniority (Below 10)	Weight	0.62	0.234	0.146	0.407	0.279	0.314	0.382	0.268	0.35	0.432	0.305	0.263
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.252	0.173	0.195	0.089	0.063	0.082	0.063	0.044	0.038
	Rank	--	--	--	1	3	2	4	6	5	6	8	9
Seniority (Under 11)	Weight	0.457	0.34	0.203	0.48	0.212	0.308	0.575	0.189	0.236	0.559	0.27	0.171
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.219	0.097	0.141	0.196	0.064	0.08	0.113	0.055	0.035
	Rank	--	--	--	1	5	3	2	7	6	4	8	9
Short-haul flight	Weight	0.482	0.299	0.219	0.327	0.231	0.442	0.493	0.191	0.316	0.453	0.291	0.256
	Rank	1	2	3	2	3	1	1	3	2	1	2	3
	Total Weight	--	--	--	0.158	0.111	0.213	0.132	0.08	0.087	0.099	0.064	0.056
	Rank	-	-	-	2	4	1	3	7	6	5	8	9
Long-haul flight	Weight	0.591	0.264	0.145	0.503	0.251	0.246	0.493	0.191	0.316	0.504	0.293	0.203
	Rank	1	2	3	1	2	3	1	3	2	1	2	3
	Total Weight	--	--	--	0.297	0.148	0.145	0.13	0.05	0.083	0.073	0.043	0.03
	Rank	-	-	-	1	2	3	4	7	5	6	8	9
Overall Results	Weight	0.554	0.277	0.169	0.439	0.249	0.313	0.463	0.236	0.301	0.486	0.292	0.221
	Rank	1	2	3	1	3	2	1	3	2	1	2	3
	Total Weight	--	--	--	0.243	0.138	0.173	0.128	0.065	0.083	0.082	0.049	0.037
	Rank	-	-	-	1	3	2	4	7	5	6	8	9

4.4 Discussion

Based on the above results, all demographic groups, as well as the overall analysis, indicate that company planning factors (C) is subject to the highest level of fatigue, followed by work related factors (P) and personal factors (S).

In terms of sub-criteria, "with 80% of passengers on board, the crew is tired even with legal flight attendants (C3)" in company planning factors (C) which is also the leading cause of fatigue in short-haul flights, and also the leading cause in the overall weight ranking. It shows significant difference from other groups. According to literature, fatigue occurs when pilots repeat short flights at the same take-off and landing site, or when they are on duty under heavy workloads (Roach et al., 2012; IATA, ICAO and IFALPA, 2015). In addition, Yilmaz et al. (2019) also stated excessive fatigue arises from tasks that should be fulfilled in a short time. Since the flight time of a short-haul flight is limited, even if the number of legal flight attendants meets the requirements, it is tiring for the flight attendants to complete all services, such as meal delivery, clean-up, selling duty-free goods and so on. Food and beverage services provided on a short-haul flight can lead to a significant increase in fatigue (FAA, 2007), which is consistent with the result of this study.

In personal factors (S), the group analysis found that insufficient rest before flight (S1) has higher weight and is ranked first. The result is also consistent with of Van Den Berg et al (2019) which stated that a good rest before a flight is extremely important. FAA (2010) also found cabin crews rarely start their work with sufficient rest. When the cabin crews are tired at the start of the workday, there is "floor effect", meaning they do not have much room to deliver excellent performance during their shifts. Thus, it is important to disseminate the concept of sufficient rest time before flight to flight attendants.

In the overall weight, this study found that "male flight attendants" and flight attendants with "over 11 years of experience" not only indicate "scheduling arrangement (C1)" to be the main cause of fatigue, but also consider "continuous and excessive service requests (P1)" to be a cause. Anderson (1993) has pointed out that flight attendants are emotional labor workers and spend a long time with passengers, which leads to a high emotional labor workload.

Furthermore, the ranking between below 35 years old and less than ten years' seniority, and between older than 36 years old and more than eleven years' seniority, results are also showed similar between age and seniority in the study. Widyanti and Firdaus (2019) studied on the mental workload of flight attendants and results also indicated that age and work experience didn't have significant differences on the mental workload of the flight attendants. Thus, it might be able to use one of age or seniority to be a variable in the future studies.

Additionally, the flight attendants considered the "scheduling arrangement", among all groups and overall analysis, as the most important factor causing fatigue. It collected

eight scheduling methods and asked senior flight attendants to explore the severity of fatigue by using a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree) in the study. Results are in Table 8. Consecutive morning shifts, consecutive shifts and flying across time zones with heavy workload were the top three severity of fatigue in the company planning. Especially the continuous morning shift, duty periods with early-morning start times affect the amount of sleep obtained by shift workers, and the several consecutive early-morning starts should be avoided where possible (Roach et al, 2012).

Table 8: Severity of fatigue caused in the company planning

Item	Maximum	Minimum	Average	Rank
consecutive morning shifts	7	6	6.64	1
consecutive night shifts	7	1	4.95	8
cancellation of overnight flights and round trip flights on the same day	7	1	5.68	5
consecutive shifts	7	5	6.45	2
ultra-long distance flights	7	4	6.18	4
flying across time zones with heavy workload	7	5	6.41	3
mixed scheduling of morning and night shifts	7	2	5.59	6
scheduling under abnormal conditions	7	3	5.55	7

5. CONCLUSION AND SUGGESTIONS

5.1 Conclusions

1. Based on the literature review, three main criteria and nine sub-criteria were selected by MDM, and GRA to explore the influential factors of flight attendants' fatigue in the study. In terms of the criteria of fatigue, the demographic group and the overall analyses found that company planning factors (C) has the most influence on fatigue, followed by work related factors (P) and personal factors(S). As for the sub-criteria, scheduling arrangement

(C1) has the highest weight in the company planning factors (C). In the work related factors (P), the highest weight factor is continuous and excessive service requests (P1). In the personal factors (S), insufficient rest before flight (S1) has the highest weight.

2. In the short-haul flight, the results showed that with 80% of passengers on board, the crew is tired even with legal flight attendants (C3) is a highest factor influence on the fatigue of flight attendants. Due to the amount of services that they need to complete within a short amount of time.
3. As to the severity of fatigue caused in the company planning, the top three ranking were consecutive morning shifts, consecutive shifts and flying across time zones with heavy workload.
4. This study also found that age and seniority have almost the same results which may due to airlines in Asia prefer to hire young flight attendant. Therefore, it might use one of item to be a variable in the future studies.

5.2 Suggestions

1. As the issues of working hours and fatigue on flight safety in the aviation industry have gained much attention. Besides the governmental policies and airline regulations, it is suggested that airlines should understand the causes of fatigue in order to management the crew fatigue and offer training courses on fatigue management.
2. The overall results showed that the "problem of scheduling" is a main factor causes of fatigue. Therefore, it is recommended that not only to follow the standards but also to consider the workload and/or load of the flight to arrange the number of flight attendants.
3. To make it convenient for the flight attendants to serve meals quickly, airlines should minimize the number of food items that need to be processed or heated. For example, routes in Asia, soup bases and soup are heated separately, or one meal contains several items to be heated, while the number of ovens is not enough. This is among the top three factors causing fatigue. Therefore, airlines could improve the meal planning to reduce workload which also can reduce fatigue.
4. Finally, it is suggested that future studies can focus on the methods to reduce and alleviate fatigue or propose incentives to motivate flight attendants to reduce fatigue, so as to improve the effective and efficient of flight attendants and enhance the competitiveness of airlines in the study.

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DIGITAL TECHNOLOGIES AND INNOVATION IN AIRPORT SERVICES: A BENEFIT MODEL APPROACH

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ABSTRACT

Significant changes have taken place at airports due to market liberalization, airport privatization and growing competition. The growing demand and evolving expectations of passengers, require new ways of using technologies, to enhance operational processes and the whole travel experience. The digital era is transforming the aviation industry and has a significant impact on its future. The aim of this study is to assess the benefits of applying digital technologies to airports and airlines and their inseparable connection with innovative services provision to passengers, while it describes how to create a seamless end to end experience at the airport, maintaining a high level of security. Moreover, the study underlines the contribution of digital technologies to aviation industry, focusing on the organizational integration and passenger experience optimization. Reference is made to the pandemic, of COVID-19 and its impact on air travel. Primary research methodology is qualitative, with structured personal interviews, while the main findings indicated that through digital technologies and innovative services, the benefits for airports, airlines and passengers are increasing. Finally, this paper discusses a benefit model approach, based on the literature review and the research findings, with theoretical and practical implications.

KEYWORDS: innovation, digital technologies, airports, airlines, passenger experience, benefit model

1. INTRODUCTION

Passenger satisfaction is mainly influenced by the environment and services at the airport, both on arrival and departure, as well as during the transfer to and from the airport. Passenger experience at the airport is significantly influenced by the technologies used to process their data. The overall process that passengers go through to plan and schedule their journey, check-in, baggage handling and security procedures often have a big impact on their experience and reduce their level of satisfaction. Little research has been done, with aggregated information, as to which airports are implementing strategic use of digital technologies in the aviation industry and their impact on airport economic growth and overall passenger experience. The literature related to the determinants affecting service quality at airports and the evolution of digital practices at airports has created the need to understand the interdependence of these concepts. Rhoades, Wagnespack and Young (2000), developed a list of key indicators of airport service quality and identified the factors that mainly influence customer perception, however their study focused, only on the passenger perspective. Konstantinova (2019) studies the digital transformation of tourism and focuses on artificial intelligence and robotics but does not expand on other advanced technologies and makes little reference to airports. Patel (2018) extensively describes how advanced technologies and biometrics can facilitate passenger handling and security processes at airports rather than airlines.

However, the references to improving the passenger experience through new technologies focus more on the technical part of the services. Florido-Benitez et al. (2016), concentrated only on analyzing the impact of mobile marketing on passenger experience and satisfaction at the airport. Little (2015) conducted research to examine the potential of digital technology to reduce the overall cost of airport operations. However, in that case, the airline and passenger sides are not considered. Furthermore, Kilic et al. (2021) postulate that "despite the increasing focus of industry and academia on innovation in general, there is no research specifically focusing on the question of how innovation can be achieved at airports". Based on the above, although the digital strategy of airports seems to lead to an improvement in passengers' perception of the quality of airport services, there is a gap in the current literature concerning the employment of this strategy both in airports and airlines. Therefore, in a context of aviation excellence spearheaded by digital technologies and innovation, this paper aims to better understand the implementation of digital technologies in the aviation industry and highlight both their technical and commercial importance for all stakeholders, i.e., airports, airlines and passengers by developing of a benefits model.

2. LITERATURE REVIEW

Due to the global growth of air transport, the demand for airport services and more efficient passenger, baggage and aircraft handling processes have increased in parallel (Pabedinskaite and Akstinaite, 2014). The intensification in competition among airlines has resulted in air carriers seeking to operate at airports that offer efficient operations in order to increase the quality of service to their passengers and reduce their operating costs (Oum, Yu & Fu, 2003). The period when airports were a place only for departures and arrivals has passed. Nowadays, airports, are multifunctional travel nodes, with a plethora of services offered. This evolution has been driven by the ever-increasing number of passengers travelling by air, due to the improved living and economic standards. At the same time, the new experiences that passengers have gained in their travels, force them to increase their demands and expectations of the services provided. Consequently, airports are aiming for continuous modernization and quality services in order to be able to meet these needs and desires on an ongoing basis.

Airport managers, acknowledging the need to assess their customers' perceptions of the quality of their services (ACI, 2013), regularly conduct passenger satisfaction surveys in order to immediately identify opportunities to improve these services and reduce unsatisfied passengers (Fodness & Murray, 2007). However, it is worth mentioning that there are several airports worldwide that have exceeded passenger expectations and provide a unique passenger experience (ACI, 2015). For example, they use social robots, artificial intelligence and the Internet of Things to provide enhanced passenger experience. Regarding the passenger-airline interaction, there is an increasing trend in terms of passengers' use of technology, according to IATA's (2019) survey results. Since the IATA’s very first survey in 2012, in a seven-years period, passengers have shown a clear preference for self-service and connectivity. Besides, passengers wish to constantly interact with airlines throughout their journey through apps on smartphones for timely and accurate information about their flight.

Service speed and airport waiting times are of concern to passengers, who are more willing than ever to share sensitive personal data, with governments and airlines to drive a smoother and better travel experience. It is noted that, travelers want to be in control of their travel and have choices and they are willing to pay extra for services if they are very important, as long as the overall product is improved and lives up to their high expectations. We should not ignore an increasing segment of passengers comprised of elderly and disabled people. The above surveys included travelers belonging to these groups and their responses showed that, compared to the others, they need the assistance of an airport agent for check-in and the delivery of their luggage, but the monitoring of luggage and connectivity concerns them just as much as the others. Overall, today's passengers are looking for:

- efficiency,
- comfort,
- less waiting and
- control over their journey.

2.1 COVID-19 and Airports

Airports are global hubs that connect the world and facilitate economic development. The COVID-19 pandemic brought global traffic to a standstill in 2020 (Nhamo et al., 2020) and caused huge damage to the once growing aviation sector. Before the pandemic broke out, many airports around the world were congested due to the rapid increase in air traffic volumes, which put additional pressure on the existing infrastructure. However, in 2020, due to the pandemic, a huge drop in travel was caused and created new demands on health and hygiene protocols.

Research by the Airports Council International on the impact of COVID-19 on airports (ACI, 2020) showed that a reduction in passenger numbers of over 6 million passengers was expected by the end of 2020 in the global aviation industry. According to the same study, while the airline industry was expected to generate approximately $172 billion in 2020, with the onset of the crisis, airport revenues resulted in a decrease of $111.8 billion, 65% lower than the pre-COVID-19 forecast. Also, in April 2020, commercial flights, globally, dropped by 75%, compared to the same period in 2019 (Petchenik, 2020). Some countries saw an even larger drop, of up to 90% (OAG, 2020). Contactless travel is the key to restoring passenger confidence and will fuel a rapid revival in air travel (Collins Aerospace, 2020). Airports were never designed for social distances, instead, they have been designed to promote social interaction. Therefore, it is urgent to adopt a model that drastically reduces costs and increases the operational efficiency of airports and the speed of passenger processing, while enhancing the quality of services provided, to reduce the likelihood of spreading the disease (Dube et al., 2021). Airports have high fixed costs and try to reduce variable costs where possible (closing infrastructure departments, laying off employees, cutting salaries). Therefore, automation of several processes is unavoidable.

Similarly, for airlines, restructuring and resizing will be unavoidable in order to support their liquidity and mitigate the risks that threaten their viability. Measures were taken such as employees' layoffs and retirement of old and large aircraft, to increase their operational efficiency in a more cost-effective way (Dube et al., 2021). Most airlines, expect that air travel will not return to normal levels for the next 2-3 years (Atkinson, 2020). However, there is also a prediction of strong aircraft demand over the next 20 years (Seymour, 2021). In any case, technology innovations propelled by COVID-19, such as inflight social distancing and utilizing touchless technologies at airports are useful strategies to offset disruption caused by the pandemic (Amankwah-Amoah, 2021).

Technology is an important force to create flexibility in the tourism industry (Hall et al.,2020). Robots, automation technologies and artificial intelligence, have the potential to reduce costs, improve liquidity and enhance flexibility. The digital transformation of airports can lead to sustainable long-term growth by meeting travelers' needs. The transformation and automation of operations are a necessity in the industry now. Through technology, pandemic-specific problems at airports can be easily managed, including (Sharma et al., 2021):

- The flow of passengers through the airport
- The control of travelers
- The detection of COVID-19 cases with temperature sensors, etc.

Furthermore, during the pandemic period, it was observed that the public increased their trust in technology (Sharma et al., 2021). In the short term, airports, will have to decide when to reopen sectors that were closed due to the massive drop in traffic. With the opening of infrastructure, increased operational costs will have to be offset against maintaining social distance and satisfactory performance (Serrano and Kazda, 2020). Experts in the aviation sector, however, state that, the pandemic, is likely to have also a positive impact on the industry, because it will force airports to immediately adopt better features in terms of design and technology, which otherwise may have taken years to implement. Once this crisis is over, airports and airlines will have to be more proactive and capable of enhancing their digital transformation, both on the organizational and commercial side, in order to reposition themselves in the global aviation industry (Poulaki and Papatheodorou, 2021).

During this pandemic, it is important to maintain the standard air travel experience and operational procedures. However, in the wake of the pandemic, there is also an opportunity to explore the potential of advanced technologies that will make passenger contact points intact and flexible, ready to receive passengers at all stages of air travel, effectively addressing any health and safety concerns arising. For example, the adoption of new technologies can significantly reduce staff interaction with passengers at the airport, ensuring social distance. The application of artificial intelligence (AI) technology can help the seamless flow of passengers because passengers can be screened faster and more accurately. The need for contactless security checks in the context of the pandemic may accelerate the development of AI technologies (ICAO, 2021). The development of biometric technologies at airports will allow airport operators to efficiently and accurately analyze large amounts of data, such as passenger ID verification, etc. (Amankwah-Amoah, 2021). COVID-19 had an immediate, dramatic impact on airport traffic and revenue. As people stop flying, non-aviation revenues from parking facilities, restaurants or tax-free, are equally reduced (IFC, 2020). However, with the use of technology, especially in security screening, passengers will waste less time in these processes and will have more time to spend in restaurants and shops, which improves their overall airport experience and increases non-aeronautical revenue for airports (Zaharia & Pietreanu, 2018).

2.2 Airport Innovative Services using Digital Technologies

Artificial Intelligence. AI is a technology that enhances both existing and new business opportunities for airlines and airports, as well as other aviation organizations. In the field of artificial intelligence, several new technologies used by airports to provide a new experience for air travelers include:

- Facial recognition technologies
- Virtual reality applications
- Chatbots
- Robots
- Interactive maps
- Language translators
- Ease of shopping, etc.

In the general aviation sector, the adoption of AI applications can facilitate (IATA, 2018c):

- Services available 24/7
- 100% up-to-date system
- Security and real-time monitoring

- Baggage delivery
- Commercial decision making

However, it should be mentioned that, while all the above applications are already technically possible, some of them may have regulatory hurdles or are not commercially viable yet. Furthermore, despite the significant benefits that AI has to offer, some limitations also arise. As Mercier-Laurent et al. (2015) mention, to date, AI cannot surpass human intelligence. There are additional areas where AI could be used and make improvements (IATA, 2018c), such as:

- Airport security
- Transparency in payments

Biometric Identification. International organizations and individual states cooperate with IATA, to formulate policies and regulations that will facilitate safe and sustainable industry. IATA has already created standards for messaging and exchanging passengers' data between airlines and governments, including API (advanced passenger information) and PNR (passenger name records). IATA has also developed the "ONE ID" initiative, aiming at replacing the electronic passport and improving processes and passenger experience from the beginning to the end of their journey. Biometric identification is at the core of this service (IATA, 2020). To facilitate passenger flow, facial, fingerprint or iris recognition will be performed at airport gates. The consolidation of biometric identification brings multiple benefits for passengers, airports, airlines and governments alike (Patel, 2018). Passengers will benefit from a seamless experience with a single identity (IATA, 2020) since:

- They will not have to worry about the numerous documents they currently have to carry
- They will have easy identification
- They will not need to go through repetitive procedures
- There will be no need for unnecessary paperwork; they will not have to worry about having to go through a lot of hassle
- They will avoid long queues, allowing passengers to arrive at the airport and be ready to fly,

while airlines and airports:

- Will increase their efficiency and performance, relative to their operating costs.
- Their staff will not spend time at ID checks, thus improving their productivity.
- Will have the ability to know, in real time, where passengers are at the airport, potentially directing them to the appropriate procedure.

Mobile Applications. Smartphones have become a key accessory for travelers who rely on them to get instant information and connect to their social network. Airlines are not stopping at introducing features for mobile devices to improve passenger processing and information flow. The use of these technologies as communication tools has been recognized by airlines seeking to improve their efficiency towards their passengers. Mobile applications enhance airlines' innovation since they increase communication speed, frequency and availability, while they can transform the travelers' experience boosting customer loyalty and increasing airlines' revenues (Katsoni and Poulaki, 2021). Large airports, following the commercial guidelines of their operators, are implementing a business model focused on developing a more creative environment in line with new technologies, leaving behind the image of a simple intermodal hub (Benitez, 2016).

Mobile applications are increasingly being used to access entertainment, games, news, weather and many other information sources. Major airports are taking advantage of mobile devices to create apps for advertising reasons. These apps have led to the creation of a new type of marketing, mobile marketing, which, due to its multiple functions, has been evolved in recent years into a product, rather than a simple communication medium. Mobile marketing contributes to the exploitation of the content of the services offered and increases the level of passenger satisfaction within the airport. The availability of new mobile applications, is one of the many products offered by their business portfolio, helps to manage passengers' time in an efficient way, for as long as they are at the airport, providing real-time information. At the same time, it favors the efficiency of the processes that passengers carry out at the airport, confirming the multifunctionality of this marketing tool is. More and more airports are resorting to mobile marketing in order to improve passenger satisfaction and experience at their facilities. The main benefits of mobile applications are (Benitez, 2016):

- Convenience provision,
- Address customized needs
- Quicker information dissemination

Passengers want to have the details of their journey available at their fingertips without having to call or wait for a travel agent to respond or send an email. As airlines strive to innovate, their approach must be practical and realistic. Consequently, in order to bring real innovation, airlines must provide information customized to the location of the passengers and their personal preferences. Globally, mobile technology can differentiate the airline product, however, fulfilling this goal is to some extent difficult. Certainly, every new opportunity that arises for airlines to beat the competition has its difficulties. The mobile device technology is a unique opportunity, given the speed at which these devices are evolving and the efforts that airlines are making in terms of using ancillary services and market segmentation techniques to differentiate their products.

2.3 Benefits for airports, airlines and passengers

Airports. By digitalizing airports, the objectives of operational efficiency and improved passenger experience are being achieved in terms of:

- Airport Operations
- Passenger Journey
- Ancillary revenues

An effective digital transformation does not come from implementing the latest technologies, but from transforming organizations to realize the potential offered by digital solutions (ACI, 2017). Digitalization brings many benefits to airports, business partners and customers, at different levels. Through digitalization, airports are positioning themselves in the wider ecosystem, joining forces with other partners and stakeholders. In doing so, they ensure that, they benefit from market innovation and create greater value for all their customers (ACI, 2017). The benefit of enhanced interaction through digital technology with passengers is twofold (Amadeus, 2019) passengers have access to tailored, detailed information, efficiently and in return, airports gain valuable insight into customer behavior and needs.

Particularly for the airports, some of the benefits are summarized below are (ACI, 2014; Gardy, 2016):

- Efficiency of operations
- Automation activities
- Real-time monitoring processes
- Provision of real-time self-service, guidance and travel information to passengers
- Process optimization
- Improving employee productivity
- Cost reduction
- Innovative business model
- Development of new revenue streams (other than aviation)
- Segmentation of airline passengers (in order to offer new services to the right people, at the right time, at the right price)
- Improving customer experience
- Processing of undocumented passengers
- Improving brand value (creating a strong brand)

The digital offerings of any airport define its digital strategy and allow it to differentiate from competitors. Through a digital strategy, airports are improving areas of quality, interaction and service diversion and they are overcoming operational and capacity shortcomings. Operational efficiency can be improved through new innovative systems, advanced technology, such as biometrics, which identifies and processes passengers faster. Capacity issues become more apparent in cases of flight delays, disruption, mistaken passengers and disappointing experiences. With the use of artificial intelligence, there is the potential for accurate flight forecasting, allowing airports to do better planning (Little, 2015).

Airlines. In recent years, an impressive wave of digital innovation has emerged across the airline industry. The digital transformation of airlines is revolutionizing the way airlines use their technology and human sources and adapt their processes to radically change their business performance (Boulton, 2017). This is a new look at how airlines are integrating new technologies into their processes:

- To better serve their customers
- To become more efficient
- To increase their commercial value

The main benefits resulting from the digital transformation of airlines are summarized below (Dubos, 2017):

- Better passenger experience thanks to personalization and customization
- Digital transformation helps boost ancillary sales
- Strengthen customer loyalty
- Improve customer support
- Crisis management
- Strategic integration of distribution/partner channels
- Insightful business analysis
- Protecting brand value
- Creating a virtuous cycle of innovation
- Protection against market disruption

Passengers. Passengers today expect a fully digital experience from airports and airlines, that need to develop a strong digital identity. New technologies, give passengers control over their journey and minimize the time required to process their data at every step at the airport until boarding the aircraft. Therefore, they have a comfortable travel experience (Raina, 2020). A good travel ecosystem is well shaped by new technologies and digital transformation, which represent the means to simplify the life of passengers (Baust, 2017). They offer the passenger the convenience of booking their entire journey through a platform that has it all (e.g., ticket, staging area, car rental, etc.). Furthermore, through innovative technologies, passengers are benefited from personalized services that meet their needs and preferences, in summary, the main benefits that passengers gain from the adoption of innovative services at airports are:

- Convenience
- Ease of access
- Simplification of procedures (e.g., personalization)
- Safety
- Reduced waiting time at the airport
- Minimize stress
- Control of the journey at all stages

From all the above, we conclude that through the innovative digital products and services that airports and airlines provide to passengers, their level of service is enhanced in all dimensions of their journey, and they have the flexibility to manage it at all stages.

3. RESEARCH METHODOLOGY

In this paper, qualitative research has been conducted through structured personal interviews. Qualitative research aims to explore and deepen understanding of a case study or social phenomenon. It is a flexible method, in terms of the research process, which explores trends, motivations, perceptions and experiences that interviewees have gained from their experience of the topic being researched. The analysis of responses and the small sample of participants are characteristics of qualitative research. With the interview method, the researcher, groups and compares the views of the respondents. The method of data collection used is structured face-to-face interview and the sample was selected using the judgment sampling method, in which the researcher selects a representative sample according to their opinion (Kent, 2003). Through the questionnaires used for the interviews, the selected sample is asked to answer the same set of questions in a specific order. Specifically, the interview was based on an 11-question inquiry. To formulate questions for the questionnaire, the objective of the research was first identified, the method of data collection was selected, and the characteristics of the respondents were understood.

The questions of the interview (appendix), aim to capture the experiences and opinions of the participants regarding digital transformation and innovative service delivery at airports, as well as the resulting benefits for all stakeholders. In addition to these, there are questions, referring to the COVID-19 pandemic crisis, such as whether the pandemic crisis can promote industry change and whether it represents an opportunity for the digital transformation of airports and airlines. In summary, while drafting the questionnaire, an effort was made to include questions that would ensure variety and breadth in order to draw safe conclusions. Each question constituted a separate topic, corresponding to a separate digital transformation area. The validity and reliability of the questions, are based on the fact that they were derived from a) two IATA conferences, the first one on technology and its advancement in the evolution of passenger experience and infrastructure at airports (IATA, 2019), and the second one, the Global Airport and Passenger Symposium, held in 2018 (IATA, 2018a); b) an IATA study exploring the forces shaping the future of aviation and the potential implications for the aviation industry (IATA, 2018b); c) the World Customs Organization's study on new airport technologies (WCO, 2019); and d) the Amadeus report on the digital transformation of airports (Amadeus, 2019). The characteristics of the interviewees are summarized in Table 1.

Table 1. The interview sample

Professional Status	*Organization*	*Experience*
Flight Operations Manager and Deputy Accountable Manager	Airline	many years of experience in the aviation industry in the fields of flight safety and crisis communication management
Product and Services Manager	Airline	many years of experience in airport terminal operations
Airport Services Manager	Airline	overseeing all airport terminals in Greece
Head of Customer Care Center	Airline	many years of experience in passenger service at both airport and airline
Chief Commercial Officer	Airline	many years of experience in commercial directorates, most of them in managerial positions
Information Technology and Telecommunication (IT&T) Business Unit Director	Airport	22 years of experience in the aviation sector and actively involved in airport technology issues
Customer Relationship Management (CRM) Team Leader	Airline	experienced in customer oriented big data analytics

Seven interviews were conducted with persons actively involved in the Greek aviation industry (dominant airline and Athens International Airport - AIA). The passenger volumes served in 2019 exceeded fifteen million for the airline and twenty-five million for the airport. Thus, it is considered as a significant market to investigate. Their representatives were initially approached by telephone and the interviews took place in their offices or via videoconference, during the first two waves of the COVID-19 pandemic in 2020. In order to draw useful and correct conclusions, all the opinions on the various issues were analyzed. First, the common responses to the different themes were coded and then, the differences and similarities of the expressed opinions were listed. Based on the recordings of the interviews, the following section is an evaluation of the findings, along with two axes: similarities and differences.

3.1 Research Limitations

A limitation of the current study is the small number of people interviewed. The more views covered, the more secure the conclusions. The chosen sample, however, was selected according to the professional status and their direct relationship with the airports. Additional limitations arise because the interviewees could not provide further information due to data confidentiality.

4. FINDINGS

4.1 Similarities

From the interviews conducted, it was apparent that the interviewees agree on most issues, while they have different opinions only on a few issues. All the respondents believe that technology can be a competitive advantage for an airport or airline, and they stressed the importance of technology which is now an integral part of the travel experience. Also, all the responses indicated that technology may improve the overall passenger experience through its potential and benefits all stakeholders. In terms of the level of digitalization at AIA, there was a general agreement that it is at a good level, unlike other Greek airports, and all respondents cited several examples to demonstrate their estimation. Furthermore, a commonality in the respondents' answers is the view that the COVID-19 pandemic will bring about changes in the aviation industry and enhance the role of technology in line with the differentiated needs of airlines and passengers. In addition, they unanimously argue that air travel is being driven towards full digitalization, and the consequent abolition of travel documents cannot negatively affect passengers' personal security. Another common factor is the increase in passenger confidence resulting from the real-time information on their journey, which is now available through advanced technology. Passengers' loyalty to the brand is enhanced by innovative services, as interviewees jointly argue, because technology brings efficiency. Furthermore, there was a similarity in the responses on the improvement of the passenger experience using technology by the airport and airlines, indicating the value of investments in this area and the benefits for all participants. All also agreed that their future business plans were dramatically affected by new technologies and indicated that further digitalization of products and services was in their first priorities. Finally, all respondents felt that the role of technology would be enhanced following the COVID-19 pandemic, which would facilitate tourism recovery.

4.2 Differences

On the other hand, it was observed that the respondents have different views on one of the interview questions. In particular, there are disagreements on the issue of personalizing the passenger experience and whether this is still a vision or a tangible goal, using the data available today. Half believe that it is a tangible goal that can be achieved with the right cooperation between stakeholders and the appropriate organizational structure, while the rest believe that it is a goal that has already been materialized and is happening now.

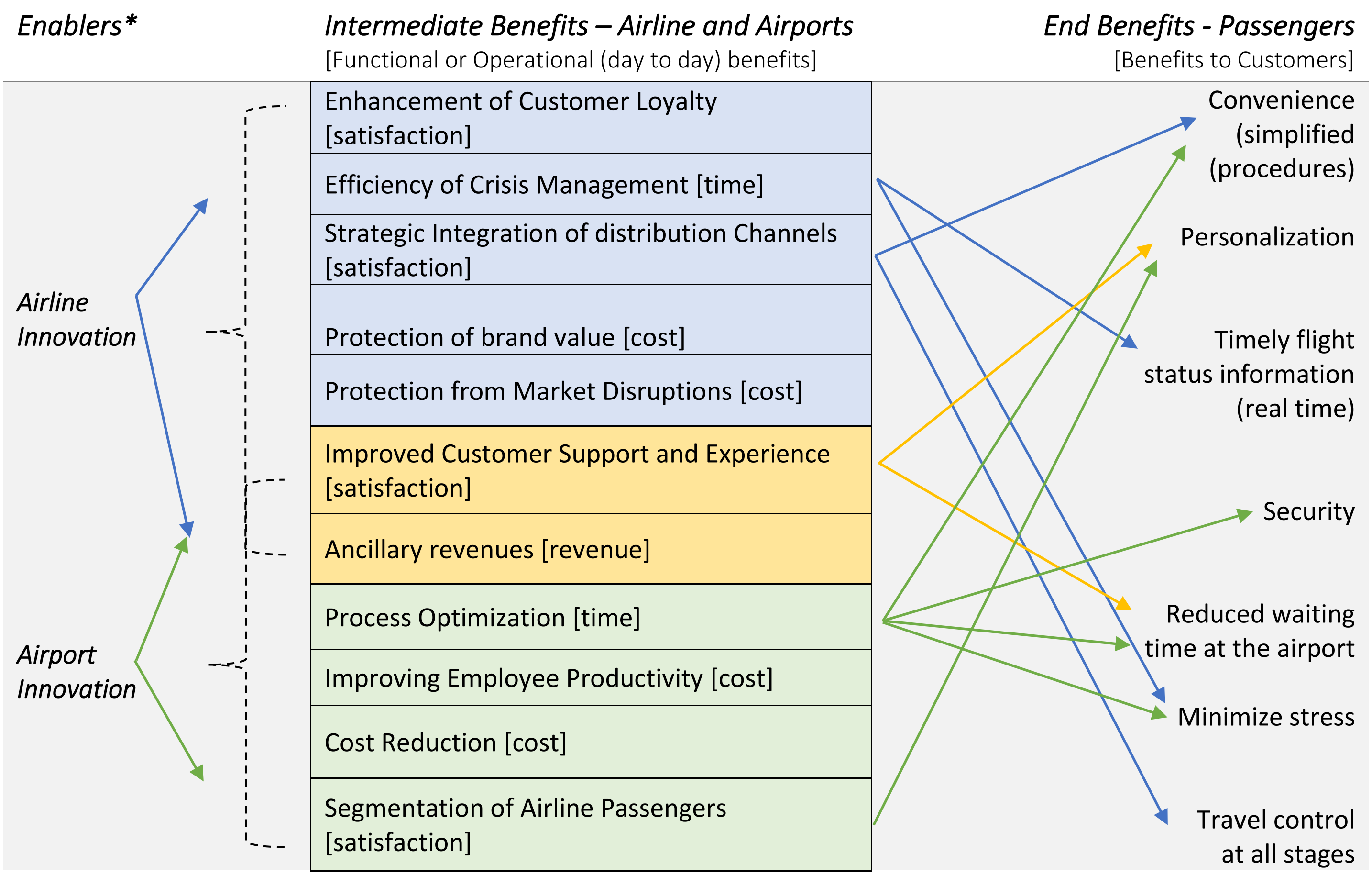
The COVID-19 pandemic caused a global crisis and the international quarantine measures, had a negative impact on tourism. Travel postponement or cancellation due to COVID-19 is estimated by the Global Business Travel Association to cause losses to industry operators that could reach $820 million worldwide, by the end of the year 2020 (Rutynskyi and Kushniruk, 2020). A recent IATA survey showed that people are concerned about COVID-19 when they travel (IATA, 2020). IATA argues that the measures introduced to protect passengers, are leading to the restoration of confidence in travel, but this will take some time. According to Sigala (2020), COVID-19, may be an opportunity to transform the tourism industry. He argues that it will significantly influence travel attitudes, intentions and future behaviors, claiming that crises accelerate technological innovation and change.

5. DISCUSSION

Research findings confirm previous relevant studies, while both literature review and research findings indicate a triangular relational system involving airports, airlines and passengers, in which the use of digital technologies results in innovation and brings benefits to all stakeholders. The authors, based on the benefit modelling approach of the Northern Ireland Department of Finance (DoF), developed the benefit model for innovative air travel. After the benefit identification, the relationship between the different levels of benefits is clarified, while the benefit model is developed in a graphical representation with three main sections (from left to right). These sections include:

- Enablers, that concern new capabilities, directly attributable to the investment in digital technologies connected to the innovative services provision.
- Intermediate Benefits, that concern the actual operational and services provision improvement, driven by the use of digital technologies, when it comes to the internal processes and integration.
- End Benefits, that concern the strategic benefits to the customers resulting from the middle-level intermediate benefits to the organizations.

According to this benefit model approach of DoF, intermediate benefits should have a unique identifier that may include cost/revenue, time and satisfaction.



** [New tangible capabilities directly attributable to the investment in digital technologies]*

Figure 1. The Benefit Model for Innovative Air Travel

6. CONCLUSIONS AND THE WAY FORWARD

This paper explored the interaction between airports, airlines and passengers in the light of innovative technologies used in airport services. Its objective was to capture the implementation of innovative technologies in airports and to highlight both their technical and commercial importance from the perspective of the main stakeholders: airports, airlines and passengers. For the purpose of the study, a review of the development of services at airports was carried out, a reference was made to the basic services of airports and the necessity of adapting services to modern trends was presented. Subsequently, a literature review was conducted in the field of new technological innovations adopted globally by airports, in recent years. The issue of technological development of airports and airlines has been studied more in the international literature, while Greek references on this issue are scarce. In addition, online sources and the studies of international organizations, such as IATA and ACI, contributed greatly to the completion of the literature review. The benefits of digital transformation for airlines, airports and passengers were then investigated. Primary research was conducted to document the study through interviews and the findings were presented.

The COVID-19 pandemic has greatly reduced tourist traffic and has particularly affected air travel, but the findings of the study suggest that the use of technology is one of the important factors that will help passengers to regain their confidence in air travel. New technologies can make a decisive contribution to the development of a country's aviation sector and tourism product, improving quality and making it more competitive in terms of pricing. Passenger volumes continue to grow, and their needs and expectations are diversifying. Airports and airlines cannot meet these expectations with traditional approaches. Digital technologies can help airports to ensure that their facilities utilize maximum capacity, enhancing passenger flows and time efficiency, which is very important both for airlines and passengers. The need for aviation industry digitalization is growing significantly, mainly for two reasons: the pursuit of revenue growth and increased competition. The importance of commercial revenue is crucial for airports that saw their aeronautical revenues hit hard by the pandemic. Airports, therefore, need to take advantage of technology to communicate their marketing strategies, increasing passenger satisfaction levels and non-aeronautical revenues. Digital technology can offer many opportunities in this direction. For several years now, the aviation industry has been exploring, installing and using technologies designed to accelerate the flow of passengers through airports. Biometrics, artificial intelligence, mobile apps, self-service capabilities and other technology solutions are rapidly transforming the airline industry as an ecosystem. These technologies are providing passengers with a much more enjoyable travel experience. At the same time, they are bringing significant improvements in airport capacity and greater border control and security. However, it must be made clear that to reap the full benefits of new technologies in the future, airports must continue to evolve every day. Sustaining the benefits is influenced by developing a culture and the ability to anticipate future digital technologies, innovating on those technologies, applying them to every airport and investing in partnerships that will make digital transformation sustainable.

The aviation industry gains a competitive advantage using new technologies, but the sales of airlines are particularly affected. Because of the specificity of their activities, airlines have more room than airports to build and maintain relationships with passengers at every stage of their journey. However, airports are not remaining passive and are increasingly responding to the needs of the market. Around the world, technology is transforming the future of air travel. Not only must airlines keep pace with passenger expectations, but they must also maximize the unique opportunity to use new technologies to differentiate their products, increase sales and enhance customer brand loyalty. The study highlighted a strong future development in ancillary revenues, from the use of new technologies in mobile devices. These services can entice passengers to maximize their spending. Easy access to ancillary services offers flexibility and convenience to passengers while benefiting airlines and airports with additional profits. Through mobile marketing, airports are effectively enhancing passenger experience and satisfaction. Airlines, through mobile apps, are reducing the cost of passenger services and gaining the opportunity to establish real-time, interactive contact with passengers. The use of these applications is a source of numerous benefits for the travelers themselves eventually. Designing products and systems that meet passenger expectations, making their journey easier, can create long-term value for airports and airlines through customer perception and ultimately loyalty. The results of the primary research showed that technology and the new services resulting from it have a positive impact on passengers' overall perception, meeting their expectations in terms of security efficiency, the control they gain over their travel and the ability to be informed in real-time. In addition, it was found that the use of technology contributes to an increase in passengers' trust and loyalty to airports and airlines. Ultimately, the use of technology benefits all major aviation stakeholders and finally reaches to satisfy the final recipient: the passenger.

Efficiency, personalization, self-service, and the infinite possibilities offered by advanced technologies are more necessary today than ever before. The usefulness and benefits resulting from the digital transformation of airports and airlines are confirmed by industry professionals. The findings of the primary research are fully in line with the findings of the international literature. It is also concluded that airports and airlines should make more efforts to improve the services they provide to passengers by developing a quality strategy based on modern practices and advanced technology to gain a competitive advantage. Following the proposed benefit model for innovative air travel, airports and airlines should invest more in technology introducing it into the processes they already have in order to ensure passenger experience optimization. It is necessary to continuously evaluate the quality of procedures and services offered by airlines and airports altogether, in accordance with the needs and requirements of passengers, intending to increase their satisfaction and improve the tourism and economic development of the whole country. To further explore the individual points of this study, the following are proposed: Although hub airports have the financial capacity to implement their digital transformation, it would be useful and interesting to examine, which technologies should be prioritized, in those airports that do not have the luxury of resources. The markets offered, for additional services, through mobile applications, by airlines, before or even during the journey, may affect airports. It would therefore be useful to investigate the commercial impact, which airlines have developed in recent years, on the commercial activity of airports. Finally, it would be interesting to study passenger satisfaction in relation to the technological development of airports and airlines they use for their travel.

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APPENDIX

Research Questionnaire (Interviews)
1. Can technology be a competitive advantage for an airport/airline? At what points of contact with the passenger can it improve the passenger experience?
2. What stage of digitalization is Athens International Airport at, and what digitalization projects has it already carried out to ensure a seamless travel experience?
3. What kind of long-term structural changes do you think the COVID-19 pandemic will bring about in tourism?
4. Can the COVID-19 crisis promote industry change? Is it an opportunity for digital transformation?
5. A "smart" airport, which has adopted advanced technologies such as artificial intelligence, robotics and other digital developments, is leading to paperless (documentless) air travel processes. Do you think this may shake the passenger's confidence in the airport/airline as to their personal safety?
6. With the adoption of innovative services, for example, real-time information on mobile devices from the airline about the status of the flight, does this increase passenger loyalty to the brand of the company?

7. Do you consider that the investment you have made so far in the digitalization of the passenger experience has contributed first to the financial growth of the company and then to the improvement of the customer experience? Which parts of the company have benefited most from the above investment?
8. Can you think of an example where the digital transformation has improved an airport process?
9. Is personalizing the passenger experience, with the availability and accuracy of data that exists nowadays, a tangible goal, or is it still a vision?
10. To what extent have your plans, development-wise, been affected by the COVID-19 pandemic? What were your plans before the pandemic outbreak?
11. What is your vision for the digital future of the air travel experience as it relates to the passenger, post-pandemic containment? Do you believe that the role of technologies in the recovery and redefinition of tourism will be enhanced?

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ASSESSMENT OF NOISE IMPACT OF AIRCRAFT OPERATIONS AROUND PODGORICA AIRPORT

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ABSTRACT

This paper analyses the impact of aircraft noise on community around Podgorica Airport, Montenegro. The airport is located 12 km from the city centre of the Montenegro capital, Podgorica. It served 1.3 million passengers and 7.5 thousand operations in 2019. The noise impact assessment is conducted in IMPACT web-based modelling platform using the distribution of operations by aircraft types, time of the day, and radar tracks for the busiest day (August 15) in 2019. Noise contours are assessed for Lden and Lnight indicators. They were merged with the Global Human Settlement Layer to assess the number of people exposed to different noise levels. In addition, based on the World Health Organization recommended exposure levels related to their health implications, the percentages of the population highly annoyed and highly sleep-disturbed are estimated. Furthermore, facilities of public importance (schools, hospitals, churches, etc.) are assessed against compatibility with the requirements set for the Zones with increased noise protection in national regulations. The results show that the exposure of community around Podgorica Airport to aircraft noise is still not a serious issue. The near vicinity of the airport is industrial zone and the number of people highly annoyed by noise is approximately 3.2% of the total city population. Nevertheless, it is crucial to draw attention to planners to preserve airport neighbourhood from potential inhabiting, to avoid problems that some airports in the region are facing nowadays.

KEYWORDS: aircraft noise modelling, noise impact assessment, population noise exposure, noise contours, noise annoyance

1. INTRODUCTION

The aviation industry was and will be continuously challenged to reduce environmental impact in the face of constant (although temporarily interrupted) increase in demand [1]. In 2017, The European Commission (EC) defined Flight Path 2050 strategy [2], which represents the vision of air traffic systems and the aviation industry in 2050. This strategy sets important safety, infrastructure, operational, environmental protection, and others goals. Flightpath 2050 sets the goal to reduce the perceived noise emission of flying aircraft by 65%, relative to typical new aircraft in 2000.

Aircraft noise is considered to be disturbing to population who live around airports. Increasing the number of take-off and landing operations may lead to increased resentment of the population, which may result in limiting the further development of the airport. Airports are facing a constant struggle to reduce the harmful effects of noise on the surrounding population to a minimum. Otherwise, air traffic may jeopardize its own development due to noise problems.

For decades, the industry has been working to reduce noise and numerous decisions have been made to mitigate negative impact of noise. The

International Civil Aviation Organization (ICAO) has defined "Balanced approach" [3] to aircraft noise management. The Balanced Approach identifies the noise problem at a specific airport and analyses various measures available to reduce noise, which can be classified into four principal elements: Reduction of Noise at Source (Technology Standards), Land-use Planning and Management, Noise Abatement Operational Procedures, and Operating Restrictions.

At the European level, Environmental Noise Directive 2002/49/EC (END) [4] has been introduced for the assessment and management of environmental noise. The Directive introduced the obligation of strategic noise map development and subsequently implementation of noise action plans. In course of that, numerous studies have been conducted to meet these requirements. Following the European Noise Directive, Ozkurt et al. [5] assess the level of aircraft noise exposure around İstanbul Atatürk Airport. In [6] noise levels for the day, evening and night time slices around İzmir Adnan Menderes Airport were calculated, showing that about 2% of the resident population was exposed to noise levels of 55 dB(A) or higher during day-time in Izmir. Study on Aircraft Noise for Athens International Airport [7] based on 2006 and 2011 Strategic Noise Maps (SNM) and Noise Action Plans for the EU indicators L_{den} and L_{night}, has been done. In [8] a complete Strategic Noise Mapping research and Action Noise Plans assessment and evaluation, for the Larnaka International Airport in Cyprus, were presented and aimed to access land use management as an effective tool for protection from aircraft noise. In [9] the noise impact produced by the airport Galileo Galilei in Pisa, Italy, was estimated and exposed population were evaluated.

This paper examines the noise impact on community around Podgorica Airport in Montenegro. The analysis was done in the IMPACT web-based modelling platform, for the day with the largest volume of traffic (August 15) in 2019.

The paper is organized as follows. Section 2 provides some general information about Podgorica Airport, including location of the airport, the number of passengers and aircraft operations, the airlines that operate at the airport, etc. Section 3 provides methodology together with information about IMPACT software and required input data for noise impact analysis. Section 4 summarizes the results on noise exposure analysis for the Podgorica Airport case study. Noise contours were assessed for L_{den}, as well as for L_{day}, $L_{evening}$ and L_{night} indicators and the number of people highly annoyed and highly sleep disturbed by the aircraft noise, was estimated. Section 5 contains conclusions and ideas for future works.

2. PODGORICA AIRPORT

The main goal of this study was to analyse impact of aircraft noise on community around Podgorica Airport. Podgorica Airport (ICAO: LYPG) is an international airport located 12 km south of the capital of Montenegro, Podgorica, and together with Tivat Airport (ICAO: LYTV) is one of the two civil airports in Montenegro. The airport is located next to the main roads E65 and E80, which connects Podgorica with the coast via Skadar Lake and the Sozina tunnel.

Podgorica Airport has one runway 2500 m long and 45 m wide, with a north-south orientation 180°/360°. The airport has ICAO classification 4E/ILS CAT I, though ILS landing is only possible on runway 36. The northern approach to runway 18 is visual only, possible under visual meteorological conditions (VMC). This is due to the proximity of the Dinaric Alps on the north.

International flights and domestic flights within Montenegro take place from Podgorica Airport. Due to the proximity of LYPG and LYTV, there are no scheduled flights, only charter flights. At Podgorica Airport, the number of flights depends on the time of year. Some of airline companies that use Podgorica Airport are: Montenegro Airlines, Air Serbia, Wizzair, Ryanair, Alitialia, Turkish airlines, Austrian airlines, etc. In the summer months there is an increase in traffic, and companies flying to Podgorica are: Lot Polish Airlies, Enter Air, Rossiya Airlines, Tui Fly Belgium, Aegean Airlines, etc.

During the period from 2014 to 2019, the number of passengers at Podgorica Airport was constantly increasing, Figure 1. Podgorica Airport handled nearly 1.3 million passengers in 2019, which was an increase of 85.7% compared to the number of passengers in 2014 (0.7 million) [10].

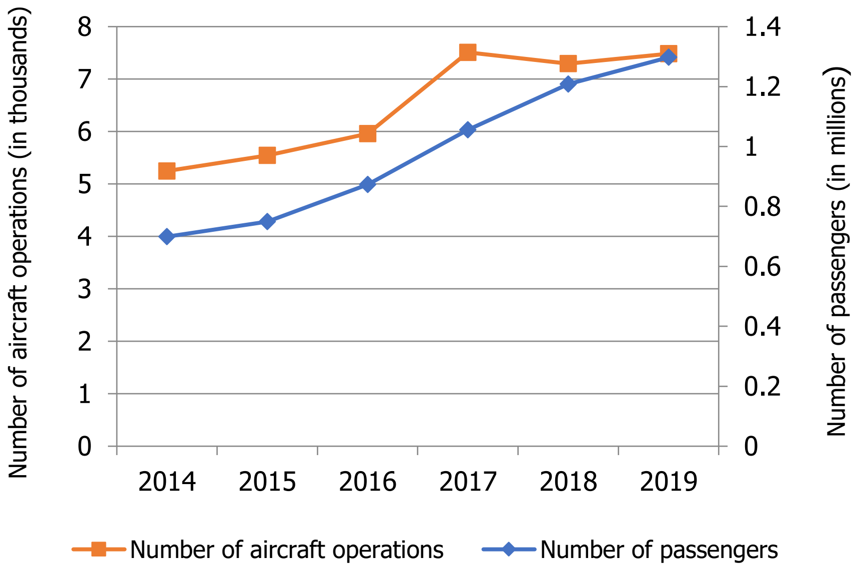

Figure 1. Total number of passengers and aircraft operations at Podgorica Airport

From 2014 to 2017, the number of aircraft operations was constantly increasing, while in 2018 there was a slight decline [10]. In 2019, the number of aircraft operations increased again and it was around 7500, which was an increase of 42.6% compared to number of aircraft operations in 2014 (around 5250).

3. METHODOLOGY

To analyse the impact of aircraft noise on community around Podgorica Airport, several steps were performed. In the first step, the software for noise prediction and mapping were chosen. Subsequently, all required input data, such as number of aircraft operations, aircraft types, arrival and departure routes, runway in use, meteorological data (temperature, atmospheric pressure, relative humidity, headwind speed), population data, terrain data were collected and used by software for the noise contours calculation. The obtained noise contours and the collected population data were used for noise exposure analysis. A brief description of the software that has been used for noise contours modelling and collected input data is given bellow.

3.1. Impact Software

There are many different noise prediction and mapping software that could be used to calculate noise exposure around an airport. For the purpose of making this study IMPACT (Integrated aircraft noise and emission platform) software was used.

IMPACT [11] is a web application for assessing the impact of civil aviation on the environment in terms of noise and gaseous/particulate emissions. IMPACT produces noise maps around airports according to widely used and recognised noise metrics such as LA_{eq}, L_{den}, LA_{max}, and SEL. It calculates the area of each noise contour and the number of people living within it. IMPACT uses reference data such as the Aircraft Noise and Performance database (ANP) [12] and/or the Base of Aircraft Data (BADA) [13]. ANP is a database that accompanies the ECAC Doc 29 [4] and ICAO Doc 9911 [14] guidance documents on airport noise contour modelling. ANP provides reference data for the modelling of departure and approach flight phases, as well as for determining noise levels. BADA is an aircraft performance database and model that provides all the required parameters to calculate the 4D trajectory of an aircraft by using the Total Energy Model. IMPACT takes into account the fact that different aircraft types overfly locations at different altitudes and thrust settings.

3.2. Input Data

Traffic data were collected for the day with the highest number of aircraft movements in the 2019 (August 15th). During the observed period, there were 64 operations, out of which 33 departures and 31 arrivals. The runway 18 was used for 28 operations (44%), while the runway 36 was used for 36 operations (56%). Since departing and arriving aircraft vectoring is mostly in place at Podgorica Airport, actual radar data (Figure 2) [15] were used for departure/arrival route modelling instead of Standard Instrument Departure (SID) and Standard Arrival Routes (STAR). The blue colour in Figure 2 indicates departure routes, while arrival routes are marked in red.

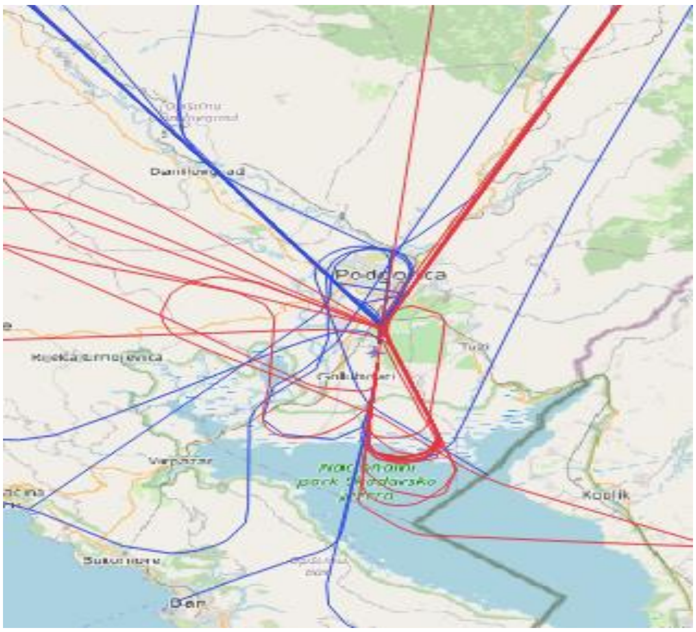

Figure 2. Departure and arrival routes (source: Flightradar24.com)

The fleet mix consisted of 12 different aircraft types: Dornier 328, Fokker 100, Embraer 175, Embraer 195, Bombardier CRJ700, ATR 72, Airbus A320, Airbus A319, Boeing 737-800, Boeing 737-300, Cessna 550 Citation Bravo and Cessna Citation Excel 560. The frequency of occurrence of each type of aircraft is shown in Table 1.

On August 15, 2019, three quarters of all operations (48) were performed during the day, 14% (9) in evening and 11% (7) night flights. This flight schedule at Podgorica Airport was favourable from the standpoint of noise because the least number of operations was during the night period. However, 11% of the total number of operations is not negligible and night noise, associated with the highest sensitivity of the population, might be serious problem.

Terrain data were obtained from the NASA SRTM (Shuttle Radar Topography Mission) database [17], which contains high-resolution digital topographic database of Earth.

Population data for each location around Podgorica Airport was obtained from the Global Human Settlement Layer [16]. This spatial raster dataset depicts the distribution and density of residential population, expressed as the number of people per cell. The data obtained are very detailed with a resolution of 100 m. According to this data source, there are 177,803 inhabitants in the municipality of Podgorica.

Table 1. Aircraft frequency at Podgorica Airport (August 15th, 2019)

Aircraft type	**Number of departures**	**Number of arrivals**	**Total number of operations**	**Frequency**
Boeing 737-800	9	9	18	28.1%
Airbus 320	4	4	8	12.5%
Fokker 100	4	3	7	10.9%
Embraer 195	4	3	7	10.9%

Aircraft type	Number of departures	Number of arrivals	Total number of operations	Frequency
Boeing 737-300	3	3	6	9.4%
Embraer 175	2	2	4	6.3%
Cessna 550 Citation Bravo	2	2	4	6.3%
Dornier 328	1	1	2	3.1%
Bombardier CRJ700	1	1	2	3.1%
ATR 72	1	1	2	3.1%
Airbus 319	1	1	2	3.1%
Cessna Citation Excel 560	1	1	2	3.1%
Total	33	31	64	100%

Figure 3 shows the population distribution of the municipality of Podgorica relative to Podgorica Airport. To estimate the noise exposure of inhabitants living within each cell, for each population grid cell (100 m x 100 m) noise levels were calculated at the cell's centroid.

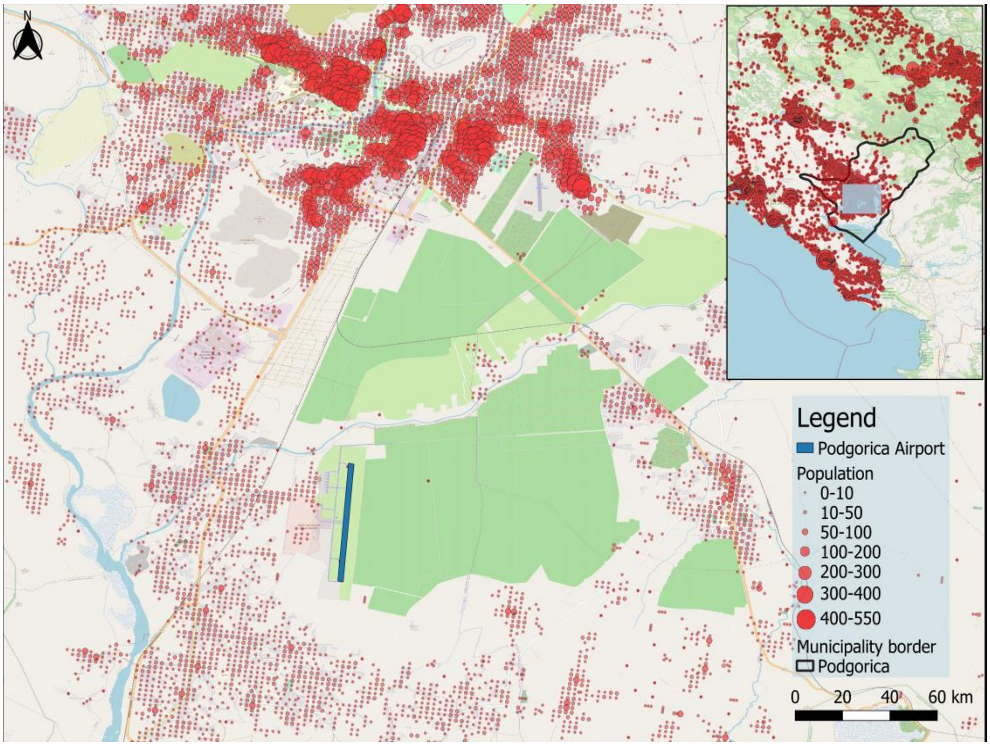

Figure 3. Population in the municipality of Podgorica

Meteorological data were collected from the Iowa Environ Mesonet [18] reports for Podgorica Airport. Average temperature in Podgorica, on 15.08.2019. was 25.57 °C. Average relative air humidity was 46.30%, the average atmospheric pressure was 29.86 inHg, while the average headwind was 6.73 kt.

4. RESULTS AND DISCUSSION

4.1. Noise Exposure Assessment

Noise contours are assessed for L_{den}, as well as for L_{day}, $L_{evening}$ and L_{night} indicators separately, according to [4] and [19]. L_{den} and L_{night} noise contours are given in Figure 4 and Figure 5, respectively. In order to assess the number of people exposed to different noise levels, noise contours were merged with the Global Human Settlement Layer [16]. The A-weighted equivalent sound pressure level in dB (L_{Aeq}) has been calculated for each period and for each location nearby Podgorica Airport. The population at locations within the same noise contours was summed and presented in Table 2 as the number of people exposed to different noise level range.

Table 2. Total number of people exposed per each noise band

	Number of people exposed per each noise band (dB)					
	<40	**40-45**	**45-50**	**50-55**	**55-60**	**>60**
L_{day}	71,686	69,500	7,380	1,178	30	5
$L_{evening}$	84,829	12,524	1,261	497	4	4
L_{night}	66,543	25,391	594	1	5	0

Only five people were exposed to noise greater than 60 dB during the period of the day and four during the period of evening. No one was exposed to noise above 60 dB during the period of the night. Thirty people was exposed to noise between 55 dB and 60 dB during the period of the day (7 am to 7 pm), four during the period of the evening (7 pm do 11 pm), and five people during the period of the night (11 pm to 7 am). For night period, lower limits are usually set than the ones for day and evening periods.

Table 3 shows limit values for outdoor noise indicators for different zones and land use in Montenegro [19]. The homogeneous acoustic zones are characterised by different noise limit values in three periods (day, evening, and night). The limit values refer to overall noise from all sources in the considered area. Indicators listed in this table (L_{day}, $L_{evening}$, L_{night}) are defined as average values of the yearly noise level during the period of the day they represent. For residential areas, legal noise limit value of 55 dB (A) was used for day period and evening periods, while noise limit value of 45 dB was used for night period.

Table 3. Limit values for outdoor noise indicators in Montenegro

Acoustic zone	**L_{day}**	**$L_{evening}$**	**L_{night}**
Quiet zone in nature	35	35	30
Quiet zone in the agglomeration	40	40	35
Zone of increased noise protection mode	50	50	40
Residential areas	55	55	45
Mixed use zone	60	60	50
Zones under the strong influence of noise from air traffic	55	55	50
Zones under the strong influence of noise from road traffic	60	60	55
Zones under the strong influence of noise from railway traffic	65	65	60
Industrial zone	Noise must not exceed the limit value of the neighbouring area.		
Mineral exploitation zone			

From Table 2 it can be seen that 35 people is exposed to noise greater than 55 dB during the day, and less than 10 (8) people during evening period. As for the night periods, 600 people are exposed to noise above set limit of 45 dB.

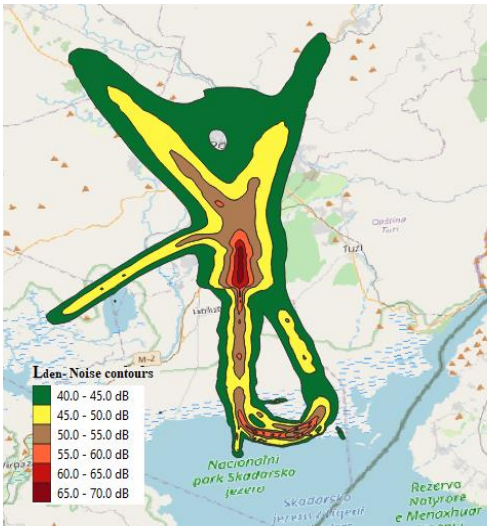

Figure 4. L_{den} – noise contours

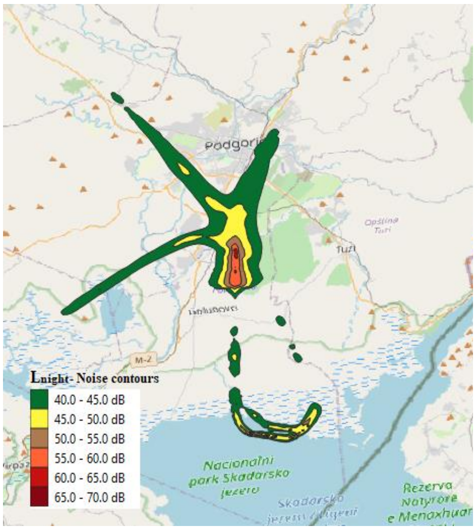

Figure 5. L_{night} – noise contours

4.2. Assessment of Harmful Effects

In order to assess the annoyance and harmful effects of aircraft noise to population, dose-effect relation is used, concerning the following (European Commission, 2020) [20]:

- the relation between high annoyance and L_{den} for air traffic noise,
- the relation between high sleep disturbance and L_{night} for air traffic noise.

For the calculation of the absolute risk (AR) with respect to the harmful effect of high annoyance (HA), defined as occurrence of that harmful effect in a population exposed to a specific level of environmental noise, the following dose-effect relations shall be used:

$$\mathrm{AR}_{HA} = (-50.9693 + 1.0168 \cdot \mathrm{L_{den}} + 0.0072 \cdot \mathrm{L_{den}}^2)/100 \quad (1)$$

For the calculation of the AR, with respect to the harmful effect of high sleep disturbance (HSD), the following dose-effect relations shall be used:

$$\mathrm{AR}_{HSD} = (16.7885 - 0.9293 \cdot \mathrm{L_{night}} + 0.0198 \cdot \mathrm{L_{night}}^2)/100 \quad (2)$$

The given equations are precise enough for practical use and are used as facilitation and replacement for assessment based on empirical data (such as surveying the population around the airport). Using the equations (1) and (2), based on the values of the noise indicators L_{den} and L_{night}, population data for each location and the World Health Organization recommended exposure levels related to their health implications [21], the number of people who may be highly annoyed and sleep disturbed by air traffic noise was estimated. The number of people who may be highly annoyed by air traffic noise were 5687, while the number of people who may be highly sleep disturbed were 3248.

According to the recommendations of the World Health Organization (WTO), the noise limit value for the day period is 45 dB, while the noise limit for the night period is 40 dB [21]. For this reason, in calculation of number of people highly annoyed and highly sleep disturbed, only locations exposed to noise greater than or equal to 45 dB during the period of the day and evening and locations exposed to noise greater than or equal to 40 dB during the night period, were taken into account.

4.3. Assessment of Noise Levels at Facilities of Public Importance

Figure 6 shows locations of some of the facilities of public importance (schools, hospitals, churches, museums, etc.) in the municipality Podgorica. According to national regulations of Montenegro [19] these facilities are defined as Zones with increased noise protection. That means that the noise in their surroundings must not exceed the limit value of 50 dB for the period of day and evening, and 40 dB for the night period. In order to examine whether the limit values are exceeded, it was necessary to calculate noise exposure for each of these locations.

During the day (7-19h) and in the evening (19-23h) none of the locations were exposed to noise greater than 50 dB. During the night period (23-07h) location such as Church of the Holy Great Martyr George (Crkva Svetog

Velikomučenika Georgija) one in Vojvodjanska Street and the other in Vladike Danila Street, Dajbabe Monastery, elementary school "Marko Miljanov", kindergarten "Artić Pinokio", and health center "Konik" were exposed to noise greater than 40 dB. Since the working hours of these institutions are during the day, the impact of noise was considered to be insignificant.

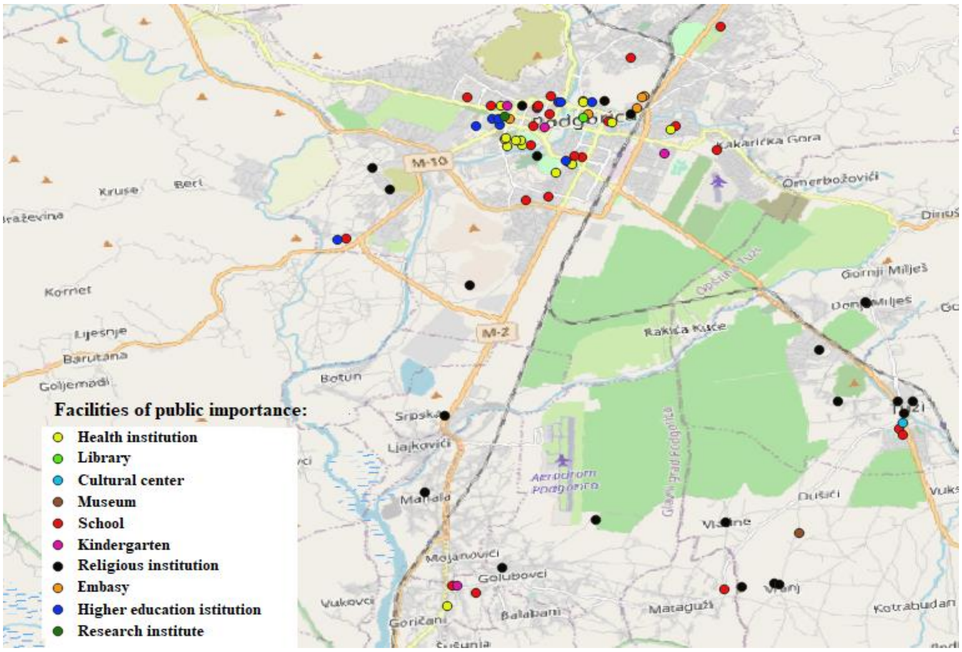

Figure 6. The facilities of public importance in the municipality of Podgorica

4. CONCLUSION

In this paper, the impact of aircraft noise on community around Podgorica Airport was analysed. The day with the largest volume of traffic was observed and it consisted of 64 aircraft operations. Noise contours around the airport were calculated and the number of people who may be highly annoyed and highly sleep disturbed by the aircraft noise was estimated.

The results show that the exposure of community around Podgorica Airport to aircraft noise is still not a serious issue. There are no larger settlements in the vicinity of the airport, the area is mostly uninhabited or there are industrial zones. The number of people highly annoyed by noise is approximately 3.2% of the total city population, while the number of people highly sleep disturbed is approximately 1.82%. Nevertheless, it is crucial to draw attention to planners to preserve airport neighbourhood from potential inhabiting, to avoid problems that some airports in the region are facing nowadays.

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THE ECONOMIC FEASIBILITY TO REDUCING ENERGY USE IN LARGE COMMERCIAL U.S. AIRPORT BUILDINGS THROUGH LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED) CERTIFICATION

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ABSTRACT

There is a growing movement in the U.S. (e.g., airports) to obtaining LEED (Leadership in Energy and Environmental Design) certification to reduce energy use. LEED advocates assert, on average, 25% less energy used by LEED-certified buildings compared to conventional commercial buildings. In the absence of studies regarding large U.S. LEED commercial airport buildings, a systematic quantitative review, content analysis and SWOT was performed to determine the economic feasibility of reducing energy use in airport buildings. A systematic quantitative literature review, combined with a comparison of LEED cost-benefit studies, and LEED certification objectives - to - airport facility energy requirements and U.S. government energy reduction initiatives was performed. Positive and negative (Pro/Cons) energy reduction findings were catalogued, charted, and analyzed. The findings from 1) LEED commercial building studies, 2) the LEED cost-benefit studies, and 3) the comparison of LEED certification program to large commercial U.S. airport energy requirements and trends were synthesized using a SWOT analysis. In aggregate, there was negligible correlation between commercial U.S. building LEED certification levels and energy use reduction. In spite of noteworthy findings regarding on-site energy reductions, there was insufficient evidence to suggest that LEED reduced overall (site and source) energy use. Therefore, little evidence supports the cost-effectiveness and economic feasibility to reducing energy use simply through the LEED certification process. This study presents the pros and cons in applying LEED certification to reducing energy use in commercial airport buildings.

KEYWORDS: airport, commercial buildings, cost/benefit, energy, LEED certification, SWOT.

1. INTRODUCTION

Commercial building energy use ranks among the highest costs in commercial U.S. airports (El Choufani, 2016), thus, facility energy efficiency is a high priority for airport management. Because of the large heating, cooling, lighting, and automation requirements of airport buildings - such as terminals, air control towers, hangers, parking facilities, etc., proactive management must find innovative ways to control and reduce energy use. LEED certification offers a systematic alternative to most traditional building and operational practices and asserts "25% less energy on average used by LEED buildings compared to commercial buildings" (USGBC, 2020, p. 1).

This study focuses on examining current literature involving U.S. commercial building energy trends, requirements, and performance to assess the feasibility of LEED certification to reducing energy use in large commercial U.S. airport buildings. The study includes a systematic quantitative literature review of published peer-reviewed studies examining LEED certified commercial building energy use and an analysis into LEED certification objectives and criteria, airport facility energy requirements and use, and U.S. government energy reduction initiatives to determine if LEED certification is economically feasible. The research study parameters focus on the economic feasibility of LEED certification in reducing energy use in large commercial U.S. airport buildings. Because of the scarcity of U.S. airport related LEED certification literature obtained searching the internet, and time limitation of the study (March – May 2021), a systematic quantitative online search included peer-reviewed English language literature involving U.S. LEED certified commercial building energy management studies covering the past 20 years. In addition, a comparison of LEED certification objectives and criteria to airport facility energy requirements and U.S. government energy reduction initiatives was performed to determine if LEED certification is economically feasible.

2. LITERATURE REVIEW

2.1 Commercial Building Energy

Scofield & Cornell (2018) explained the two common definitions for building energy in the U.S. are "site energy", and "source energy" (also referred to as primary energy). Site energy is the annual purchased energy used within the building's limits. Annual site energy is calculated by adding the British thermal units (Btu's) in natural gas and/or electricity fuel purchased for a 12-month period. Building site energy is typically referred to as "building energy". To determine a building's site Energy Use Intensity (EUI), annual site energy is divided by the building's gross floor area, also referred to as gross floorspace (gfs). Floor area is determined and expressed in squared meters or feet (m2 or ft2). Site EUI is expressed in Btu/ft2.

Scofield & Cornell (2018) emphasized site energy and EUI do not account for off-site energy losses associated with producing fuels and transporting them to the building site; an important distinction, because off-site energy losses must be considered in making energy policy or evaluating the total resource consumption, energy costs, and/or environmental impact of a building. They further explained off-site losses are particularly relevant to electric energy mostly generated from combustion processes at power plants running at approximately 35% efficiency. "Primary energy" is energy which can be harvested through solar, wind, natural gas, coal, hydro-power, and nuclear capability. Electricity is a secondary form of energy which cannot be harvested; it is produced from a primary source of energy (Scofield & Cornell, 2018).

2.2 LEED to Reducing Commercial Building Energy Use

LEED (Leadership in Energy and Environmental Design) is currently the dominant green building rating system in the world and the U.S. LEED is also the most widely used by U.S. Federal and state agencies, such as the Government Service Agency (GSA) (Pacific Northwest National Laboratory, Department of Energy, 2006; USGBC, 2020). LEED can be applied to most any building type. According to the LEED developers, the U.S. Green Building Council (USGBC, 2020), LEED is intended to provide a framework for achieving healthy, efficient, and cost-effective buildings. USGBC lists over 51,000 registered and certified U.S. commercial buildings and asserts 25% less energy on average used by LEED buildings compared to commercial buildings.

LEED energy use objectives and criteria. LEED certification is based on a scoring system allocating points (credits) to buildings from five categories: energy and atmosphere (EA), sustainable site (SS), water efficiency (WE), materials and resources (MR), and indoor environmental quality (IEQ); additionally, building projects can earn credits for "exceptional" performance or by showing innovation in design within the innovation and design process category (USGBC, 2020). Depending on the number of points earned, projects can receive a Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), or Platinum (80+ points) designation after an independent, third-party verification (USGBC, 2020). One important aspect of LEED involves Commissioning, which includes verifying and documenting a building's systems and assemblies are designed as planned, installed, tested, operated, and maintained to the project requirements (USGBC, 2020).

LEED has undergone several revisions since version 1.0 debuted in 1998; the current version is v4.1. One of the most important categories, and essential to this research, is Energy and Atmosphere (EA), which covers roughly 30% of the total amount of credits (Amiri, et al., 2019). USGBC (2020) described the objective of the EA credit category is to promote better building energy performance through innovative strategies. The 11 EA categories in the rating system are listed in Table 1. While remaining focused on commissioning, green power and renewable energy, both cost and greenhouse gas emissions energy metrics were added with v4.1 in 2019; this included an energy performance metering requirement to track building consumption at least monthly for five years and report the data to the USGBC (2020).

0	0	0		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Table 1. Rating Systems: LEED BD+C v4.1: Building Design and Construction.

Source: https://stellarfoodforthought.net/wp-content/uploads/2016/10/LEED-v4-BDC-Scorecard.png

2.3 Cost of LEED Certification

The LEED certification process Involves additional effort and expense (apart from traditional builds) involving project planning, registration, forms, fees, completed application submission, and more payment for reviews. The LEED application is then evaluated by a third-party credentialing and verification provider, Green Business Certification Inc. (GBCI), who provides the certification decision (USGBC, 2020). USGBC LEED Commercial Building and Design Fees are listed in Table 2. In addition, time and costs are involved in commissioning; all new construction must undergo a Fundamental Commission under the LEED rating system to ensure building energy systems are designed, constructed and calibrated to operate as planned (USGBC, 2020); these costs vary depending on the type of building, complexity of systems and building use.

Table 2. USGBC LEED Commercial Building and Design Fees.

Building Design and Construction Fees

Building Design and Construction Fees per Building	Silver, Gold and Platinum Level Members		Organizational or Non-members	
Registration	$1,200		$1,500	
Precertification				
Flat fee (per building)	$4,000		$5,000	
Expedited review (reduce from 20-25 business days to 10-12, available based on GBCI review capacity)	$5,000			
Combined Certification Review: Design and Construction	**Rate**	**Minimum**	**Rate**	**Minimum**
Project gross floor area (excluding parking): less than 250,000 sq ft	$0.057 /sf	$2,850	$0.068 /sf	$3,420
Project gross floor area (excluding parking): 250,000 - 499,999 sq ft	$0.055 /sf	$14,250	$0.066 /sf	$17,100
Project gross floor area excluding parking): 500,000 - 749,999 sq ft	$0.050 /sf	$27,500	$0.060 /sf	$33,000
Project gross floor area (excluding parking): 750,000 sq ft or greater	Calculate pricing		Calculate pricing	
Expedited review (reduce from 20-25 business days to 10-12, available based on GBCI review capacity)	$10,000			

Source: https://www.usgbc.org/tools/leed-certification/fees

Although empirical and projected data vary considerably, Northbridge Environmental Management Consultants (2003) determined LEED certification requirements added from 4 to 11% to a project's construction costs. Over 50% of costs were for investments in alternative systems, practices, and materials that earn points under the LEED system and go beyond standard practices. The remaining non construction, or soft costs, included incremental costs for design, documenting and verifying compliance through the commissioning process (Northbridge Environmental Management Consultants, 2003). Nyikos et al., (2012), in their analysis of cost premiums associated with sustainable facility design, construction cost, and utility data involving 160 LEED certified buildings, applied simple correlation and descriptive statistics and determined green cost premiums tend to increase on average from 2.5 to 9.4% (mean 4.1%) relative to the number of additional LEED points earned. Conversely, when evaluating the total building costs of two commercial LEED certified banks (under 5,000 ft2) with eight non-LEED bank buildings, Mapp et. al., (2011) determined the LEED building costs were within the same range as non-LEED buildings. Additionally, direct LEED certification costs were determined to be approximately 1.8% of total building costs. In investigating initial "green" premium costs of LEED-certified buildings versus conventional campus buildings (Hopkins, 2015) discovered mixed results regarding both upfront construction and full lifecycle costs when performing a cost-benefit study involving 16 higher education buildings. Although overall energy savings were reported, they found no relationship between LEED level (Gold, Platinum, etc.) and green premium costs or annual energy savings per square foot. To complicate matters, although project managers have the choice as to which criteria to select in accumulating LEED points, some government bodies, including the U.S. Navy, GAO, Maryland, New York, and Oregon, have mandated publicly funded projects apply for LEED certification. Northbridge Environmental Management Consultants' (2003) cautioned expanding certification requirements to additional districts would increase the cost of projects to the extent of exceeding potential benefits.

2.4 LEED Commercial Building Energy Use Studies

Peer-reviewed studies, using diverse research methods specific to U.S. commercial building energy use and LEED certification cost-effectiveness, were examined to better understand the benefits to LEED. A sample of the literature showed mixed results, often with disparate conclusions. For example, Newsham et al., (2009) re-analyzed data supplied by the New Buildings Institute and the USGBC by measuring energy use in 100 LEED certified commercial and institutional buildings and compared it to the energy use of the general U.S. commercial building inventory. They also examined energy use according to LEED certification level and energy-related credits, comparing the median EUI for the LEED buildings to the mean EUI in the national Commercial Buildings Energy Consumption Survey (CBECS) database. They concluded LEED buildings averaged 18-39% less energy ft2 than conventional buildings. Then again, 28-35% of LEED buildings used more energy than their conventional counterparts, and there was little correlation in measured energy performance of LEED buildings with their certification level, or their certified energy credits. It was concluded LEED buildings overall saved substantial energy compared to conventional buildings, but certification energy credits did not generally meet expectations.

However, Scofield (2009) was critical of Newsham et al. (2009) weighted average method in concluding LEED office building energy savings. Using a different weighted averaging method, accounting for the energy intensity of each building by gross ft2, yielded different means and significantly different conclusions. Schofield's analysis of the Newsom's et al. data focused on both on-site, and off-site energy. Schofield found both site and source energy in the same CBECS office buildings Newsham et al. examined to be statistically equivalent; there was no evidence LEED certification collectively reduced site or source energy for office buildings. While Scofield acknowledged the LEED buildings used, on average 10 -17% less site energy than comparable conventional buildings, it was argued Newsom et al.'s weighted average method for all commercial buildings, large and small, did not actually demonstrate an overarching reduction of site energy; particularly when very large office buildings used a greater amount of total commercial building energy and were less efficient than comparable conventional buildings.

In another study, Oates & Sullivan (2012) examined 25 of Arizona's 53 New Construction (LEED NC) higher education laboratory buildings to determine if they delivered expected energy performance, how they compared with non-LEED buildings, and if system or managerial variables correlated with efficiency. The study was designed around a five-page survey to facility managers or LEED consultants, the LEED credit score card, at least 1 year of energy data, and models associated with Energy and Atmosphere's (EA) Optimization Energy Performance credits. The variables were: site and source energy use, building gross ft2, and climate zones. Oates & Sullivan's results were mixed; LEED medium energy intense (MEI) buildings performed better on average than the national stock but worse than others located in similar climates. Also, the high energy intense structures performed substantially worse than national and similar climate averages, and the LEED buildings underperformed in baseline and design energy use simulations. Further, they determined there was little statistically significant energy consumption correlation. Oates & Sullivan (2012) concluded, "the LEED NC rating system's energy strategies failed to meet modeled efficiencies, highlighting a need for continued scrutiny and diligence when measuring sustainability and efficiency". (p. 1)

Kaddory et al., (2015) performed a documentary analysis of evidence related to the application of LEED building certification criteria and energy efficiency. They found 7 of 13 studies demonstrated improved energy efficiencies with LEED certified buildings; the other six studies showed some LEED buildings did not achieve significant energy efficiencies. They concluded the mixed results were largely due to research methodologies, the LEED system design, differences in occupancy reports, building energy uses, and different timeframes in construction.

2.5 Large Hub U.S. Commercial Airports and Buildings

The Federal Aviation Administration (FAA) defines an airport as "any area of land or water used or intended for landing or takeoff of aircraft including appurtenant area used or intended for airport buildings, facilities, as well as rights of way together with the buildings and facilities" (Airport Categories; Airports, 2021, para. 1). Operationally, airports are made up of two activities, the landside and airside. Landside areas include terminal and administrative buildings, parking lots, and access roads. Airside areas include taxiways, aprons, and runways (El Choufani, 2016). Large (Hub) commercial (service) airports are publicly owned with at least 2,500 annual enplanements and scheduled air carrier services; they are designated primary airports with more than 10,000 annual enplanements and make up 1 percent or more of the annual U.S. commercial enplanements (Airport Categories: airports, 2021). According to USGBC (2017) LEED certified buildings are increasingly prominent in the transportation industry and airports. There are registered and certified airport projects in most of the states. For example, California had nearly 100 registered and certified projects in 2017. Airport and commercial buildings have similar square footage and occupancy features, including offices, car rental centers, custom facilities, hotels, retail, support centers and terminals. USGBC reported terminals as the most common projects (USGBC, 2017).

How much demand do airports place on power sources? According to (Whiteman et al., 2015) airport energy demand depends on many factors, to include: geography and terrain, infrastructure, real estate, public policy, regulatory and compliance requirements, energy costs, tax credits, ownership, safety, security, staffing issues, and many others. El Choufani (2016) estimated terminal and building services consume roughly fifty percent of electrical energy in an airport and most of the natural gas consumption because of complicated air conditioning and heating (HVAC), ventilation, and other electrical/mechanical systems.

The Airport Cooperative Research Program (2010) estimated airport terminals use the preponderance of energy for lights, ventilation, HVAC and conveyance systems; with buildings, in general, accounting for 40% of the electric energy used in the U.S. The Orlando Utilities Commission (2020) estimated an average airport uses annually roughly 20 kilowatt-hours (kWh) of electricity and 35,000 Btu's of natural gas per square foot with lights and air conditioning using 46% of the overall energy. Not surprisingly, the Orlando Utilities Commission reported energy requirements make up about 10% to 15% of an airport facilities operating budget.

Airports can effectively manage energy expenses by understanding how they are charged for energy. Utility companies charge for natural gas based on the amount delivered. On the other hand, electricity is usually charged based on consumption and demand (Orlando Utilities Commission, 2020). Consumption is based on the amount of electricity, expressed by kilowatt hours (kWh) used in a month. The demand component involves peak demand in kilowatts (kW) per month. Also, because demand charges can widely range from $2 - $20 per kilowatt based on the highest peak recorded over 12 months, managing and reducing peak demand becomes a key management objective (Orlando Utilities Commission, 2020).

Managing energy efficiency from an energy consumption and energy supply standpoint is an effective reduction strategy (Büyükbay et al., 2016). Airports have eliminated unnecessary energy consumption using basic conservation strategies. For instance, HVAC zone management based on demand times, light timers, and educating employees and tenants on energy savings behavior, such as powering down appliances and computers, turning out lights and closing doors as they leave a space (Airport Cooperative Research Program, 2010).

Airports have also been improving operational and maintenance procedures, to include optimizing existing equipment, management systems and energy facilities, installing new energy efficient HVAC and lighting systems, and using renewable energy (Ortega & Manana, 2016). Importantly, Model for improving energy use in u.s. airport facilities (2007) explained energy rates, hours of operation, climate conditions, equipment efficiency, and accuracy of control systems are key factors in estimating payback periods (recoupment of investment) and the airport's overall approach to energy management.

Consequently, renewable energy supply management has been gaining favor recently due to ideal airport site locations, reduced installation costs, technological innovation and government funding. Large commercial airports often have expansive landscapes ideal for capturing renewable energy from the sun, water, wind, and thermal heat, thus, promising to be financially worthwhile. The ACRP (2010) described how several airports have used terminal roofs and land for geothermal, solar, and wind alternative energy systems. Interest in costly solar PV has been driven by government incentives, the expanding market and financial benefits from lease payments to airports, and electricity price stabilization strategies using long term contracts (Whiteman et al., 2015). ACRP (2010) concluded the "diversity of strategies and relative costs associated with airport energy efficiency and cost reduction ensures no two airports are equal, nor will they benefit the same from any improvement" (p. 42).

2.6 Government Funding and Energy Policy Influence

Miller et al. (2020) explained airport operators look for additional outside funding sources to offset expensive improvement projects. Airports receive revenue from a variety of sources; each with different rules, restrictions, and approving authorities determining how funds can be used. GAO (1998) reported airport funding sources, both public and private, to finance large expenditures and capital development, primarily come from federal and state grants, passenger facility charges (PFCs), airport and special facility bonds, and airport-generated income.

Federal sponsored infrastructure funding and financing for airports is tied to the FAA managed National Plan of Integrated Airport Systems (NPIAS). The majority of grants available are, however, restricted to the FAA's Airport Improvement Program (AIP) and used mostly for "airside" operations related to aircraft, such as runways, taxiways, aprons, and navigation aids (Congressional Research Service, 2019; Miller et al., 2020). AIP funding for airport commercial building energy reduction improvements appeared restricted. Funding can also come from state and local governments in the form of full or partial (matching) grants tied-to energy payback considerations based on airport characteristics, existing energy costs, airport ownership, public sustainability policies/programs, regulations, and/or safety requirements (ACRP, 2010). Costly solar photovoltaic (PV) systems investment and payback times, for example, depend largely on suitable site locations and rebates/incentives offered by utility companies, state, and federal agencies (ACRP, 2010). For example, in 2011, an extensive interior terminal building lighting upgrade at Eastern Iowa Airport was accomplished with a grant from the Iowa Office of Energy Independence matched by local funding.

In addition to grants, airport operators have turned to alternative financing mechanisms, such as energy service companies (ESCOs) and public-private partnerships for funding large projects (Outcomes of Green Initiatives: Large Airport Experience, 2014). Growing in importance to the Federal government and the FAA are sustainable "Green" policies and programs, resulting in guidance issued for energy management in airport terminal sustainability planning, for instance. According to the FAA (2018):

> *sustainability incorporates economic, environmental, and social considerations into planning, design, construction, operations, and maintenance through a concept called the "Triple Bottom Line." High and stable levels of (1) economic growth, (2) environmental quality, and (3) social responsibility are the three pillars of sustainability. In addition to the three pillars, the airport industry adds "operational efficiency" as an equal consideration. This is called the EONS approach (economics, operations, natural resources, and social responsibility) to airport sustainability. (p. 9)*

Important features to such federal, state and local government agency sustainability initiatives include energy efficiency, conservation, renewable energy, sustainable design and construction. As an example, all 15 major airports surveyed regarding green practices (Outcomes of Green Initiatives: Large Airport Experience, 2014) reported they had a sustainability policy in place, which included energy reduction. In another case, Phoenix Sky Harbor Airport (PHX), a city owned airport, followed city policy to use LEED for new and major building construction and renovations.

According to Miller et al. (2020), lease agreements between airports and tenant airlines also determines the distribution of financial risks. Further, differences in local government arrangements and physical assets impact an airports' ability to raise capital. To compound matters, airports have different cash reserves, planning delays, airline competition, and limited real estate. Further, public priorities and land-use policies also influence funding matters (Miller et al., 2020).

2.7 Airport LEED Certification Cost-Benefit

Airport project investments involve spending capital funds and other resources to create future profits, cost savings, and/or social benefits. A worthwhile investment should result in the future benefit comparing favorably to the expenditure of resources. Chen (1996) explained economic evaluation is critical to the investment appraisal by examining, quantifying, measuring, and comparing relevant factors using monetary expression (Chen 1996). An economic evaluation helps determine a project's chances of success.

Withstanding other factors, like compliance concerns, neighbors and community, and demonstrating leadership in the community, assessing the economic feasibility of using LEED to reduce energy use requires airport management analyze the monetary costs and benefits associated with the proposed building project. However, because a detailed economic evaluation, which includes fixed costs, variable costs, depreciation, working capital, and initial capital investment etc., can be time-consuming, Chen (1996) suggested a less complicated economic evaluation could provide sufficient information to determine whether or not to proceed to the next step. One such approach involves examining cost-benefit prediction studies to understand the relationships among green costs, strategies, and the benefits achieved to determine if the extra financial benefits outweigh the costs of green applications. Another approach is by applying a Strengths, Weaknesses, Opportunities, and Weaknesses (SWOT) analysis. SWOT "allows for the creation of a plan of actions necessary for using a company's strengths and for minimizing the effect of its weaknesses in order to increase the company's opportunities and lower the risk of threats" (Kolbina, 2015, p. 76).

Khoshbakht et al., (2017) examined the cost-benefit prediction methods used in green building studies. Their literature review showed considerable variation in the cost-benefits of green building due to the different methods used in estimation. Their review of cost-benefit prediction methods combined with a SWOT analysis of data collection and analytical approaches, revealed five major methods of data collection were used: subjective and objective studies, simulations, surveys, and meta-analysis; with most lacking validity and reliability, and including different degrees of bias. Their takeaway: "much of the current cost-benefit research lacked systematic and reliable methods for data collections and analytical approach" (Khoshbakht et al., 2017, p. 176). Pham, et al., (2020), investigated the selection of LEED version 4 credits and the additional costs and challenges for sustainable building projects and found although studies have analyzed previously collected data using statistical methods and data mining techniques to build a foundation for predictions and recommendations for future LEED projects, they analyzed a limited number of attributes (LEED credits) and used old data from projects under previous LEED versions. Pham, et al., (2020) concluded the LEED New Construction version 4 (LEED-NC-V4), which replaced

LEED 2009 for all new projects, had been significantly updated with several new credits being added, thus, creating a considerable gap in applying findings of previous studies to new projects.

2.8 Literature Review Summary

Although specific literature was not found regarding LEED certified airport energy effectiveness, studies have been performed on U.S. commercial buildings similar in size, purpose and energy criteria to analyze LEED's cost-effectiveness. Therefore, performing a systematic quantitative literature review of LEED certified commercial building energy studies, combined with a comparison of LEED cost-benefit studies, LEED certification objectives to airport facility energy requirements, and government energy initiatives, provides insight as to the economic feasibility of applying LEED to facilities planning and operational practices in reducing airport energy use.

3. METHODOLOGY

A systematic quantitative literature review, combined with a comparison of LEED cost-benefit studies, and LEED certification objectives - to - airport facility energy requirements and U.S. government energy reduction initiatives was performed to test the research hypothesis it is economically feasible to reduce energy use in large commercial U.S. airport buildings through LEED certification. A SWOT analysis was applied to examine the energy use savings and economic feasibility to using LEED, thus, assisting airport managers, operators and service providers in the selection of LEED certified projects in design, build, and maintenance applications. An online search included peer-reviewed English language literature involving U.S. LEED certified commercial building energy performance studies over the past 20 years. Data relating to studies evaluating the energy performance of certified commercial buildings was entered into an excel database. Data included bibliographic information, location of the research, subject descriptions, study methods and designs, population, study variables measured, and discipline of study. Data was obtained by searching the internet for peer-reviewed English language studies concerning actual energy consumption and savings of LEED commercial buildings. Safari was used as the search engine. Initially the words peer: reviewed: LEED: energy: building: U.S. were searched through by title for the period 2010 – 2021 were screened for inclusion.

Additionally, current LEED certification objectives and requirements were compared and contrasted with airport facility energy requirements, and U.S. government energy reduction initiatives found in the literature review. Relevant literature and content from magazines, journal articles, academic papers and books were obtained accessing the internet over the period of March through May 2021. Positive and negative (Pro/Con) energy reduction findings were catalogued, charted, and analyzed. The findings from 1) LEED commercial building studies, 2) the LEED cost-benefit studies (literature review), and 3) the comparison of LEED certification program - to - large commercial U.S. airport energy requirements and trends were synthesized using a SWOT analysis to assess the economic feasibility of reducing energy use in large commercial U.S. airport buildings through LEED certification.

4. RESULTS

Systematic Quantitative Literature Review of LEED to Reducing Commercial Building Energy Use Studies

17 peer-reviewed studies, performed between the years 2000-2021, were found concerning actual energy consumption and savings of LEED commercial buildings. Collectively, the studies involved multiple authors, from different geographic locations, and research disciplines. LEED commercial building energy use studies ranged in topics from assessments of energy use in educational buildings in Florida (Agdas et al., 2015), to office buildings in New York city (Schofield, 2013), to the application of LEED building certification criteria in determining energy efficiency (Kaddory Al-Zubaidy, 2015), and cluster analysis to evaluate the simulated energy use of 134 U.S. LEED NC office buildings (Heidarinejad et al., 2014).

The studies included a mix of different commercial building sizes from 222 sq. ft. to over 200,000 sq. ft. (Heidarinejad et al., 2014). Sample size also ranged from modeling energy use in five LEED and 13 conventional buildings (Chokor & El Asmar, 2017) to benchmarking the municipal energy data of over 551 LEED buildings across 10 major cities (Scofield et al., 2021). The complete listing of authors', study titles, subject descriptions, geographic locations, and the populations examined are displayed in Table 3.

Table 3: Authors, titles, subject descriptions, geographic locations, and populations

Author's & Study	Subject Description	Geography & Population
Agdas et al.(2015). Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy.	Energy consumption trends of 10 LEED-certified buildings and 14 non-LEED certified buildings at a major university in the US.	LEED & non-LEED campus Buildings University of Florida (UF), Gainesville, Florida, U.S.
Amiri et al. (2019). Are leed-certified buildings energy-efficient in practice?	Are LEED-Certified Buildings Energy-Efficient in Practice?	26 studies of LEED-certified buildings US & canada
Chokor & El Asmar (2017). Data-driven approach to investigate the energy consumption of leed-certified research buildings in climate zone 2b	Investigates correlation between LEED certification and the actual energy consumption by a case study of LEED-certified research buildings in climate zone 2B from 2008-2011	18 buildings: 5 LEED-certified facilities and 13 non-LEED facilities. Climate zone 2B, U.S.
Heidarinejad et al.(2014). Cluster analysis of simulated energy use for leed certified u.s. office buildings.	Cluster analysis of simulated energy use for leed certified U.S. office buildings in 13 climate zones in the U.S., and vary in size from 222ft to ~199,999 ft	134 U.S. LEED NC office buildings. US & canada
Hopkins (2015). Leed certification of campus buildings: A cost-benefit approach.	Cost-benefit analysis (LEED) buildings certified within the higher education sector	Sixteen institutions of higher education (IHEs). U.S. undisclosed locations.
Menassa et al. (2012). Energy consumption evaluation of u.s. navy leed-certified buildings.	Analyzed whether the 11 LEED-certified USN buildings have achieved the expected energy consumption savings	11 U.S. Navy buildings. Undisclosed locations
Newsham et al. (2009). Do leed-certified buildings save energy? yes, but….	Re-analysis of New Buildings Institute and US Green Buildings Council on measured energy use data from 100 LEED certified commercial and institutional buildings	100 U.S. LEED certified commercial and institutional buildings. U.S.
Nyikos et al. (2012). To leed or not to leed: Analysis of cost premiums associated with sustainable facility design.	Analysis of cost premiums associated with sustainable facility design	160 LEED certified buildings throughout U.S.
Oates & Sullivan (2012). Postoccupancy energy consumption survey of arizona's leed new construction population.	Postoccupancy energy consumption survey of arizona's leed new construction population	25 Arizona higher education laboratory buildings. U.S.
McNaughton et al. (2018). Energy savings, emission reductions, and health co-benefits of the green building movement.	Energy savings, emission reductions, and health co-benefits of the green building movement	Commercial/institutional buildings; LEED buildings. Five countires & U.S.
Kaddory Al-Zubaidy. (2015). A literature evaluation of the energy efficiency of leadership in energy and environmental design (leed) -certified buildings.	A literature evaluation of the energy efficiency of leadership in energy and environmental design (leed) -certified buildings.	Commercial LEED certified buildings. U.S.
Sadatsafavi & Shepley. (2016). Performance evaluation of 32 leed hospitals on operation costs.	Performance evaluation of 32 leed hospitals on operation costs	LEED & non-LEED Hospital Buildings. Various States throughout Continental U.S.
Scofield, J. H. (2009). Do leed-certified buildings save energy? not really….	Critical review of Newsham, et al., (2009) weighted average method in concluding LEED Office Buiding energy savings.	LEED certified office buildings. U.S.
Scofield, J. H. (2013). Efficacy of leed-certification in reducing energy consumption and greenhouse gas emission for large new york city office buildings.	Efficacy of leed-certification in reducing energy consumption and greenhouse gas emission for large new york city office buildings	LEED certified office buildings. NY U.S.
Scofield & Cornell. (2018). A critical look at "energy savings, emissions reductions, and health co-benefits of the green building movement".	Review of Harvard's "energy savings, emission reductions, and health co-benefits of the green building movement" methodoly.	Commercial/institutional buildings; LEED buildings. Five countries & U.S.
Scofield & Doane (2018). Energy performance of leed-certified buildings from 2015 chicago benchmarking data.	Energy performance of leed-certified buildings from 2015 chicago benchmarking data	Chicago, U.S.
Scofield et al. (2021). Energy and greenhouse gas savings for leed-certified u.s. office buildings.	Energy and greenhouse gas savings for 551 leed-certified U.S. office buildings.	10 major U.S. cities

A wide variety of conclusions were found regarding the effectiveness of LEED-certification in reducing commercial building energy use. Appendix A summarizes the major findings of each study. One study espoused the virtues of LEED certification. 12 studies concluded various degrees of energy savings (or not) depending on what method and variable (certification category, onsite energy, offsite-energy, and/or building characteristics, etc.) were considered; some determined although LEED buildings did not generally demonstrate energy savings, there were notable exceptions; others determined there were somewhat more advantages to LEED, depending on the particular variable. Four studies concluded there were no energy savings from LEED. The results of these three categories of LEED energy reduction findings and conclusions (Positive, Mixed, and Negative) are discussed in further detail.

Positive LEED energy savings: McNaughton et al., (2018) applied Harvard's Co-BE (Co-Benefits of the Built Environment) Calculator to determine (model) energy cost savings, emission reductions, and health co-benefits for six countries, including the U.S. They used data from the Green Building Information Gateway (GBIG) to estimate annual energy savings using a baseline energy use intensity (EUI) of conventional commercial/institutional buildings. EUI of LEED buildings was calculated from GBIG and compared to the benchmark to determine each fuel source's annual energy savings. Energy savings were translated into emission reductions for GHGs and pollutants. They determined energy use reductions varied significantly across different sub-regions due to floor space of LEED-certified projects and baseline energy intensity, and geographical distributions of energy reductions were different for each fuel type. They concluded an estimated 88.50 billion kWh of U.S. energy was saved from LEED-certified projects between 2000 to 2016.

Mixed LEED energy savings: In addition to the six studies discussed earlier in the paper (Hopkins, 2015; Newsom et al., 2009; Scofield, 2009; Oates & Sullivan, 2012; and Kaddory et al., 2015), there were an additional six studies with mixed conclusions regarding LEED certification energy savings. Amiri et al. (2019) analyzed 44 peer-reviewed article results concerning LEED energy-efficiency. Studied buildings varied in size, occupants, locations and climate zones. The results were ambiguous; 10 articles stated LEED certification indicated energy efficiency while eight papers concluded otherwise. The remaining papers did not take any position on LEED certification leading to energy efficiency. They concluded although LEED certification reduced energy use in higher levels of certification (Gold and Platinum), energy efficiency of LEED-certified buildings was questionable, particularly at lower certification levels such as Certified. They highlighted small sample sizes and different characteristics of buildings among the different studies which were crucial parameters in influencing findings.

Expanding on the costs of LEED-certification, Nyikos et al. (2012) analyzed cost premiums associated with sustainable facility design by collecting construction cost and utility data on 160 LEED certified buildings to determine if green cost premiums were justified. Variables included utility costs, energy intensity, and facility construction costs. Regarding energy conservation, LEED-NC certified buildings averaged 31% lower energy costs than conventional buildings. LEED certified buildings operating costs were also $0.70 per sf2 less than others. However, LEED cost premiums ranged from 2.5 to 9.4% with a mean of 4.1%; they determined because the median value was 30%, data more closely represented a normal distribution, thus, few statistically significant correlations among design variables. They cautioned following LEED criteria alone does not necessarily equate to cost effectiveness or successful sustainable design.

Scofield et al. (2021), applied municipal energy benchmarking data from 2016 to 10 major cities to evaluate LEED building energy and greenhouse gas savings. Annual energy use and greenhouse emissions were compared between LEED and conventional offices by city and in total. They determined mixed results; LEED offices showed 11% site energy savings but only 7% source energy and GHG emission savings. While LEED offices saved 26% in non-electric energy there was no significant savings in electric energy. Furthermore, LEED savings in GHG and source energy increased to 10% when compared with newer, non-LEED offices, but minimal correlation in savings for Existing Buildings (EB). Disappointingly, total site energy savings for LEED-NC was 11% lower than expected, and total source energy savings for LEED-EB was 81% lower than projected. Only gold-level LEED offices demonstrated statistically significant savings in source energy and greenhouse gas emissions. They concluded although there was wide variability in LEED building energy performance, LEED office buildings, on average, achieved statistically significant source energy savings and reductions in greenhouse gas emissions.

Scofield & Doane (2018) examined the energy performance of LEED buildings by applying 2015 Chicago benchmarking data; they cross-referenced the data of 132 commercial buildings, with greater than 50,000 ft2 each, with the U.S. Green Building Council's LEED project database. They applied 21 variables, including site and source energy, square footage, and different energy sources. Scofield & Doane concluded LEED buildings, in aggregate, used no less source energy than similar conventional buildings. However, they used roughly 10% less site energy than conventional buildings. Also, LEED offices demonstrated 10% lower site energy and 7% lower source energy than new conventional Chicago offices. Interestingly, no source energy was saved by any large building type.

Heidarinejad et al., (2014) applied a cluster analysis of simulated energy use in 134 new construction LEED office buildings to classify them into intensity clusters. They determined the Energy and Atmosphere Credit 1 intended to improve the energy performance of buildings has a direct correlation with the building clusters, whereby low intensity buildings benefitted from higher points. The study provided a quantitative evaluation demonstrating the disparity in energy intensities among high-performance office buildings because of unregulated internal process loads. They concluded improving assumptions and accuracy of internal process loads is required to predict energy performance in buildings. They recommended energy simulations guidelines and rating programs encourage common conservation practices for reducing internal loads for reducing total building energy use. They argued if certification energy assumptions are to be valid, unregulated process loads should be accounted for in the LEED design.

Menassa et al., (2012) performed an energy consumption evaluation of 11 U.S. Navy LEED-certified buildings by comparing their electrical use to the national averages for commercial buildings in the CBECS database. Seven of the 11 LEED buildings had electric energy savings compared to conventional Navy buildings. However, they found no direct correlation between LEED points obtained for Energy and Atmosphere (EA) and average electric savings. Navy LEED buildings consumed more electricity than the national CBECS averages. They highlighted not all buildings, new and old, had a standardized method of collecting utilities data (i.e., electric, natural gas) to provide a comprehensive set of data for analysis, thus preventing a full understanding and measure of energy performance to determine if the set metrics were achieved through LEED building design. Scofield (2013) compared 2011 energy consumption, GHG emission, and ENERGY STAR energy performance rating data for 21 LEED-certified office buildings to similar conventional building characteristics, time period, and location and climate zone to examine the effectiveness of LEED-certification in reducing energy use and GHG emissions in large New York City office buildings. Scofield determined LEED buildings, collectively, used the same amount of source energy and emitted the same amount of GHG as conventional NYC office buildings. Impressively, LEED Gold buildings showed a 20% reduction in source energy consumption and GHG emission than other buildings. However, LEED Certified and Silver buildings used more energy and emitted more

GHG than other NYC office buildings. They concluded there was no evidence LEED certification, except the Gold level, was progressing NYC any closer to carbon neutrality.

Negative LEED energy savings: Agdas et al. (2015) assessed the energy use of educational buildings and sustainable energy policy. Variables included energy efficiency, LEED building rating systems and sustainable energy policy. They concluded no statistically significant energy use differences were identified between certified and non-certified buildings, and the new construction LEED rating system's energy strategies failed to deliver modeled efficiencies. They highlighted the need for ongoing scrutiny and diligence when measuring sustainability and efficiency.

Chokor & El Asmar (2017) undertook a data-driven approach to examine the energy use of LEED-certified research buildings in climate zone 2B in southern California, Arizona and Texas. Eight performance models were applied to 13 non-LEED buildings, and modeled to five comparable LEED certified buildings. Variables included heating, cooling, and electricity data comparisons to actual energy consumption of the non-LEED benchmark. Results showed the failure of LEED certification in saving energy, with the average energy consumption of all LEED buildings higher than conventional buildings. Moreover, the authors showed an inconsistency in LEED building performance due to earlier defined building characteristics regarding energy performance and savings. Sadatsafavi & Shepley (2016) performed an evaluation of 32 LEED hospitals' operation costs by comparing the operation and maintenance costs of healthcare facilities of similar type, ownership, and location. The variables included energy efficiency, including on-site renewable energy. Energy clusters included Platinum, Gold, and Silver certified office buildings. They found there is still a high variability in the operation and maintenance costs of green healthcare facilities, just as there are with hospital buildings. Scofield & Cornell (2018) applied previous study findings (consensus) to critically review the Harvard group method/design assumptions used by McNaughton et al. (2018). They argued McNaughton et al. only examined LEED commercial buildings, assuming each consistently achieved the energy savings projected by the design team, and the fuel mix of LEED buildings is the same as the average of other buildings in the same region. Furthermore, many studies demonstrated buildings, on average, use more energy than design simulations. Scofield & Cornell pointed to research demonstrating LEED-certified buildings, on average, achieved little or no primary energy savings compared to conventional buildings; and any reduction in site energy is achieved through increased off-site energy use. Scofield & Cornell concluded the environmental benefits calculated by MacNaughton et al. is based on assumptions inconsistent with measured LEED building energy performance.

The Literature Review and Results provided information in determining the economic feasibility of LEED certification to reducing energy use in large commercial U. S. airport buildings by: 1) examining LEED energy performance and cost-benefit studies; 2) comparing LEED objectives and criteria to both U.S. commercial building stock and airport buildings (to include physical characteristics, purpose, location, energy requirements, and performance); and understanding government policy's effect on airport and/or LEED energy objectives, criteria, and costs.

5. DISCUSSION

The LEED commercial building energy use studies consisted of a substantial range of topics, methods, sample sizes, and variables resulting in divergent, and mostly inconclusive, determinations; one study was positive, the large majority (12) were mixed, and four studies concluded there was no energy savings from LEED-certified commercial buildings. Trends identified included the lack of a standardized, systematic collection method with actual energy usage data; many studies relied on surveys, simulations and literature reviews. Second, while there was evidence of "Gold" certified building effectiveness, in aggregate, there was scant correlation with LEED certification levels of commercial U.S. buildings reducing energy use as designed. Lastly, in spite of considerable findings in site energy reductions, there was insufficient evidence to suggest LEED reduced overall (site and source) energy use.

Two cost-benefit prediction studies examined the relationships among green costs, strategies, and performances to determine if the financial benefits outweighed the costs of sustainability applications. Both studies concluded the variations in methods of estimation, data collection, and analysis made it difficult to determine the cost-effectiveness and economic feasibility of using LEED-certification. Khoshbakht et al., (2017) examined the cost-benefit prediction methods used in green building studies and found there was considerable variation in the cost-benefits of green building because of different methods used in estimation. They also found most studies demonstrated poor validity and reliability, with varying degrees of bias. They concluded most cost-benefit research was deficient in applying systematic and reliable methods of data collection and analysis. Pham, et al., (2020), compared the LEED version 4 with the additional costs and challenges for sustainable building projects and determined previously collected data, used for predicting and recommending future LEED projects, only analyzed limited attributes (LEED credits) applying old data from previous LEED versions. They concluded the updated version made it difficult to apply the findings of previous studies to new projects.

According to the review of literature, airport buildings possess similar square footage and occupancy features as commercial buildings (USGBC, 2017), and energy requirements depending on the energy costs, geographic location, terrain, real estate, public policy, regulatory and compliance requirements, tax credits, ownership, safety, security, and occupant behavior (Whiteman et al., 2015). Airport buildings have similar energy demands as benchmark commercial buildings; with terminals and buildings consuming roughly fifty percent of electrical energy and most of the natural gas because of complicated air conditioning and heating (HVAC), ventilation, and other electrical/mechanical systems (El Choufani, 2016; Orlando Utilities Commission, 2020). Akin to other commercial building operators, airport managers focus on energy efficiency from a consumption and energy supply standpoint (Büyükbay et al., 2016) by applying basic conservation strategies and modern operational and maintenance procedures. Similar in practice to commercial buildings found throughout the U.S., airport building efficiencies also come from measures to improve and optimize existing equipment, management system and energy facilities, adding energy efficient HVAC and lighting, and through renewable energy.

LEED energy strategies can be applied to most any building type, with the Energy and Atmosphere (EA) credit covering roughly 30% of the total amount of LEED credits. The objective of EA being to promote better building energy performance through innovation. LEED certified buildings have become increasingly prevalent in airports (USGBC, 2017). The cost of LEED certification involves additional effort and expense, with costs varying depending on the type of building, complexity of the systems and building use; this holds true with airport projects. There are also similarities as to how airports manage and fund energy projects by applying a variety of methods, including commercial loans, municipal bonds, grants and self-generated income. However, funding unique to airports include specific federal and state grants, passenger facility charges (PFCs), and airport and special facility bonds (GAO, 1998). Airport operators also use alternative financing schemes like energy service companies (ESCOs) and public-private partnerships, for funding large projects (Outcomes of Green Initiatives: Large Airport Experience, 2014). Federal and FAA sustainability policies, programs, and funding restrictions impact economic, environmental, and social considerations given to airport design, construction, operations, and energy management; all factors which can influence airport energy project decisions dependent on rebates and financial incentives offered by utility companies, state, and federal entities (ACRP, 2010). Lastly, use-and-lease agreements between airports and tenant airlines can impact financial risk, and local government arrangements and the status of physical assets can affect an airports' ability to raise capital. To summarize and illustrate these complexities, and the feasibility in achieving airport energy reduction using LEED, a Strengths, Weaknesses, Threats, and Opportunities (SWOT) analysis is provided in Figure 2.

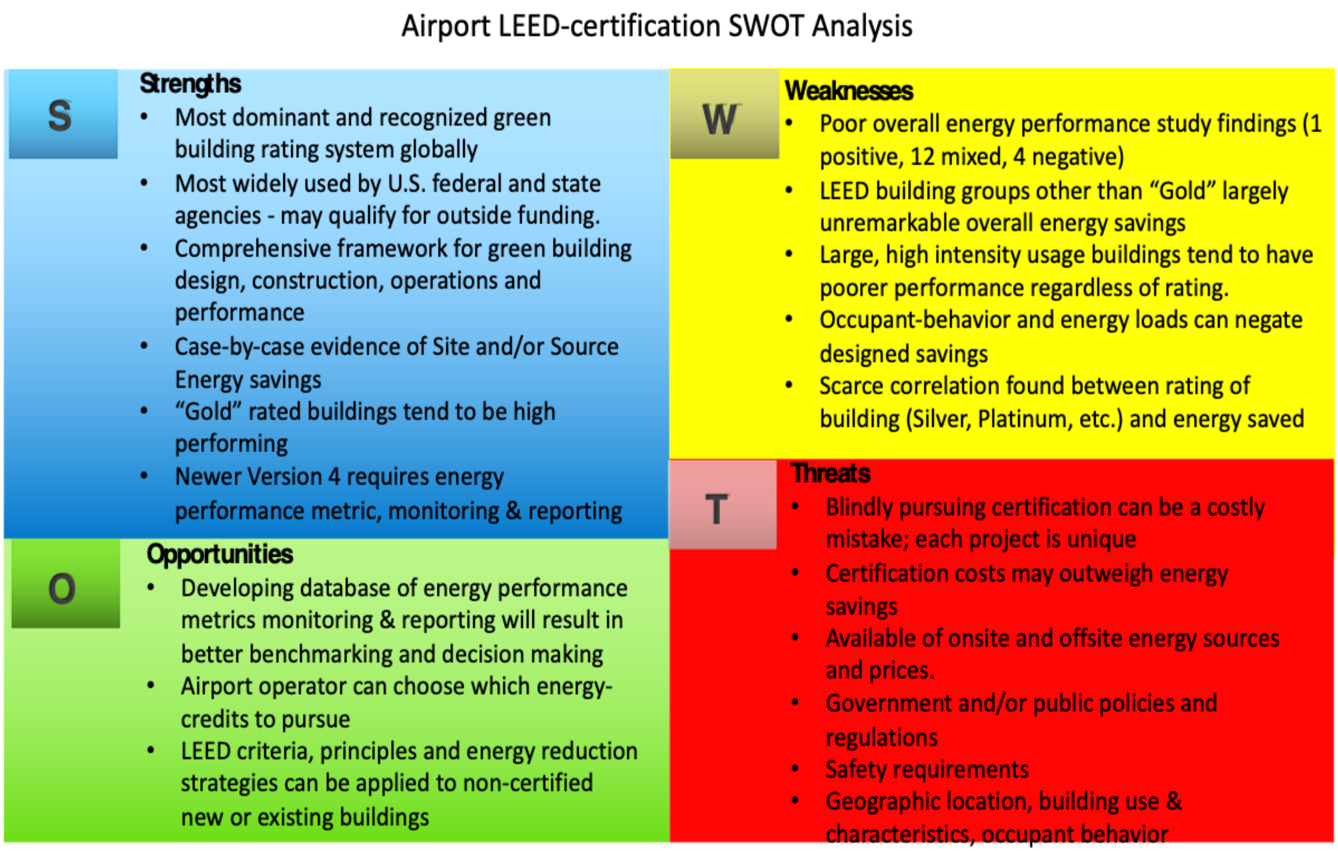

Figure 2. Strengths, Weaknesses, Threats, and Opportunities (SWOT) analysis chart

6. CONCLUSIONS

There was insufficient evidence revealed in the Systematic Quantitative Review to suggest it is economically feasible to reduce the energy use of large U.S. commercial buildings simply through LEED-certification. Furthermore, economic feasibility studies concluded the variations in methods of estimation, data collection, and analysis made it difficult to determine the cost-effectiveness and economic feasibility of using LEED-certification. As evidenced by LEED certified buildings increasing prevalence in airports; and by comparing airport commercial building physical characteristics, energy demand, occupancy, usage, and management approaches to U.S. commercial buildings, it was demonstrated LEED studies can prove useful in determining LEEDs' application and effectiveness in airports. Airport operator practices are also comparable in managing and funding building energy projects; However, alternative financing schemes, like energy service companies (ESCOs) and public-private partnerships, offer unique opportunities to fund (and possibly offset) large LEED-certified energy project costs. Complicating matters, Federal and FAA sustainability policies, programs, and funding restrictions are fluid and can positively (or negatively) impact considerations given to airport design, construction, operations, and energy management from an economic, environmental, and/or social standpoint; all factors which can create uncertainty as to the economic feasibility of applying LEED to airport energy projects. Is it economically feasible to reduce energy use in large U.S. commercial airport buildings through LEED certification? It depends; because of the large differences in scope and scale of airport projects, building characteristics, available energy sources, geography and climate, funding, and changing political, social, and economic conditions, airport managers considering the LEED approach need closely evaluate and apply each energy criteria based on their unique situation and not accept LEED certification claims at face value.

7. RECOMMENDATIONS

The aviation management and environmental design fields would benefit from future airport-specific LEED-certified building energy performance studies. Importantly, the application of a standardized quantitative method, using historical and/or real-time metered data to compare building performances, would provide a more accurate measure of factors, such as the age and size of buildings, load usages, climatic zones, and occupant-behavior, leading to improved energy performance strategies for certified and non-certified commercial buildings.

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Appendix: Systematic Quantitative Literature Review Findings Summary

Author	Major Finding	Support LEED Energy Savings
Nyikos et al. (2012)	LEED-NC certified buildings incur an average of 31% lower energy costs than non-LEED buildings, however, correlation analysis suggests there are very few statistically significant correlations among the design variables. Blindly following LEED criteria may not be the most cost effective or successful sustainable design approach	Mixed
Oates & Sullivan (2012)	On average, Arizona's LEED NC medium energy intense (MEI) buildings performed better than the national average yet worse than buildings located in similar climates. Arizona's high energy intense (HEI) structures performed considerably lower than national and similar climate averages. The LEED NC sample underperformed both design and baseline energy use simulations. Little Energy consumption correlation	Mixed
Scofield et al. (2021)	In aggregate, LEED offices demonstrated 11% site energy savings but only 7% savings in source energy. LEED offices saved 26% in non-electric energy but demonstrated no significant savings in electric energy. The total measured site energy savings for LEED- NC was 11% lower than projected. Only LEED offices certified at the gold level demonstrated statistically significant savings in source energy compared with non-LEED offices.	Mixed
Scofield & Doane (2018)	No source energy saved by any large building type. Offices, on aggregate however, saved 10% site and 7% source energy.	Mixed
Agdas et al.(2015)	No statistically significant energy consumption differences were observed between certified and non-certified buildings	Negative
Chokor & El Asmar (2017)	The average energy consumption of all LEED buildings is higher than that of non-LEED buildings.	Negative
Sadatsafavi & Shepley (2016)	No source energy saved by any large building type. Offices, on aggregate however, saved 10% site and 7% source energy. Analysis showed that there is still a high variability in the operation and maintenance costs of green healthcare facilities	Mixed
Scofield, J. H. (2009)	Newsham et al. offer no evidence that LEED-certification has collectively lowered either site or source energy for office buildings. However, LEED buildings use an average 10 -17% less site energy than comparable non-LEED buildings.	Mixed

Scofield & Cornell (2018)	The environmental benefits of LEED buildings calculated by MacNaughton et al. have questionable value because they are based on assumptions that are inconsistent with measured LEED building energy performance.	Negative
Heidarinejad et al. (2014)	Improving assumptions, accuracy, and granularity of internal process loads is necessary to accurately predict energy performance in buildings. Energy simulations guidelines and rating programs should consider allowing and promoting common techniques for reducing internal loads as valid methods for reducing total building energy use	Negative
Menassa et al. (2012)	7 of the 11 LEED-certified buildings had electric energy savings compared to their non-LEED counterparts. However, there is no direct correlation between LEED points obtained for Energy and Atmosphere and average electric savings for the corresponding buildings. Also, the majority of sampled LEED-certified buildings actually showed more electricity consumption than the national averages	Mixed
Scofield, J. H. (2013)	Collectively, LEED buildings use the same amount of source energy as other NYC office buildings. However, LEED Gold buildings showed a 20% reduction in source energy consumption. LEED buildings at the Certified and Silver level actually use more energy than other NYC office buildings.	Mixed
McNaughton et al. (2018)	The energy use reductions vary significantly across different sub-regions, largely related to the floor space of LEED-certified projects and baseline energy intensity. The geographical distributions of the energy use reductions are different for each fuel type. Estimated 88.50 billion kWh U.S. energy savings from LEED-certified projects between 2000 to 2016.	Yes
Amiri et al. (2019)	Results are contradictory; out of 44 reviewed articles, ten articles state that LEED certificate indicates energy efficiency while eight papers stated the opposite conclusion. The rest of the papers did not take any stand.	Mixed
Hopkins (2015)	Mixed results from both an upfront construction cost and full lifecycle perspective. No relationship between LEED level and green premium/sf. Also, no relationship found between LEED level and energy savings per square foot per year. However, annual energy savings were reported by all surveyed.	Mixed
Newsham et al. (2009)	On average, LEED buildings used 18-39% less energy per floor area than their conventional counterparts. However, 28-35% of LEED buildings used more energy than their conventional counterparts. Further, the measured energy performance of LEED buildings had little correlation with certification level of the building, or the number of energy credits achieved by the building at design time.	Mixed
Kaddory Al-Zubaidy (2015)	7 of the 13 studies showed improved energy efficiencies associated with a LEED certified building; the other 6 studies showed some LEED buildings did not achieve significant energy efficiencies.	Mixed

Note: Positive major findings highlighted in green color. Negative findings highlighted in black color.

AUTHOR'S BIO

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