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Risk Management in Aviation Infrastructure: A Statistical Analysis of Selected European Countries

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The main contribution of the article is the statistical analysis of the aviation infrastructure in selected European countries. Research explores various factors that contribute to aviation infrastructure and evaluates their impact on risk management. The paper presents a detailed description of the aviation infrastructure and its division, including graphs and data analysis. The study found disparities in the level of development of aviation infrastructure between selected countries, with Germany having significantly more hub airports compared to other countries. The results of the study provide information on the state of the aviation infrastructure and inform risk management strategies to improve the safety and quality of air transportation.

Keywords: Aviation, Infrastructure, Static Analysis, Transport, Safety.

1. Introduction

The construction of transportation infrastructure is crucial for the development of a country Percoco (2010), and also serves as an important indicator of economic growth. It forms the backbone of the tourism industry, supporting the movement of goods and people throughout the country and thus driving the national economy.

Risk management plays a vital role in ensuring the safety and efficiency of aviation infrastructure. As the rapid growth of air travel and cargo transportation continues, there are significant fluctuations in airport capacity, influenced by various economic and political factors. Effective risk management in the aviation infrastructure is crucial to address these challenges. Key factors that play a vital role in risk management include: physical infrastructure, security, air traffic management, environmental factors, human factors, technological factors, regulatory compliance, stakeholder collaboration, continuous improvement, and monitoring. By considering these factors and implementing appropriate risk management strategies, the aviation industry can navigate fluctuations in airport capacity and maintain safe and efficient operations.

In the context of risk management, ensuring the safety of aviation infrastructure is of utmost importance. This involves identifying and mitigating risks associated with airport construction and operation, considering factors such as safety protocols, regular inspections and maintenance, and appropriate personnel training. Security is also a critical aspect, as the aviation infrastructure must be protected against threats such as terrorism and unauthorized access. Implementing robust security measures, including access controls, surveillance systems, and screening procedures, helps mitigate risks and maintain the integrity of the aviation system.

Furthermore, risk management in aviation infrastructure considers the environmental impact. Assessing and managing environmental risks associated with airports, such as noise pollution and air pollution, is essential to minimize negative impacts on surrounding communities and ecosystems. Compliance with environmental regulations, conducting environmental assessments, and adopting sustainable practices are all important measures in this regard.

Operational efficiency is another key consideration in risk management. Identifying and addressing potential risks that can disrupt airport operations, such as equipment failures, weather events, or air traffic congestion, is crucial. Implementing contingency plans, investing in redundant systems, and utilizing advanced technologies are strategies to minimize operational disruptions and improve efficiency.

Lastly, effective risk management involves the participation of stakeholders. Collaboration and communication with government agencies, airlines, airport operators, local communities, and industry organizations facilitate the sharing of information, the identification of potential risks, and the implementation of coordinated risk mitigation strategies. By considering these important aspects of risk management, the aviation infrastructure can operate safely, securely, and efficiently, minimizing potential risks and improving overall resilience of the system.

Research on the efficiency of aviation infrastructure has been carried out, among others, by Gitto and Mancuso (2012) on a group of 28 Italian airports. The study found that productivity is significantly influenced by the location of airports, which is indirectly linked to the GDP of the inhabitants of each area. Furthermore, the authors showed that the form of airport ownership does not significantly affect their productivity and that airports managed by concessions have higher productivity scores than those with partial and temporary partial concessions Jacyna-Gołda et al. (2018). This thesis is also confirmed in the study of Merkert and Mangia (2014) based on data from Norwegian and Italian airports.

In the article Štimac et al. (2020) examines the impact of different airline business models on airport infrastructure and operational capacity Jacyna et al. (2014). Particular attention was paid to the need to adapt the airport infrastructure to the requirements dictated, among other things, by the volume of air traffic Ziółkowski et al. (2020); Kowalski et al. (2021). As a solution to the problem, a model capable of optimizing the capacity of aviation infrastructure and operations is presented by maintaining an acceptable level of service Żak et al. (2021). An analysis of business models is also presented in the article Pearce (2012).

To date, most of aviation infrastructure research has been associated with increasing or optimizing airport capacity. However, with the severe impact of the COVID-19 pandemic in 2020 on airport operations, it was necessary to examine the airline market for new developments. This topic was addressed, among others, in the articles Magniszewski (2022). The authors of the publication unanimously point out that the reduced demand for transport in 2020 has had a significant impact on the aviation infrastructure. The decline in passenger numbers directly contributed to the loss of profitability of some airports, which may have been a direct cause of the closure of some of them. The importance of the problem is confirmed by the graph in Figure 1, which shows the changes in the number of passengers over the years. The changes shown imply the need to analyze the aviation infrastructure and adapt it to the needs of the changing market.

The purpose of this study is to document and analyze, for the first time, the change process that is taking place in the aviation infrastructure of countries of the European Union with an area comparable to that of Poland. First, the countries and elements of the aviation infrastructure to be analyzed are defined and identified. The article focuses mainly on showing the changes that occurred between 2014 and 2021, interpreting them from a statistical point of view. Trends and relationships are presented in this study. Parameterization of the indicated trends will be the subject of future research.

2. Methods

An Index Number is the method that is used to measure the change at the level of phenomena (Ralph et al., 2015). It is the relationship of the magnitude of a phenomenon at a particular time to the magnitude of the same phenomenon at another time. Index Number Base Methods are divided into Fixed Base Method and Chain Base Method. The fixed-base method describes the change in the value of the phenomenon analyzed in relation to the base period. The calculation of a given indicator consists of dividing the successive values of the survey period by the baseline value starting in the survey period, which can be represented by the following relationship:

$$X = \frac{P_i}{P_0}, \quad i = 1, ..., n \tag{1}$$

where:
P_0 – baseline,
P_i – subsequent value,
n – number of observation, period. The initial value determines the line against which the rest of the results should balance positively or negatively, depending on whether there has been an increase or decrease in the number during the period.

Chain-based method - The changes presented are obtained based on successive values of the examined phenomenon in relation to the values immediately preceding the analyzed period. Evaluation of a given indicator consists of dividing each number in the statistics directly by the previous one. When presenting a given indicator on a graph, it is possible to observe changes in relation to the preceding value. Chain Base Method indicators can be calculated by the following relationship:

$$Y = \frac{P_i}{P_{i-1}}, \quad i = 1, ..., n \tag{2}$$

where:
P_i – subsequent value,
P_{i-1} – prior value,
n – number of observations, period.

3. County selection

One of the determinants of aviation development is the size of the country, therefore countries of similar size were selected for further analysis. However, attention was paid to other factors such as GDP and population. Poland was selected as the main country of interest, with Norway, Finland, Germany, and Italy as countries of similar size. The area difference between the selected countries is no more than 16%, however, the number of inhabitants and GDP per capita differ significantly. In 2021, the population of Germany was approximately 15 times that of Norway. These are the two countries with the highest distinction in comparison in terms of population per km^2. In terms of GDP per capita in 2021, the largest disparity was observed between Poland and Norway. On average, Norwegians earned five times more than Poles. It should be noted that Norway is the only country in this ranking that is not a member of the European Union. The impact of these factors on the aviation infrastructure and the number of flight operations will be examined later in this article.

Table 1. Basic characteristics of countries selected for the analysis for year 2021.

Country	Area (km^2)	Number of inhabitants	GDP Per capita (Euro)
Poland	312 679	37 840 001	13 760
Germany	357 376	83 155 031	35 480
Finland	338 440	5 533 793	37 250
Norway	324 220	5 391 369	71 150
Italy	302 073	59 236 213	26 780

Source: Own elaboration based on data from Eurostat (2023)

3.1. *Poland*

Poland has 14 functioning airports, which in 2019 served a record number of almost 47 million passengers. However, due to the COVID-19 pandemic in 2020, this number has decreased by 70%. Currently, the situation related to air transport in Poland is improving, as evidenced by the increase in the number of passengers served in Poland in 2021 by nearly 37% compared to the previous year.

3.2. *Germany*

Germany's aviation infrastructure is one of the most developed in Europe. In 2019, it included nearly 41 major airports and 567 aircraft, which allowed the transport of a record number of 226 million passengers. To ensure the safety and efficiency of air transport, Germany is constantly developing its infrastructure by modernizing airports and purchasing new aircraft. In 2021, German airlines acquired 171 new aircraft and carried 27% more passengers than in 2020.

3.3. *Finland*

In 2019, Finland had 18 major civil airports and a fleet of 84 aircraft, which, combined with other elements of the aviation infrastructure, allowed it to handle a record number of 23 million passengers. This result, similar to other countries, decreased significantly in 2020. The number of passengers served is estimated to have decreased by 76%. Furthermore, Finland, as the only country mentioned, recorded a decrease in the number of passengers served by 17% in 2021.

3.4. *Norway*

According to Williams et al. (2007), Norway has one of the highest air transport dependencies in Europe. In 2003, the country's domestic air trip rate was recorded at 1.87 per capita, which is three times higher than the average rate of other European nations. However, this trip rate is not uniformly distributed across the country, with varying rates observed in different regions. For example, as reported in Solvoll et al. (2020), the Helgeland district in Nordland county had a trip rate of 3.98, the second highest after Finnmark county, which had a rate of 5.81.

3.5. *Italy*

In 2019, Italy recorded 160 million passengers carried, which, like the rest of the countries noted in the article, is a record Sergi et al. (2020). In 2020, this Figure fell fourfold due to the pandemic. It is worth mentioning that Italy is the only country on the list cited to record an increase of nearly 47% in the number of passengers served in 2021. This high percentage was recorded despite a slight reduction in the number of airports and the number of aircraft, demonstrating the excellent adaptation of Italy's aviation infrastructure to changing conditions.

4. Results

A factor forcing the development of aviation infrastructure is the increase in passenger numbers. Increased interest in flying is forcing the development of airports, increasing their capacity, the number of people serving passengers, etc.

In the Figure 1 the total number of passengers served by each country is presented as a function of time. The Figure shows that the number of passengers in Germany significantly exceeds the number of people flying to and from other countries. This significant difference is mainly because Germany has many hub airports. These serve a significant number of passengers whose destination or point of departure is not a German airport. They merely serve as transfer points for onward connections. It can be unequivocally stated that until 2019, each of the selected countries has seen an increase in the number of passengers using the airport infrastructure. The breakthrough year turned out to be 2020, in which the number of passengers served by selected countries decreased by a total of 76% due to the pandemic. The countries handling the highest number of passengers decreased by around 170 million and 120 million for Germany and Italy, respectively. It is worth mentioning that the trend is slowly returning to its pre-pandemic state, as evidenced by a nearly 37% increase in the number of passengers served in the countries surveyed in 2021, with Italy and Germany recording the largest increases of 19 million and 16 million, respectively. The only country among those mentioned in the article that recorded a decrease in passenger numbers in 2021 was Finland.

Figure 1. Number of air passengers by country.

Poland noticed an almost twofold increase in the number of passengers served between 2013 and 2019. The trend line presented in Figure 2 represents the growth of passenger numbers for 2020 and 2021. The blue color indicates the points that show the actual number of passengers served in 2020 and 2021. Passenger numbers are currently expected to continue to grow, as before the pandemic. This is evidenced, among other things, by the optimistic forecasts recorded for 2020-2021.

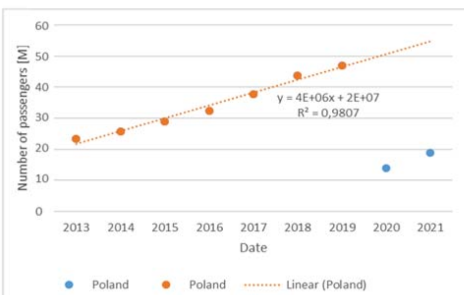

Figure 2. Number of air passengers in Poland.

Monitoring changes in passenger flow allows for forecasting the needs related to aviation infrastructure, such as the number of airports, the number of aircraft, and avoiding the risk of aviation infrastructure congestion.

Analyzing the base chain coefficient of the number of commercial airports per country (Figure 3) shows a large decrease in the number of airports throughout the pandemic period because many of them did not reach the 15,000 passenger threshold per year. Statistical analysis of the base chain factor reveals regional disparities in airport development.

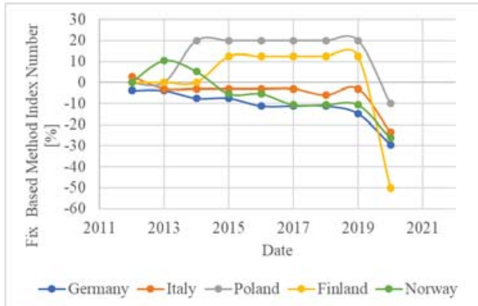

Figure 3. Fixed Base Method Index Number of commercial airports by country.

It can indicate which regions or countries are witnessing significant growth in the number of commercial airports, potentially leading to increased air traffic and associated risks. On the other hand, a lower coefficient may mean that existing airports face increased congestion, which can lead to security risks and operational challenges. Statistical analysis of the base chain factor can provide information on the resilience of aviation infrastructure in different countries. Countries with a stable or increasing number of airports over time may exhibit greater infrastructure resilience, indicating their ability to adapt to changing demands and potential threats. On the other hand, countries with a declining number of airports may need to assess the underlying factors that contribute to the decline and take appropriate risk management measures.

A summary of the change in the number of passenger aircraft registered in each country is shown as a function of time in Figure 4 and in Figure 5. Data are presented in two forms, fixed base method index number and chain base method index number, respectively.

When comparing the two mentioned coefficients, long-term trends can be distinguished, such as the decrease in the number of passenger aircraft in Italy from 302 in 2001 to 77 in 2021,

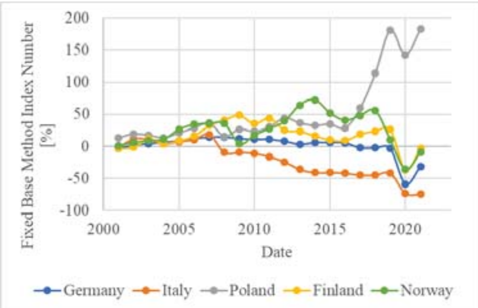

Figure 4. Fixed Base Method Index Number of commercial aircraft fleet by country of operator.

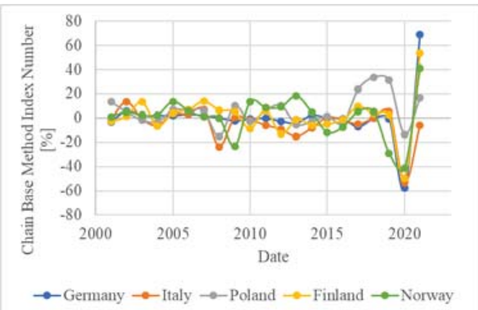

Figure 5. Chain Base Method Index Number of commercial aircraft fleet by country of operator.

which began in 2008. Other countries, where the number of aircraft remained stable (Germany) or increased, showed a decrease of around 20% during the 2008-2009 crisis and significant drops in 2020 during the pandemic period. This information can help develop risk management strategies by identifying areas with potential challenges in terms of capacity and operational activities, especially during crisis situations. By analyzing changes in the size of the air fleet and changes in the number of aircraft of different sizes (Tables 2 - 5) over time, it is possible to understand which types of aircraft are added or removed from the fleet. This information is valuable for risk management, as different types of aircraft can involve different operational, maintenance, and safety aspects. Additionally, changes in the fixed base index can provide information on the age profile of commercial aircraft fleets in different countries. Changes in fleet size over time can indicate fleet renewal or retirement patterns, which can impact risk management. Older aircraft may have different risk profiles compared to newer ones, and understanding the age distribution of the fleet can help identify potential safety concerns and guide maintenance and inspection programs. Furthermore, sudden changes in the number of aircraft can indicate a poor condition of a selected carrier in a particular country and may require a reassessment of associated risks.

Table 2. Number of airliners with 50 or less seats.

Date	Germany	Italy	Poland	Finland	Norway
2012-2016	14	1	5	2	34
2017	16	0	6	1	34
2018	11	0	6	0	33
2019	10	0	5	0	34
2020	9	0	3	0	33
2021	6	0	5	0	28

Source: Own elaboration based on data from Eurostat (2023)

Table 3. Number of airliners with 51 to 150 seats.

Date	Germany	Italy	Poland	Finland	Norway
2012-2016	219	16	37	40	59
2017	169	15	33	33	41
2018	164	14	43	33	35
2019	137	16	46	33	25
2020	77	17	40	26	21
2021	98	15	41	29	18

Source: Own elaboration based on data from Eurostat (2023)

In Table 4 the number of aircraft designed to carry between 150 and 250 passengers is presented. The data in the table indicate that aircraft of this type are most popular in Germany, Poland, and Norway. This is because the increased number of seats does not necessarily come at the cost of a significant increase in fuel consumption.

As can be concluded from the Table 5, Germany has the highest number of aircraft with more than 250 seats in this list, this is mainly due to the fact that the German economy is very well developed, which reflects in the size of German airports and

Table 4. Number of airliners with 151 to 250 seats.

Date	Germany	Italy	Poland	Finland	Norway
2012-2016	211	75	16	27	56
2017	257	20	36	28	89
2018	267	18	50	29	92
2019	276	14	63	29	57
2020	104	5	74	4	21
2021	213	6	87	19	41

Source: Own elaboration based on data from Eurostat (2023)

their number. Additionally, the high demand for intercontinental travel seen in Germany requires suitable aircraft. In this case, aircraft with a large number of seats works best due to the possibility of spreading the costs over a larger number of passengers and potentially higher profits.

Table 5. Number of airliners with 250 or more seats.

Date	Germany	Italy	Poland	Finland	Norway
2012-2016	140	7	5	15	8
2017	134	9	8	19	21
2018	139	8	8	20	28
2019	144	6	13	22	22
2020	54	0	8	13	4
2021	98	0	12	17	6

Source: Own elaboration based on data from Eurostat (2023)

The composition of the aircraft fleet is an important factor in aviation infrastructure and risk management. The number of aircraft and their seating capacity can significantly impact operations and profitability.

A statistical analysis of the composition of the fleet reveals interesting insights. For example, there is a large disparity in the number of aircraft assigned to each country. Norway stands out with a significant number of passenger aircraft with 50 seats or less, attributed to challenging terrain and the need for smaller aircraft. Italy has a high number of aircraft within the range of 51 to 150 seats, likely influenced by its geographical location as a transfer point in the Mediterranean. Germany, Poland, and Norway have a notable proportion of aircraft in the 150 to 250-seat range. Germany also leads in the number of aircraft with more than 250 seats, reflecting its well-developed economy and the high demand for intercontinental travel.

The popularity of certain aircraft types is driven by factors such as cost-effectiveness and the demand for affordable airfares. The availability of different aircraft sizes allows airlines to cater to varying market demands and optimize profitability.

Understanding the composition of the aircraft fleet helps in risk management by identifying potential capacity challenges, operational considerations, and cost optimization strategies. It allows stakeholders to assess the suitability of the fleet for different routes, passenger demand, and market dynamics. In addition, it provides information on the requirements for infrastructure development, including airport facilities and runway capacities, to accommodate different types of aircraft.

In general, analyzing the composition of the fleet provides valuable information for effective risk management in aviation infrastructure, allowing stakeholders to make informed decisions and allocate resources accordingly.

The changes in the number of aircraft shown in Tables 2-5 are due to the purchase of new aircraft and the end of service of obsolete aircraft, which most often reach the end of their service life.

5. Summary

The findings of the statistical analysis have implications for risk management in the aviation infrastructure. Understanding the specific characteristics and trends within each country's aviation sector can help identify potential risks and develop effective risk management strategies.

For example, the significant number of hub airports and a large fleet of commercial aircraft in Germany may require robust risk management measures to ensure operational safety, manage congestion, and handle increased passenger volumes. The concentration of air transport around smaller airports in Scandinavian countries highlights the importance of addressing potential challenges related to access, infrastructure maintenance, and emergency response capabilities in these regions.

Furthermore, the high number of aircraft accommodating between 151 and 250 passengers in Italy suggests the need for risk management strategies that address the unique operational requirements of larger aircraft, such as maintenance planning, crew training, and compliance with safety regulations.

Incorporating these insights into risk management efforts can help aviation stakeholders proactively mitigate risks, improve safety measures, optimize infrastructure planning, and improve overall resilience of aviation systems. Further research and analysis, including the development of forecasting models, will contribute to a more comprehensive understanding of risk management in aviation infrastructure.

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