SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 224

MANAGING FLIGHTS DURING FOG EVENTS ON THE EXAMPLE OF KRAKÓW-BALICE AIRPORT

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Purpose: To quantify the impact of fog on flight diversions at Kraków Airport (EPKK) and to analyze the implications of this operational vulnerability, specifically in relation to the airport's Category I Instrument Landing System (ILS).
Methodology: This study employed a retrospective, quantitative research design to empirically investigate the influence of fog on aircraft diversions at EPKK. The study is a flight operations data (Eurocontrol PRISME) and meteorological records (METAR) analysis using a four-month annual sample allowing for a longitudinal examination of patterns and correlations over an extensive eight-year period (2015-2023). All data acquisition, processing were conducted using custom scripts developed in the Python programming language.
Findings: Fog is the primary driver of disruptions, causing 63.6% of all flight diversions in the sample. These events are highly seasonal, peaking in December, and are a direct consequence of visibility frequently dropping below the airport's CAT I operational minima. This forces a heavy reliance on Katowice Airport (EPKT) as the primary alternate destination.
Research limitations: The primary limitation is the use of sampled monthly data, which may not capture the full annual impact.
Originality: This paper provides novel, quantitative evidence linking specific fog characteristics to operational disruption rates at a major Polish airport. It offers significant value to airport managers, airline strategists, and transport policymakers by grounding critical investment decisions in robust, empirical data.
Keywords: flight diversions, low visibility procedures, fog.
Category of the paper: General Review.

1. Introduction

With air transport operations becoming the most viable form of passenger transport, it took the regional and global markets by storm becoming the threads of the connectivity network. It facilitates and indicates economic growth of the region, enables touristic traffic and travel for business enterprise. Airports, as the basic nodes in the network, require high reliability and operational upkeep to meet increasing demand for air travel. However, performance of these hubs might be undermined dramatically by various factors, among which, include adverse weather conditions that pose a persistent and complex challenge. Fog, in particular, by directly impacting pilots' visual references is one of phenomenon requiring airports to implement specific operational procedures, very often reducing capacity. The consequences of severe fog conditions are far-reaching and can lead to further delays, cancelled flights and diversions to other airports. All those send ripple waves through operator networks, affecting schedules, crew rosters, aircraft schedules and making the passenger experience much less pleasant. Therefore, understanding and managing adverse fog events is critical to airport and aircraft operators.

John Paul II International Airport Kraków-Balice (EPKK/KRK), regional hub for Lesser Poland Region in southern part of the country is notably susceptible to fog. The geographical location, particularly close proximity to the Vistula River and surrounding terrain can favor the formation of radiation fog, especially during autumn and winter months. This occurrence frequently translates into operational challenges for Kraków Airport, with media coverage and preliminary observations attributing large number of flight diversions to neighboring airports to low visibility conditions at EPKK. Not only this incurs direct financial costs for airlines but also affects nearby airports resources and disrupts the travel plans of thousands of passengers annually.

2. Literature Review

In Poland, the fog that forms are usually radiation fog, which happens when there are clear skies, light winds, and high humidity, mostly at night and in the early morning. The southern part of the country, around its largest city, Kraków, is known for having fog form frequently. This is because of its specific geography, namely its location in the Upper Vistula River basin and its closeness to hilly terrain (Łupikasza, Niedźwiedź, 2016; Skrzyńska, 2019).

Further studies by Łupikasza and Niedźwiedź (2016) confirm that Kraków has a high number of foggy days each year, with averages between 53 and 67 days. The fog is most common between September and January, with October being the month with the most fog. Recent climatological studies by Zawadzka-Manko and Markowicz (2025) show that fog in inland southern Poland usually lasts from 3.7 to 6.1 hours, and visibility often drops below 500 meters. Even though some areas in Poland have seen fewer foggy days because of climate change, Kraków hasn't had a big decrease, probably because the local basin microclimate, which traps cold air, is still there (Skrzyńska, 2019).

2.1. Airport Operations

Fog is a major problem for airport operations because it reduces visibility, which is essential for landing, taking off, and moving planes on the ground (Figure 1).

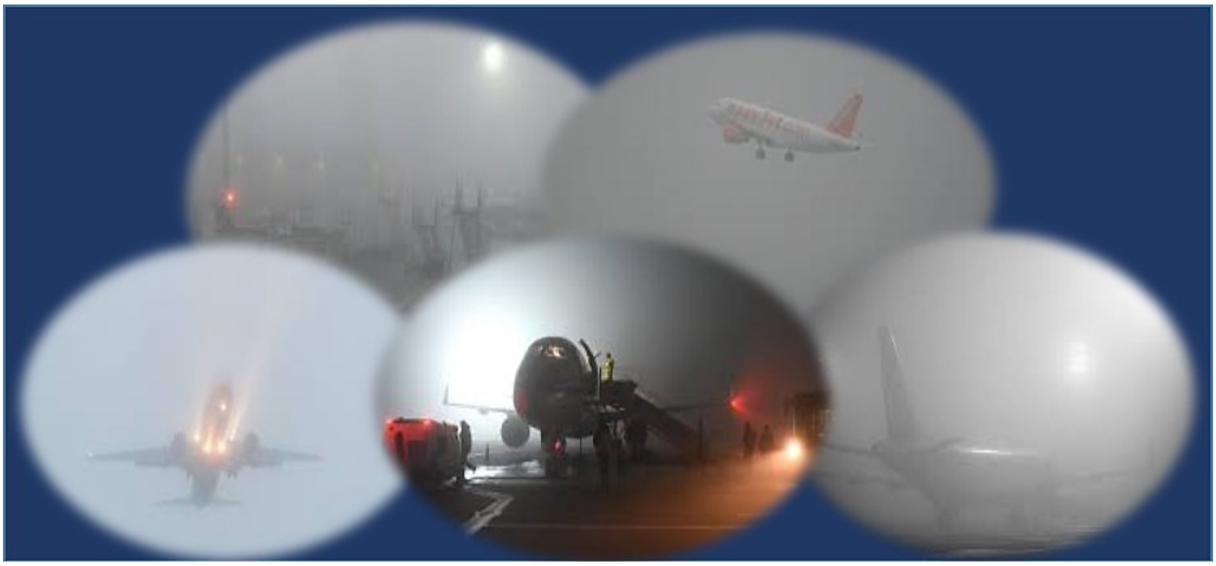

Figure 1. Fog as a major problem for airport in Kraków.

Source: own elaboration based on random google search images results.

When the Runway Visual Range (RVR) is lower, pilots have to switch to Instrument Flight Rules (IFR) and use Instrument Landing Systems (ILS). The disruption to operations caused by fog is well-documented all over Europe. Research by Pilguj et al. (2020) shows that events with limited visibility happen most often in the autumn and winter, which matches the seasonal fog patterns in Poland. Low visibility not only affects planes that are arriving and departing but also puts extra pressure on air traffic control and ground crews. Case studies from Polish airports show that thick fog often leads to go-arounds and holding patterns, which adds extra costs for fuel and time (Skomorowski, Piotrowski, 2018).

John Paul II International Airport Kraków-Balice (EPKK) is particularly at risk for fog-related problems because it's in a valley and has a lower level of technology. The airport currently uses a Category I Instrument Landing System (ILS), which only lets planes land if the RVR is 550 meters or more. This limit is often not met during the autumn and winter, which causes frequent diversions to other airports.

A study by Kwasiborska et al. (2023) that looked at the 2019 operations at EPKK found that the airport had 160.5 hours where operations were stopped or limited because of low visibility. In comparison, Warsaw Chopin Airport (EPWA), which has a Category III ILS, had zero hours of these kinds of disruptions in the same year. Katowice–Pyrzowice Airport (EPKT), with a Category II ILS, had far fewer hours of disruption (60.5 hours). This shows how important better navigation systems are for dealing with the impact of fog. These disruptions have both direct and indirect effects. Airlines have to pay more for fuel and crew time, and passengers have to deal with delays, cancellations, and missed connections. The operational problems also affect nearby airports, which have to take in diverted flights, impacting the entire air transport network. Upgrading EPKK to a higher-category ILS would greatly improve its ability to handle these situations. Kwasiborska et al. (2023) estimate that putting in a Category II ILS could cut down on weather-related operational downtime by as much as 50%, and a Category IIIa system could reduce it by almost 65%.

3. Research Methodology

This study used a quantitative, archival research method to look into how fog affects aircraft diversions at John Paul II International Airport Kraków-Balice (EPKK). The main approach was to collect, process, and analyze historical weather and flight data from an eight-year period, from March 2015 to March 2023.

There were two main sources of data. Weather records, specifically the Terminal Aerodrome Forecasts (METAR) for EPKK, were taken from the Iowa Environmental Mesonet (IEM) Automated Surface Observing System (ASOS) data archive. These reports were then put into a structured format for analysis. At the same time, aircraft operational data, which included details on flight arrivals and diversions, was gathered from the Eurocontrol PRISME (Pan-European Repository of Information Supporting the Management of EATM) database. A key limitation was that the PRISME data was only available for certain months—March, June, September, and December—for each year in the study. All the initial data work, like getting, organizing, filtering, and combining the datasets, was done using special software scripts in Python.

A core part of the analysis was clearly defining the key variables. A "fog event" that could be linked to diversions at EPKK was defined by METAR reports showing the "FG" (fog) weather code along with a reported horizontal visibility of 550 meters or less. An "aircraft diversion" was counted from the Eurocontrol data whenever a flight that was planned to land at EPKK ended up landing somewhere else. To connect these two things, a "fog-related diversion" was defined as any diversion where the plane landed at another airport within one hour before or after a recorded fog event at EPKK. This time link, based on timestamps, was key to connecting specific fog conditions with the diversions.

The data analysis was done in two main parts. First, a descriptive analysis was done to understand the characteristics of both fog events and diversions. This included figuring out the frequency and timing (yearly, seasonally, and daily) of major fog episodes. The main features of these episodes, like how long they lasted and the visibility levels, were also measured. At the same time, the total number of diversions was studied to find trends and patterns, including which alternate airports were used most often. In the second part, an inferential analysis was carried out to test the relationship between fog and diversions. The main tool used was the Pearson correlation coefficient (R). This statistical test measured how strong and in what direction the linear relationship was between the total hours of significant fog each month and the total number of fog-related diversions in that same month. A p-value was also calculated to see if this correlation was statistically significant.

Ethical concerns were handled by making sure all the data, both from Eurocontrol and the public weather data, was anonymous. No personal information about crew, passengers, or air traffic controllers was used or needed. The data was used according to the relevant agreements and only for the purpose of this research, which was to analyze how fog impacts aircraft diversions.

Finally, when looking at the results of this study, it's important to remember some limitations of the methodology. Because the Eurocontrol data was only from specific months, the conclusions are mostly about what happens during those times and might not apply to the whole year. Defining a fog event based on 1-hour METAR reports might not perfectly capture when fog started or ended. Also, the ±1-hour window for classifying a diversion as fog-related shows a strong connection in time, but it doesn't prove cause and effect, as other things happening at the same time could have played a role, or some fog-related diversions might have happened outside this window. The study also focused mainly on fog, and other reasons for diversions (like aircraft or crew certifications, airline rules, or other weather) were not included because of the study's scope and the data available. While the data sources are generally trustworthy, there is always a chance of small errors in large datasets.

4. Research Results

The analysis of flight operations data for John Paul II International Airport Kraków-Balice (EPKK) over an eight-year period from March 2015 to March 2023, sampled from the months of March, June, September, and December, found a total of 206 flight diversions. A careful and detailed analytical process was used on each of these diversions to see how they were related to the weather conditions. This meant classifying any diversion as "fog-related". The most important and clear finding of this research was that 131 of the 206 diversions, which is a significant majority of 63.6%, were directly linked to heavy fog conditions. This first result is powerful, showing that widespread fog is the single biggest and most important factor causing flight diversions and operational shutdowns at EPKK in the studied data. It confirms that what people have been saying for a long time is actually a measurable and major operational problem.

The number of these diversions, especially the ones caused by fog, changes a lot from year to year. This points to the changing nature of weather patterns but also shows the airport's ongoing vulnerability. This is shown in detail in Table 1 and Figure 2. For example, the year 2020 stood out with the highest number of problems, with 58 total diversions, and a massive 54 of them (93.1%) were because of fog. Even though air travel was much lower globally during this time because of the COVID-19 pandemic, this finding strangely highlights how fundamental the impact of weather is. With fewer flights, the problems caused by bad weather became even more obvious and important, showing a basic weakness that is there no matter how much traffic there is. On the other hand, years like 2017 and 2018 had far fewer incidents, which suggests that during those times, the weather conditions were not as favorable for the formation of long-lasting, low-visibility fog in the area. This variation shows that while the risk isn't constant, in any year with bad weather patterns, fog quickly becomes the main cause of disruption.

Table 1.
Annual Diversion Summary

Year	Total Diversions	Fog-Related Diversions	Percentage of Fog Diversions (%)
2015	46	34	73.9
2016	29	24	82.8
2017	9	0	0
2018	7	2	28.6
2019	9	4	44.4
2020	58	54	93.1
2021	19	7	36.0
2022	25	6	24
2023	3	0	0

Note. 2023 data is partial (March only).

Source. Own elaboration based on Eurocontrol PRISME database.

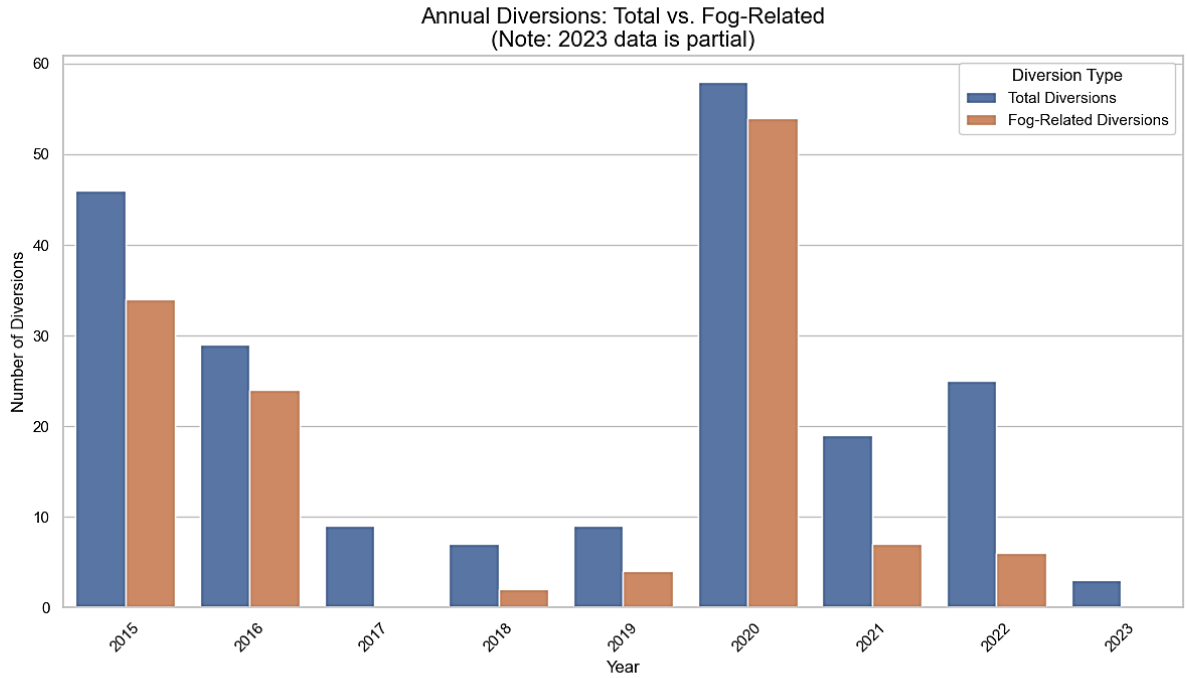

Figure 2. Annual Diversions: Total vs. Fog-Related.

Source: Own elaboration.

A very strong and important seasonal trend is also clear in the data, identifying a specific time of year when the operational risk for the airport is highest. The monthly breakdown, shown in Table 2, shows that December is affected much more than other months and can be seen as the center of weather-related operational problems for EPKK. During the study period, the sampled December months alone had an incredible 138 total diversions, with 117 of those (an amazing 84.8%) being classified as fog-related. This high number of incidents in a single month is a big contrast to the quiet operations during the summer; the sampled June months, for instance, had only one fog-related diversion over the entire eight-year period. The detailed time-series analysis in Figure 3 visually confirms this sharp seasonal difference, showing clear, sharp, and repeated spikes in both the total hours of fog and the number of aircraft diversions almost only during the late autumn and winter months. This gives airport management a clear and predictable calendar of its highest operational risk.

Table 2.
Summary by Month

Month	Total Fog Hours	Total Diversions	Fog-Related Diversions	Percentage of Fog Diversions (%)
March	879	14	5	35.7
June	155	31	1	3.2
September	577	22	8	36.4
December	2167	138	117	84.8

Note. 2023 data is partial (March only).

Source: Own elaboration based on Eurocontrol PRISME database.

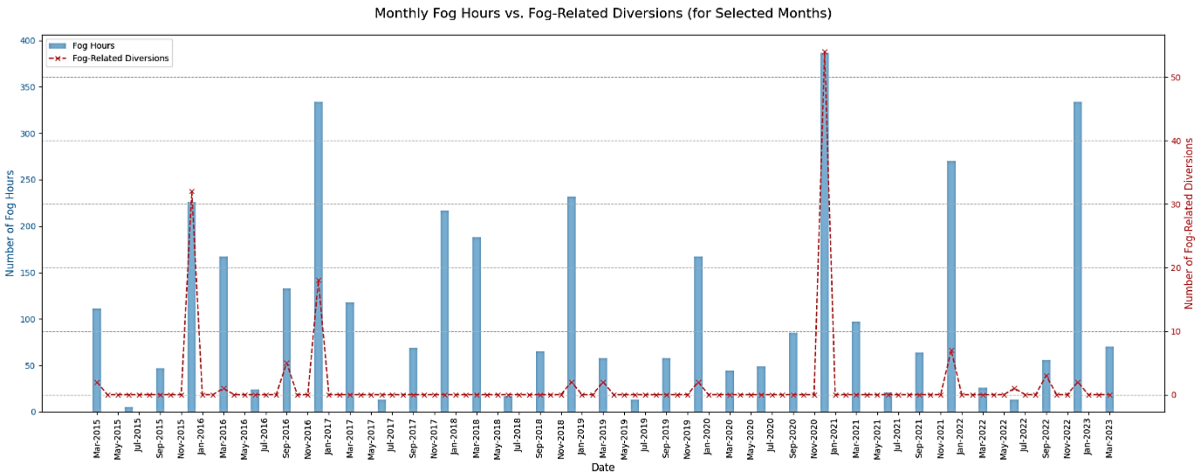

Figure 3. Monthly Fog Hours vs. Fog-Related Diversions.

Source: Own elaboration.

The specific timing and nature of these fog events are very important to fully understand how they disrupt airport management, airline schedules, and network stability. A detailed daily analysis confirms that fog at EPKK is mostly a nighttime and early-morning event, a pattern typical of the radiation fog common in the area. Figure 4 clearly shows that the most fog events happen between 02:00 and 07:00 UTC. This timing is especially bad from an operational standpoint because this window directly conflicts with important overnight cargo flights, the arrival of early-morning passenger flights that connect to other hubs, and the first wave of morning departures that set the pace for the airport's schedule for the whole day.

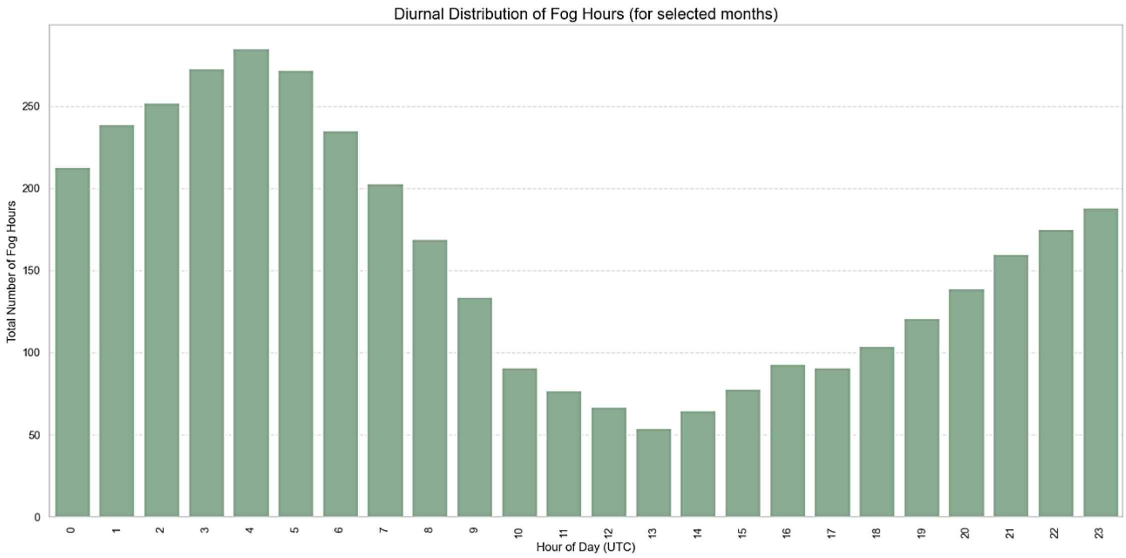

Figure 4. Diurnal Distribution of Fog Hours.

Source: Own elaboration.

The detailed heatmap in Figure 5 and Figure 6 adds to this understanding, showing that during the critical month of December, a thick blanket of high-probability fog often starts in the late evening and lasts through the entire morning, often not clearing until after 10:00 UTC. This creates a long and difficult period of deep operational uncertainty.

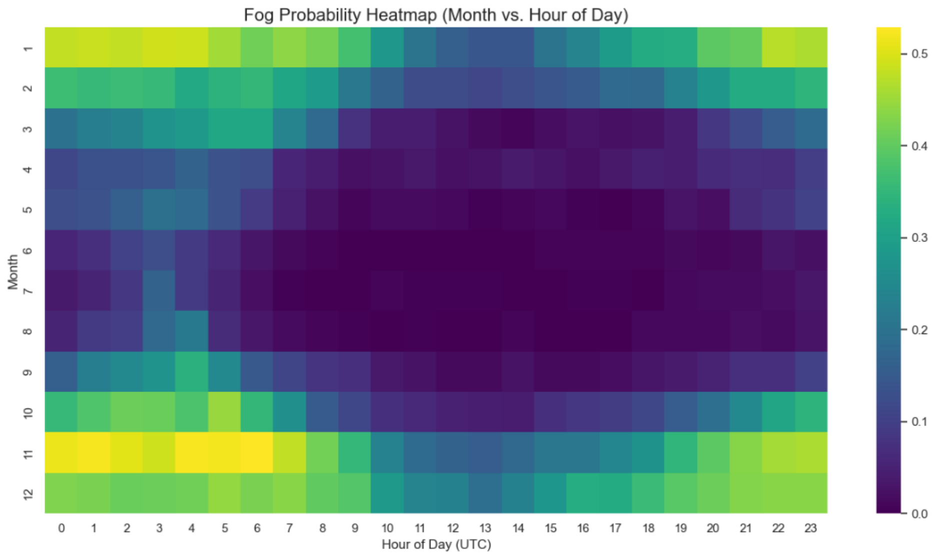

Figure 5. Fog Probability Heatmap by Month and Hour.

Source: Own elaboration.

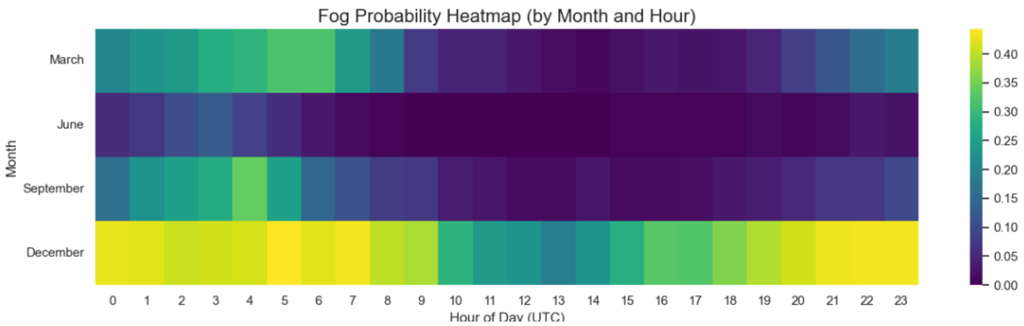

Figure 6. Fog Probability Heatmap by Month and Hour for selected months.

Source: Own elaboration.

The length of these events varies, with the median duration of a continuous fog episode being a significant 3.0 hours. However, the average of 6.2 hours is higher because of a few very disruptive long-lasting events, as shown in the distribution in Figure 7. This includes four separate episodes that lasted for over 48 hours, effectively shutting down normal operations for several days in a row. In the end, from a direct operational point of view, the recorded visibility during these events is the most important limiting factor.

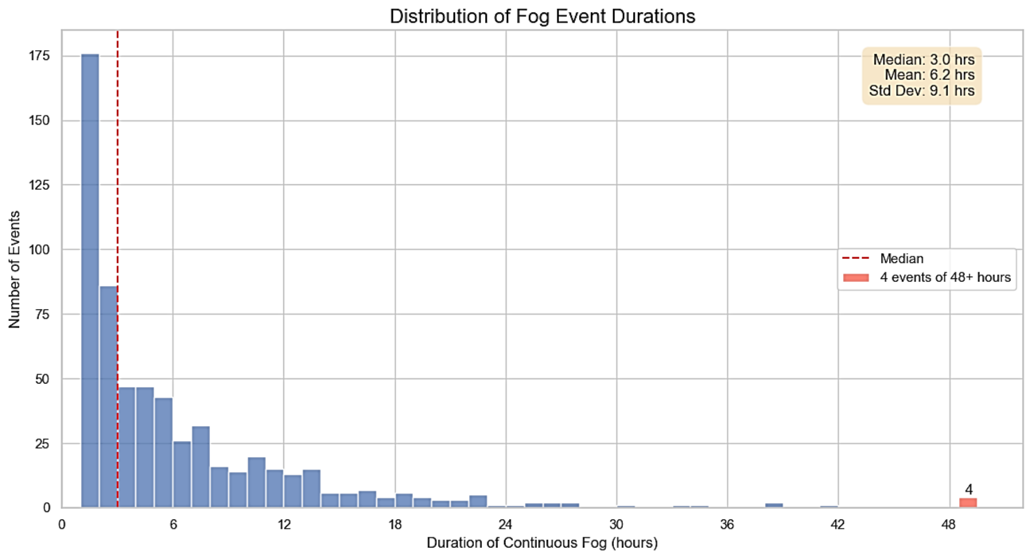

Figure 7. Histogram of Fog Event Durations.

Source: Own elaboration.

The analysis of visibility conditions shows that the airport's capacity is not just strained but often completely stopped. The median visibility during these fog episodes was measured at about 300 meters, a value shown in Figure 8. This is not just below, but critically below, the 550-meter Runway Visual Range (RVR) minimum required for the airport's Category I (CAT I) Instrument Landing System (ILS). This single piece of data provides the final explanation for the high rate of diversions, as these conditions make landings physically and legally impossible for most aircraft and flight crews.

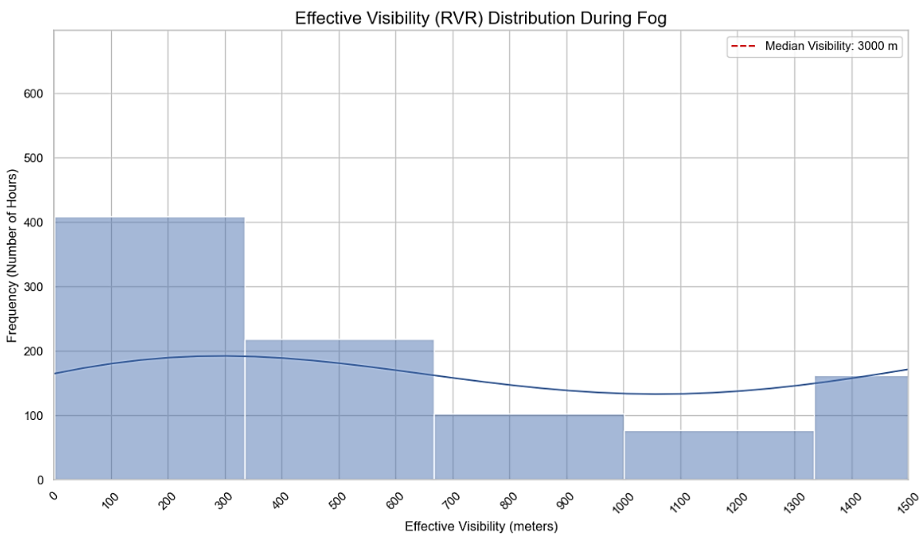

Figure 8. Histogram of Effective Visibility (RVR) Distribution.

Source: Own elaboration.

To confirm these observations, a formal statistical analysis was performed, which showed a significant and strong positive correlation between how long the fog lasted and the number of aircraft diversions. A Pearson correlation analysis looking at the relationship between the total number of fog hours per month and the number of fog-related diversions gave a correlation coefficient (R) of 0.65 with a p-value (p) of less than 0.001. This is shown visually in the scatterplot in Figure 9. This result provides clear quantitative evidence that as fog conditions become more common and last longer, the number of flight diversions goes up in a predictable and moderately strong linear way, making the amount of fog a reliable predictor of operational problems.

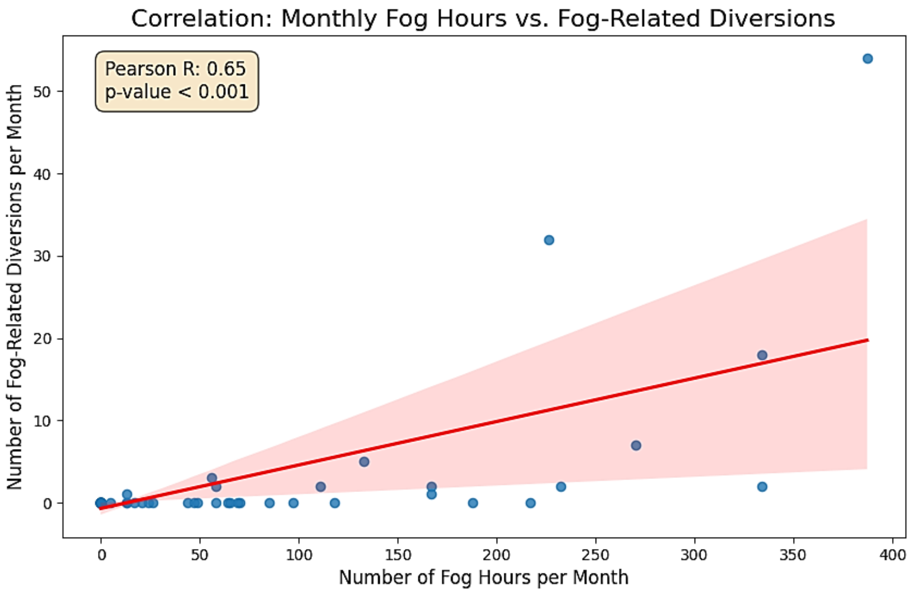

Figure 9. Scatterplot of Monthly Fog Hours vs. Fog-Related Diversions.

Source: Own elaboration.

When these diversions can't be avoided, the data shows that flights are systematically sent to one main alternate airport, which suggests a standard but very concentrated response from airlines. The data in Table 3 and the chart in Figure 10 show that the nearby Katowice Airport (EPKT) took in a huge 109 of the 131 fog-related diversions, which is 83.2% of the total. Warsaw Chopin Airport (EPWA) was the second most used diversion airport, taking 6 flights (6.8%). Other airports like Ostrava Leos Janacek Airport (LKMT) and Rzeszow-Jasionka Airport (EPRZ) each received 4 diversions.

Table 3.
Top 10 Fog-Related Diversion Airports

Alternate Airport	Number of Fog-Related Diversions
EPKT	109
EPWA	6
EPRZ	4
LKMT	4
EDDM	2
EPWR	2

Note. 2023 data is partial (March only).

Source. Own elaboration based on Eurocontrol PRISME database.

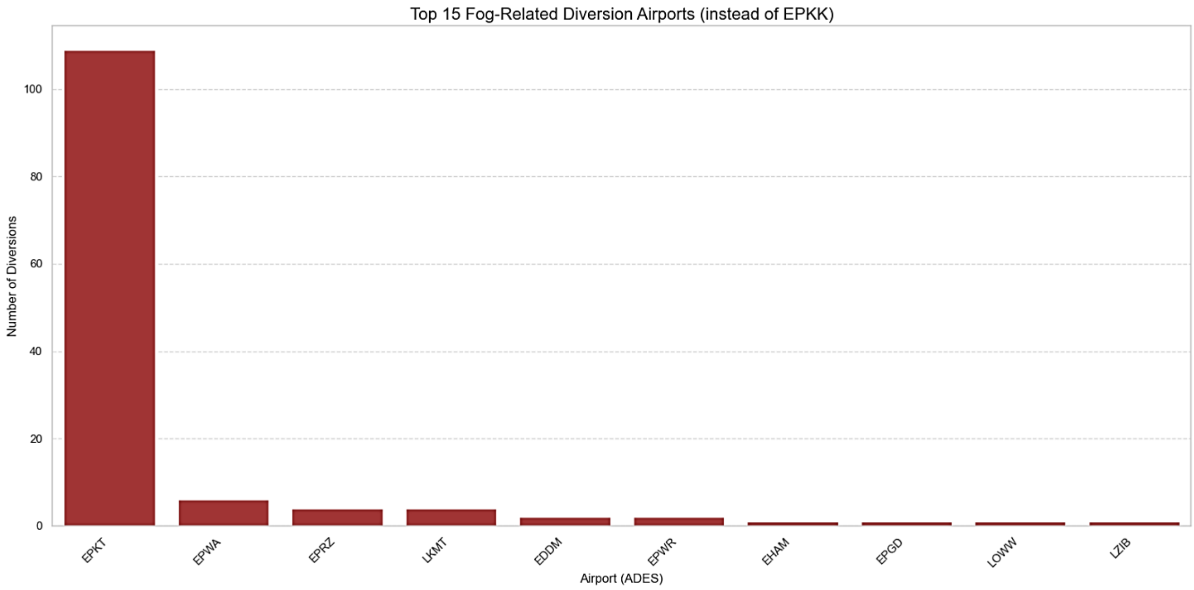

Figure 10. Top 10 Fog-Related Diversion Airports.

Source: Own elaboration.

The rest of the flights were sent to a wider variety of airports, each handling a smaller number, which shows a reliance on airports that are close by. This striking and heavy reliance on EPKT shows its absolutely critical role in the regional aviation network, acting as an essential backup for EPKK during bad weather and showing a deeply established, though potentially risky, network dependency.

5. Discussion

The results of this study provide strong quantitative evidence that fog is a major and frequent cause of significant operational problems at John Paul II International Airport Kraków-Balice. These findings are very important for the airport's management and strategy. They move the discussion from just talking about the weather to measuring the direct impact of this predictable weather event on airport operations, the stability of the regional network, and the business case for investing in infrastructure. The main point of this discussion is to see these numbers as a way to measure risk, responsibility, and the opportunity for improvement. The data changes the long-known "problem of fog" from something that is just accepted as an operational hassle into a measurable, predictable, and ultimately manageable strategic issue. At its core, this study measures a critical operational weakness that directly affects the airport's ability to provide service, its reputation, and its financial health.

The clear seasonal nature of fog, with the most occurrences in December and the least during summer months, matches the literature (Łupikasza, Niedźwiedź, 2016), which points to September to January as the main fog season for Kraków. This strong seasonal pattern highlights the role of large-scale weather conditions that are common in autumn and winter. The daily pattern, with fog mostly happening at night and in the early morning (peaking around 03:00-04:00 UTC), supports the idea that the fog at EPKK is mainly radiational, as suggested by the literature for Poland (Łupikasza, Niedźwiedź, 2016; Skrzyńska, 2019), and is likely made worse by EPKK's location.

The finding that the median visibility during fog events is only 300 meters, which is much lower than the required 550-meter minimum for its Category I ILS, scientifically confirms the concerns that were brought up before by Kwasiborska et al. (2023). It shows without a doubt that a large number of the fog events that naturally happen at EPKK automatically force a stop to all incoming flights. Management should not see this situation as a random operational risk, but as a systemic weakness that is directly tied to the airport's current technology and infrastructure. The fact that this problem is very seasonal, with most of the disruptions happening in the autumn and winter, presents a repeating, predictable challenge to service reliability, passenger satisfaction, and internal planning. Therefore, the findings strongly suggest that a strategic upgrade to a Category II or, even better, a Category III Instrument Landing System—which are made specifically to allow landings in much lower visibility—is the most direct and effective way to fix this core operational weakness. Such an investment would be a major strategic change for the airport, moving it from a position of reacting to expensive disruptions to one of being proactive and operationally resilient, which would make it more competitive among regional airports.

The heavy reliance on the nearby Katowice Airport (EPKT) as the main alternate airport, taking in over 83% of all fog-related diversions from EPKK, shows a critical and deeply rooted network dependency. While on one hand, this shows that there is good informal cooperation in the region and gives airlines a way to cope, it also creates a major systemic risk for the wider network. Any operational problems at EPKT at the same time—like its own bad weather, runway maintenance, or being at full capacity—during a major fog event at EPKK could cause a chain reaction of failures throughout the regional air transport system. This would force airlines to divert to airports that are much farther away, more expensive, and logistically harder to manage. This "EPKT dependency" highlights a hidden weakness in the regional aviation infrastructure and shows why it is urgent for EPKK's management to think about the strength and backup options of the wider network as part of its long-term strategic planning. Furthermore, this situation puts EPKK at a clear competitive disadvantage. When airlines and logistics companies are making decisions about routes and where to set up bases, they do detailed risk assessments. An airport with a known, high chance of weather-related diversions and a reliance on a neighboring airport can be seen as less reliable and more expensive to fly from, which could discourage future investment and growth.

Each of the 131 fog-related diversions found in this study represents a chain of direct and indirect financial costs that affect the entire system. These include immediate costs for airlines, like a large increase in fuel used for the extra flight time, longer crew hours that can lead to complicated scheduling problems and overtime pay, and landing and handling fees at the alternate airport. At the same time, there are major costs related to taking care of and compensating passengers, especially under rules like EU261, which require assistance and possibly financial payouts for long delays and cancellations. On top of these direct financial costs, the frequent and predictable disruptions cause damage that is harder to measure but just as bad, including a loss of passenger trust, a loss of customer loyalty, and significant harm to the reputations of both the airport and the airlines that fly there as reliable service providers. The predictable, seasonal nature of these disruptions means they are not unexpected but are a repeating problem that systematically hurts the efficiency and profitability of operations at EPKK and other airports in the region.

The detailed climatology of fog can also help with short-term operational planning. However, it is important to admit the limitations, mainly that the flight data was sampled from only four months per year. Because of this, the findings about annual diversion totals and the full extent of monthly correlations are based on these sampled periods. The definition of a "fog episode" for correlating with diversions, based on a METAR visibility of ≤550m and a fog indicator, might not capture all operationally important aspects of fog, and the time link shows a correlation, not a definite cause. Other factors that were not analyzed could also be part of the decision to divert. Lastly, the findings are specific to EPKK.

This study creates opportunities for more research, like expanding the diversion analysis to include data from the whole year, looking into the economic costs, or doing comparative studies with airports that have higher-category ILS systems.

6. Conclusions

This research gives a final, thorough, and data-supported assessment of the major operational and organizational impact of fog on Kraków Airport. It concludes with a high degree of confidence that fog is not just an occasional problem but is the single biggest, most predictable, and most impactful cause of flight diversions, being responsible for almost two-thirds of all such disruptions in the large dataset that was sampled. The study shows that this systemic weakness is fundamentally tied to the airport's current Category I Instrument Landing System. This system, while good enough for clear weather, is not technologically advanced enough to handle the low-visibility events that frequently and predictably cover the airport during the important autumn and winter seasons. The research measures the operational breaking point, showing that the median visibility during these events drops to levels that make landings impossible for a CAT I-equipped airport. The findings also highlight a major strategic dependency, with the vast majority of diverted flights being sent to the nearby Katowice Airport. This practice, while it works, creates a potential single point of failure in the regional aviation network and highlights a competitive disadvantage for EPKK.

From an organizational and management point of view, this research changes the way we talk about fog. It is shown not as an uncontrollable weather problem, but as a measurable business risk with significant, repeating financial and reputational costs. The constant cycle of diversions, delays, and passenger problems is a chronic operational issue that hurts efficiency, reduces profitability, and damages the airport's brand as a reliable international gateway. Therefore, this study provides the necessary quantitative basis and a clear reason for airport leadership, airline partners, and regional stakeholders to have a serious, data-based discussion about strategic infrastructure development. The main recommendation from this analysis is the critical need to pursue an upgrade of the airport's landing systems. Investing in a Category II or III ILS should not be seen as just a technical project or an optional expense. Instead, it must be seen as a strategic and essential investment in the airport's future. The return on this investment would be measured in much-improved operational resilience, a huge reduction in costly disruptions, better service reliability and passenger satisfaction, and a fundamentally stronger competitive position. Ultimately, taking this action is presented as a necessary step to reduce a known, measured risk and to secure Kraków Airport's long-term role as a strong, efficient, and growing economic engine for the entire region.

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