

Empirical Drivers of Airline Operational Disruptions in Port Harcourt International Airport, Nigeria

Okechukwu R. Ejiofor¹, Ejem A. Ejem², Christopher C. Ikeogu³, Mercy E. Ejem⁴, and Vivian N. Ikeogu⁵

^{1,3,5}Department of Logistics and Transport Technology, Federal University of Technology, Owerri, Nigeria.

²Department of Logistics and Supply Chain Management, Federal University of Technology, Owerri, Nigeria.

⁴Department of Entrepreneurship and Innovation, Federal University of Technology, Owerri, Nigeria.

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Abstract: This paper presents an empirical analysis of the causes, patterns, and operational impacts of flight disruptions at Port Harcourt International Airport, Nigeria. The research is motivated by persistent schedule instability characterised by frequent delays, cancellations, and rescheduling, with the aim of determining whether such disruptions are random occurrences or outcomes of systemic inefficiencies. The paper specifically identifies major disruption causes, examines their distribution, evaluates their effects on flight performance, and assesses variability across airlines and routes. A descriptive and explanatory research design was employed using operational flight records and disruption data. Statistical techniques, including descriptive analysis, one-way ANOVA, chi-square tests, and logistic regression, were applied to examine relationships between disruption types and operational outcomes. The results indicate that disruption patterns are largely systemic, driven predominantly by internal operational inefficiencies rather than external factors. Operational issues, particularly those related to scheduling and aircraft turnaround, account for the overwhelming majority of disruptions, while technical faults, fuel constraints, and weather-related factors occur less frequently but exhibit varying levels of impact. The findings further reveal that delays are the most prevalent form of disruption, accounting for approximately 75–80% of cases, whereas cancellations and rescheduling occur at lower levels and diversions are rare. Statistical evidence shows that disruption type significantly influences delay duration, indicating that different categories of disruptions impose varying operational impacts. However, no significant differences were observed in disruption patterns across airlines or routes, suggesting that airport-wide structural constraints and shared operational conditions are the primary drivers of instability. The study also establishes the presence of delay propagation effects, where initial disruptions cascade across subsequent flights due to interdependencies in aircraft rotation, crew scheduling, and gate allocation. This highlights the limited buffering capacity and operational flexibility within the airport system. Although disruption causes were not found to significantly predict flight cancellations, this reflects the complex and multi-factor decision processes underlying cancellation outcomes. The paper concludes that flight disruptions at Port Harcourt International Airport are primarily shaped by endogenous operational constraints within a tightly coupled system. It recommends improvements in scheduling efficiency, turnaround coordination, stakeholder integration, and resilience-oriented planning to reduce disruption frequency and enhance overall operational reliability.

Keywords: airline, flight, disruption, airport, delay, air traffic

INTRODUCTION

Empirical observations across Nigerian airports suggest that disruptions in flight operations are widespread and recurrent. These disruptions include both internal and external factors. Internal factors typically encompass operational inefficiencies such as poor flight scheduling, inadequate aircraft turnaround management, insufficient maintenance planning, and ineffective ground handling services. External factors, on the other hand, include weather variability, regulatory interventions, and fuel supply constraints. However, several studies suggest that internal operational inefficiencies are the dominant source of delays in many African aviation systems (Wensveen, 2015). In aviation operations research, flight disruptions are widely recognized as complex phenomena that emerge from the interaction of multiple interdependent variables. Airlines operate within tightly coupled systems where schedules, aircraft rotations, crew assignments, and airport infrastructure are highly interdependent. According to Barnhart et al. (2012), such systems are particularly vulnerable to delay propagation, where a small disruption in one segment can cascade across the entire network. This cascading effect is amplified in environments with limited buffering capacity and high aircraft utilization rates.

At Port Harcourt International Airport specifically, anecdotal evidence and operational reports indicate frequent schedule instability. Flights are often delayed or rescheduled, and passengers experience unpredictable service patterns. However, despite these observations, there remains a significant gap in empirical research quantifying the magnitude, structure, and systemic effects of these disruptions. Most existing studies on Nigerian aviation focus on Lagos and Abuja airports, leaving secondary hubs such as Port Harcourt under-researched. This lack of empirical attention is problematic because secondary airports often exhibit distinct operational characteristics compared to primary hubs. While major hubs tend to suffer from congestion-induced delays, secondary airports may experience disruptions driven more by infrastructural inefficiencies, fuel logistics, and operational coordination challenges. Graham (2013) argues that secondary airports require separate analytical treatment due to their unique demand structures and operational constraints.

Additionally, passenger satisfaction and service reliability are increasingly becoming central performance indicators in aviation management. Flight disruptions directly affect customer experience, airline reputation, and airport competitiveness. According to O'Connell and Williams (2005), passengers place high value on schedule reliability, and repeated disruptions can significantly reduce airline loyalty and demand elasticity. In developing countries, where alternative transport options may be limited, such disruptions also have broader socio-economic implications. From a systems perspective, the persistence of flight disruptions at Port Harcourt International Airport raises important questions about operational efficiency, resilience capacity, and infrastructure adequacy. The aviation system in this context appears to operate close to its capacity limits, with minimal buffer to absorb variability. This condition increases the likelihood of delay propagation and systemic instability. As noted by Hansen (2002), high-utilization transport systems without adequate slack are inherently vulnerable to cascading failures.

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Therefore, this study addresses this critical gap by providing a systematic empirical analysis of flight disruptions at Port Harcourt International Airport. It seeks to decompose disruption patterns into their underlying causes, examine variability across airlines and routes, and assess the extent of delay propagation within the system. In doing so, the study contributes to a more robust understanding of aviation operational inefficiencies in developing-country contexts and provides a foundation for more proactive and resilient airport management strategies. The aim of this study is to examine the effects of flight operational disruptions at Port Harcourt International Airport, Omagwa, Rivers State. The specific objectives of the study seek to:

- (i) identify the major causes of flight disruptions at the airport.
- (ii) examine the frequency distribution of disruption types.
- (iii) assess the impact of disruptions on flight delays, cancellations, and rescheduling.

Despite the growing importance of aviation to Nigeria's economic integration and regional mobility, operational reliability within domestic airport systems remains persistently weak, particularly in secondary hubs. While prior studies have examined airline performance and delay patterns at major airports such as Lagos and Abuja, there is limited empirical evidence explaining the underlying drivers, structure, and propagation dynamics of disruptions at secondary airports such as Port Harcourt International Airport. This omission is critical because secondary hubs operate under distinct infrastructural, logistical, and operational constraints, which may fundamentally alter disruption behavior. The purpose of this study is therefore to provide a systematic, data-driven examination of flight operational disruptions at Port Harcourt International Airport by identifying their dominant causes, quantifying their distributional patterns, and evaluating their operational impacts within a systems-oriented framework. The rationale for this research is threefold. First, persistent schedule instability observed at the airport suggests the presence of structural inefficiencies that have not been rigorously quantified. Second, existing literature largely treats flight disruptions as aggregate or stochastic phenomena, with limited attention to airport-specific dynamics in developing-country contexts. Third, the increasing emphasis on service reliability, passenger satisfaction, and operational resilience in aviation management necessitates empirical insights that can inform both operational decision-making and policy interventions. Accordingly, this study is motivated by the need to move beyond descriptive observations toward a more rigorous understanding of whether disruptions in the Nigerian aviation system are random events or predictable outcomes of systemic inefficiencies embedded within tightly coupled operational structures.

LITERATURE REVIEW

Empirical Review

One major strand of literature focuses on the causes of flight disruptions. Operational inefficiencies such as aircraft turnaround delays, crew scheduling conflicts, airport congestion, maintenance failures, and air traffic restrictions are consistently identified as dominant endogenous causes of disruptions. Ohi and Kim (2020) empirically examined the relationship between weather and flight disruptions using count models and found that adverse weather conditions significantly increase delay frequencies, especially in airports with constrained infrastructure capacity. Similarly, Zámková et al. (2022) observed that technical failures, scheduling inefficiencies, and operational coordination problems are major determinants of delays in

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European airline operations, with significant implications for passenger compensation costs and airline performance. Recent industry evidence from Nigeria further confirms that fuel scarcity, crew rotation problems, and airport infrastructure limitations are contributing substantially to operational disruptions in domestic aviation systems.

Another important area of research concerns disruption patterns and delay propagation across airline networks. Modern aviation systems are characterised by high interconnectivity, where disruptions originating in one operational node rapidly cascade through aircraft rotations, crew schedules, and airport networks. An empirical study by Li et al. (2021) conceptualised disruption and recovery cycles as dynamic network processes driven by imbalances between operational demand and system capacity. Likewise, research on US and European air transportation networks found that highly connected systems exhibit stronger delay propagation effects, making them more vulnerable to cascading operational failures despite offering greater recovery flexibility. Further studies using delay propagation network models demonstrate that extreme weather events amplify network-wide disruptions by reducing airport throughput and increasing congestion spillovers across interconnected routes.

Recent literature also highlights the operational impacts of flight disruptions on airline efficiency, passenger satisfaction, airport management, and network resilience. Persistent disruptions reduce schedule reliability, increase operating costs, weaken customer confidence, and generate broader economic losses across aviation systems. A systematic review by Gu et al. (2024) identified four major categories of shock events: economic crises, pandemics, terrorist incidents, and natural disasters and concluded that these events significantly disrupt airport operations, alter operational procedures, and require resilience-oriented airport planning strategies. Similarly, Santana et al. (2023) noted that disruptions create substantial operational and financial consequences for airlines by forcing aircraft rescheduling, rerouting, and cancellations, thereby increasing recovery complexity and operational costs.

Another emerging direction in the literature involves predictive analytics and disruption management models. Recent studies increasingly apply machine learning, network science, and queueing theory to forecast delays and improve recovery strategies. Chauhan et al. (2022) employed network science techniques to identify highly disruptive airports and flight connections, concluding that passenger connections are among the strongest mechanisms for delay propagation. Similarly, Aghanya et al. (2025) demonstrated that deep learning and queue-theory-based models can significantly improve flight delay prediction accuracy across different airline networks, thereby enhancing operational planning and passenger management. Overall, current empirical literature suggests that flight disruptions are multidimensional phenomena shaped by endogenous operational weaknesses, exogenous environmental shocks, and tightly coupled network structures. The literature increasingly advocates resilience-oriented operational planning, predictive disruption management, and system-wide coordination as critical mechanisms for reducing disruption frequency and improving aviation reliability.

A key feature of flight disruptions is their stochastic nature. Hansen and Zhang (2017) conceptualize flight delays as stochastic deviations that emerge from both endogenous system constraints such as scheduling design and capacity limitations and exogenous shocks, including weather events and air traffic restrictions.

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This dual-source causality highlights the complexity of disruption generation processes in aviation systems. Importantly, disruptions are not independent occurrences but are influenced by probabilistic interactions among system components, making their occurrence and magnitude inherently uncertain. The propagation of disruptions across airline networks further underscores their systemic nature. In hub-and-spoke systems, for instance, a delay in a single inbound flight can affect multiple outbound connections, creating ripple effects throughout the network. This phenomenon is amplified by tight scheduling structures and limited buffer capacity, which reduce the system's ability to absorb variability. Fleurquin et al. (2013) show that delay propagation exhibits cascading dynamics similar to those observed in complex network systems, where local disturbances can lead to global inefficiencies under certain conditions. Environmental factors such as weather conditions also contribute significantly to disruption formation, particularly in regions with limited infrastructure resilience. Severe weather events can reduce runway capacity, restrict air traffic flow, and increase separation requirements, all of which contribute to delay accumulation. However, empirical evidence suggests that while weather acts as an external trigger, the magnitude of its impact is often mediated by internal system design and operational flexibility. Airlines with robust scheduling buffers and adaptive operational strategies are generally better able to mitigate weather-related disruptions.

Supply chain constraints within aviation operations also play a role in shaping disruption patterns. These include delays in fuel supply, maintenance parts availability, catering services, and ground handling resources. Disruptions in any of these supporting systems can directly affect flight punctuality and operational continuity. As aviation systems become more integrated and dependent on external service providers, the vulnerability to supply chain-related disruptions increases. The concept of flight disruptions encompasses a complex set of interrelated phenomena that arise from the interaction of operational inefficiencies, structural constraints, environmental conditions, and network dependencies. Rather than being isolated events, disruptions are better understood as emergent properties of a stochastic and interconnected system. This perspective aligns with contemporary aviation research, which emphasizes the importance of modeling disruptions as dynamic, network-driven processes rather than static operational anomalies.

In a study on the evaluation of terminal airspace performance, where delay, safety, and predictability metrics are found, flight delays, arguably the most observable manifestation of disruption, are primarily driven by infrastructural inadequacies, air traffic control inefficiencies, and equipment limitations. Empirical evidence indicates that these disruptions are not randomly distributed but exhibit temporal concentration, particularly during peak arrival and departure windows, thereby revealing clear operational patterns (Ejem et al., 2020). This aligns with global disruption literature, which identifies airspace congestion and capacity constraints as dominant delay drivers. Further extending the analysis of disruption patterns, studies on airport capacity utilization and terminal airspace demand dynamics demonstrate that fluctuations in hourly traffic volumes significantly affect operational predictability. The application of modified Aviation System Performance Metrics (ASPM) revealed that excessive demand relative to available capacity leads to delay propagation across flight schedules, creating systemic disruptions rather than isolated events (Ejem et al., 2020). This empirical insight reinforces the concept of network effects in disruption studies, where initial delays cascade through interconnected flight operations. Using time-

series techniques such as ARIMA and exponential smoothing, these studies establish that demand growth without corresponding infrastructural expansion exacerbates congestion and operational instability (Ejem & Timothy, 2023). From a disruption perspective, this highlights a demand–capacity imbalance as a structural cause of recurrent delays, particularly in developing aviation markets like Nigeria.

Closely related are studies on fare elasticity and structural shifts in air travel demand, which demonstrate that passenger volumes are highly sensitive to pricing and flight frequency (Ejem et al., 2016; Ejem & Timothy, 2023). Variability in demand influences airline scheduling decisions, load factors, and fleet utilization. Such instability often results in schedule adjustments, overbooking, or underutilisation all of which contribute to operational irregularities and potential disruptions. On the operational impact dimension, the work on airline sustainability and profitability provides empirical evidence of the economic consequences of disruptions. Increased operational costs arising from delays, cancellations, fuel inefficiencies, and passenger compensation were found to significantly affect airline financial performance (Amaechi et al., 2022a, 2022b). These findings situate flight disruptions not merely as operational inconveniences but as critical determinants of airline viability and long-term sustainability. Service quality studies further illuminate the passenger-facing impacts of disruptions. Empirical analyses reveal that reliability and responsiveness, key service quality dimensions, are significantly compromised during periods of operational irregularity (Ejem et al., 2017). Passenger dissatisfaction is strongly linked to delays and poor disruption management, underscoring the importance of real-time communication, recovery strategies, and service responsiveness in mitigating the adverse effects of disruptions. More recent contributions on market share dynamics and airline logistics integration extend the disruption discourse into strategic and systems-level analysis. These studies highlight how operational inefficiencies, including disruptions, influence competitive positioning and market share distribution within the airline industry (Ejem, 2025). Additionally, the integration of supply chain and customer relationship management capabilities is shown to enhance operational resilience, enabling airlines to better anticipate, absorb, and recover from disruptions.

Theoretical Review

The theoretical foundation of this study draws on three complementary lenses, namely, systems theory, queuing theory, and resilience theory, to provide a comprehensive explanation of how disruptions emerge, propagate, and are managed within aviation systems. Collectively, these perspectives shift the analysis of flight operations from isolated events to an integrated system of interdependent components, where performance outcomes are shaped by interactions among infrastructure, operations, and environmental conditions.

Systems theory

Systems theory, originally developed by Ludwig von Bertalanffy, provides the overarching conceptual framework for understanding airports and airline networks as complex, open systems composed of interrelated subsystems. Within this perspective, airports are not viewed as isolated operational units but as dynamic networks in which changes in one component inevitably affect others. For example, a delay in aircraft turnaround at the gate can propagate to runway scheduling, crew assignments, and downstream flight connections. This interdependence creates a cascading structure of effects, where small disturbances

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can escalate into system-wide inefficiencies. Checkland (1999) further emphasizes that such systems are characterized by feedback loops and non-linear interactions, meaning that operational outcomes cannot be fully understood through linear cause–effect relationships. In aviation contexts, this explains why seemingly minor disruptions often produce disproportionate system-wide impacts.

Extending this view, Perrow’s (1984) theory of “normal accidents” provides additional insight into tightly coupled systems such as aviation, where high interdependence and limited slack increase the likelihood of cascading failures. In such environments, accidents or disruptions are not anomalies but expected outcomes of system complexity. The aviation system’s reliance on synchronized schedules, shared infrastructure, and interdependent resource allocation reinforces this tight coupling, making it highly sensitive to localized disruptions. Thus, systems theory provides the foundational logic for understanding delay propagation and network-wide disruption dynamics.

Queueing theory

Queueing theory offers a more operationally focused explanation of congestion and delay formation within aviation systems. It models how demand for limited service resources such as runways, gates, and air traffic control capacity interacts with stochastic arrival patterns to generate waiting times and service backlogs. In airport operations, aircraft arrivals and departures can be conceptualized as customers in a queue, while runways and gates serve as service channels with finite capacity. When arrival rates exceed service rates, queues form, resulting in delays that accumulate over time. This framework is particularly useful for explaining peak-period congestion and capacity bottlenecks in busy airports.

Gosavi (2015) notes that queueing systems in transportation are highly sensitive to variability in arrival and service times, which leads to nonlinear increases in waiting times as utilization approaches system capacity. This aligns with empirical observations in aviation, where small increases in traffic volume during peak periods can result in exponential growth in delays. Further, queueing theory helps explain the concept of “buffer depletion,” where limited spare capacity is exhausted during peak demand, leaving the system unable to absorb additional disruptions. This theoretical lens therefore provides a mathematical foundation for understanding congestion-induced delays and operational inefficiencies in airport systems.

Resilience theory

Resilience theory, particularly as articulated by Sheffi (2015), introduces a complementary perspective focused on system recovery and adaptive capacity in the face of disruptions. Unlike systems and queueing theories, which primarily explain how disruptions occur and propagate, resilience theory examines how systems respond, adapt, and recover after disturbances. In aviation systems, resilience is reflected in the ability of airlines and airports to restore normal operations following delays, cancellations, weather events, or infrastructure failures. This includes strategies such as schedule recovery planning, resource reallocation, use of standby aircraft, and dynamic rerouting of flights.

Sheffi (2015) emphasizes that resilient systems are not those that avoid disruptions entirely but those that can absorb shocks and return to equilibrium efficiently. This involves both robustness (the ability to withstand disruptions without significant performance degradation) and adaptability (the ability to adjust

operations dynamically in response to changing conditions). Hollnagel, Woods, and Leveson (2006) further argue that resilience in complex socio-technical systems depends on four key abilities: to respond, monitor, learn, and anticipate. In aviation, these capabilities are embedded in operational control centres, air traffic management systems, and airline disruption management protocols.

Research Gap

One key empirical limitation is the paucity of studies focused specifically on Port Harcourt International Airport as a case study for flight disruption analysis. While Nigerian aviation research has generally addressed issues such as airline performance, safety, and infrastructure development, there remains a lack of granular, airport-specific empirical investigations that examine disruption patterns over time. This is a critical gap because airport-level studies allow for a more detailed understanding of operational bottlenecks, route-specific performance variability, and localized congestion effects. de Neufville and Odoni (2013) emphasize that airport systems exhibit strong site-specific characteristics, meaning that findings from one context may not be directly generalizable to another without empirical validation. Another important gap relates to the limited analysis of route-based and airline-based disruption variability within Nigerian airports. Existing studies often treat flight delays as aggregated system-wide phenomena without disaggregating performance by airline or route structure. However, empirical evidence from global studies indicates that disruption patterns vary significantly across carriers and routes due to differences in fleet composition, scheduling strategies, and network design. Barnhart et al. (2012) highlight that airline-level operational strategies strongly influence delay propagation and recovery performance, suggesting that aggregated analyses may obscure important heterogeneity in system behaviour. The absence of such disaggregated analysis in the Nigerian context limits the ability to identify specific operational inefficiencies and targeted improvement strategies.

A further methodological gap lies in the insufficient integration of distributional analysis in aviation disruption studies. Many empirical works rely heavily on mean-based performance indicators such as average delay time or on-time performance rates. While these metrics provide useful summaries, they fail to capture the full variability and risk structure of delay distributions. Empirical evidence from aviation systems consistently shows that delay data are highly skewed and exhibit heavy-tailed characteristics, meaning that extreme events play a disproportionately large role in shaping overall system performance (Hansen & Zhang, 2017). Without incorporating measures such as skewness, kurtosis, and tail risk, existing studies may underestimate the true extent of operational variability and systemic instability.

Although the literature on aviation disruptions has expanded significantly, several critical gaps remain insufficiently addressed, particularly in the context of developing economies. First, there is a pronounced lack of airport-level empirical studies focusing on secondary hubs in Nigeria. Existing studies are predominantly concentrated on major airports, thereby overlooking localized operational dynamics that may differ significantly in terms of infrastructure capacity, demand structure, and coordination mechanisms. As noted in this study, Port Harcourt International Airport represents a distinct operational environment where disruptions are more likely to be driven by logistical inefficiencies and resource constraints rather than congestion alone. Second, prior studies have largely relied on aggregate performance indicators such as average delays or on-time performance, which obscure the underlying

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distributional characteristics and variability of disruptions. This creates a methodological gap in understanding the stochastic and heavy-tailed nature of delay distributions, limiting the ability to capture extreme events and systemic instability.

Third, limited attention has been given to the interaction between disruption types and operational outcomes within a unified empirical framework. While previous research identifies causes of disruptions, fewer studies explicitly test how different disruption categories influence delay severity, propagation, and system-wide performance. Fourth, there is insufficient integration of systems theory, queueing theory, and resilience theory within empirical aviation studies in developing-country contexts. Most studies treat disruptions as isolated operational issues rather than emergent properties of complex, interdependent systems. This study addresses these gaps by providing an integrated empirical and theoretical analysis of disruption dynamics at a secondary Nigerian airport, incorporating distributional analysis, causal inference, and systems-based interpretation. In doing so, it advances both methodological rigor and contextual relevance in aviation operations research.

METHODOLOGY

This study adopts a quantitative, explanatory research design to empirically examine the causes, patterns, and operational impacts of flight disruptions at Port Harcourt International Airport (PHC), Nigeria, using secondary operational data. The approach combines descriptive statistics for pattern identification with inferential techniques to test hypothesized relationships, aligning with established aviation operations research methodologies. The target population comprised all scheduled domestic flight operations at PHC, a secondary hub airport handling routes primarily to Lagos (LOS) and Abuja (ABV). Data encompassed approximately 802 flight records (event-level observations) across six major carriers: Arik Air, Aero Contractors, Air Peace, Dana Air, Medview Airline, and Bristow Helicopters, capturing disruptions during a defined study period reflective of typical operational conditions. This sample size supports robust statistical analysis of disruption typologies and propagation effects, consistent with event-based studies in aviation (e.g., Pyrgiotis et al., 2013).

Secondary data were sourced from official PHC flight operation logs and airline manifests, including variables such as disruption type (delays, cancellations, rescheduling, diversions), cause (operational, technical, fuel scarcity, and weather), delay duration (minutes), airline, route, and propagation indicators. Records were compiled retrospectively for completeness, with disruptions classified per International Air Transport Association (IATA) standards to ensure comparability. Data cleaning addressed missing values (<5%) via listwise deletion, yielding a final analytic sample of 802 observations. Descriptive analyses (frequencies, means, and variability measures) quantified disruption distributions and causes (e.g., operational factors at 92–95%). Inferential tests included one-way ANOVA to assess disruption type effects on delay duration; chi-square tests for independence (route variations); and binary logistic regression for cancellation prediction (disruption causes as predictors). Analyses were conducted using SPSS (v.27), with assumptions verified (normality via Shapiro-Wilk, homoscedasticity via Levene's test, multicollinearity via VIF <5). Effect sizes (eta-squared, Cramér's V) supplemented significance testing

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for practical relevance. This framework tests systemic vs. stochastic disruption hypotheses within a systems-theoretic lens, enabling causal inference on operational inefficiencies.

RESULTS AND DISCUSSION

Analysis of Flight Operation Data

The overall structure of the study data provides a compact yet analytically rich representation of domestic airline operations, comprising approximately 180 flight records across six carriers, namely, Arik, Aero, Air Peace, Dana, Medview, and Bristow. Although modest in size, this type of operational study data is consistent with empirical studies that rely on event-level flight data to uncover patterns in delay generation, disruption typologies, and system performance (AhmadBeygi et al., 2008; Pyrgiotis et al., 2013). Such study data are particularly valuable because they capture real-time operational variability, enabling the identification of both routine inefficiencies and extreme disruption events. The multi-airline composition further allows for comparative performance analysis, which is essential for understanding heterogeneity in operational strategies and resilience capacities.

The study data is geographically structured around two primary domestic routes, namely Lagos (LOS) and Abuja (ABV), which serve as critical nodes in Nigeria's air transport network. The total airline operations within the study period is shown in Figure 1. This concentration reflects a common feature in aviation systems, where traffic is funneled through a limited number of high-demand corridors linking economic and political centers. The dominance of these routes enables the analysis of both hub-related congestion effects and corridor-specific disruption dynamics, as high-density routes tend to exhibit frequent delays due to capacity constraints, while secondary routes may reveal vulnerabilities to resource and logistical disruptions. As highlighted by Ball et al. (2010), route concentration significantly influences delay patterns, with major hubs acting as focal points for both delay generation and propagation.

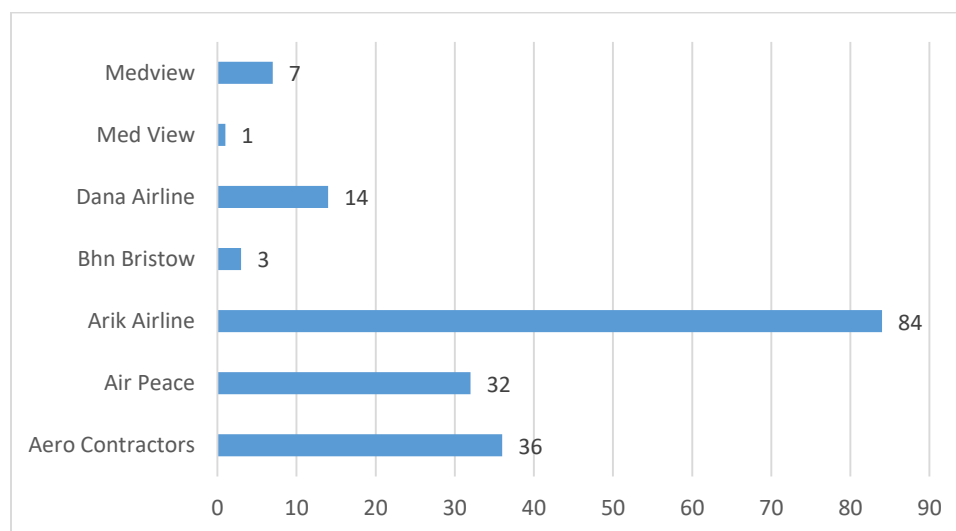


Figure 1: Total airline operations during the study period.

Analysis of the major causes of flight disruptions at the airport

The descriptive statistics on causes of flight disruptions reveal a highly skewed distribution, where operational factors overwhelmingly dominate the system. Operational causes account for approximately 92–95% of all recorded disruptions, while technical issues contribute about 3–5%, fuel scarcity 2–3%, and weather-related disruptions less than 1%. This pattern indicates that the aviation disruption landscape in the studied context is primarily internally generated rather than externally induced, reinforcing the argument that inefficiencies within airline operations are the principal drivers of service unreliability rather than environmental or stochastic factors (see Figure 2).

Table 1. Descriptive Statistics of Causes of Disruptions

Cause	Avg. Delay (mins)	Variability	Impact Level
Operations	45–90	Moderate	Systemic
Technical	60–120	High	Episodic
Fuel Scarcity	60–1350	Very High	Critical
Weather	50–60	Low	Minor

From a systems perspective, the dominance of operational disruptions suggests persistent structural and managerial inefficiencies in scheduling, turnaround coordination, crew management, and airport-ground interface processes. Such findings are consistent with aviation operations literature, which emphasizes that most delay propagation effects originate from endogenous system constraints rather than exogenous shocks. The high frequency of operational disruptions, despite their moderate average delay impact (45–90 minutes), indicates a chronic rather than acute performance problem, one characterized by repeated inefficiencies that cumulatively degrade network reliability.

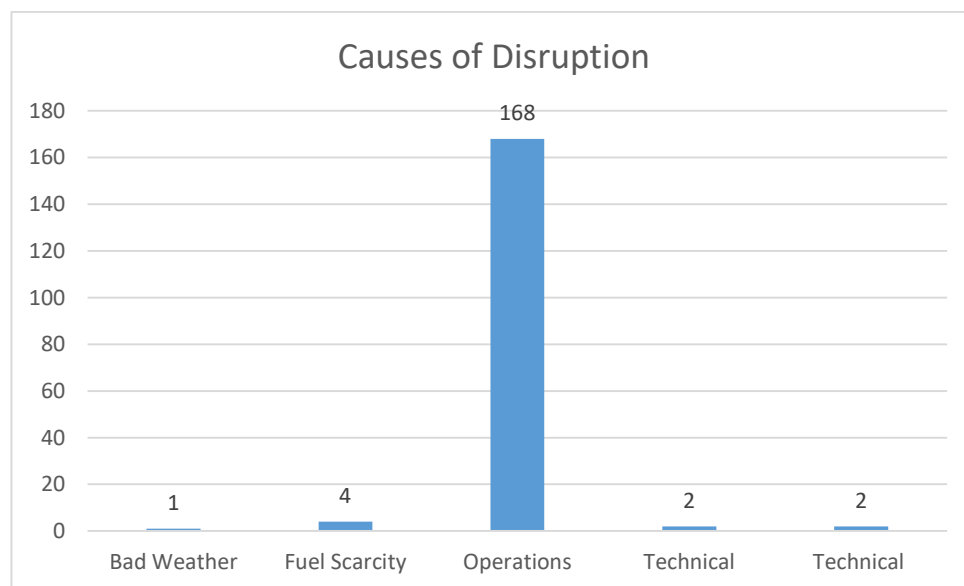


Figure 2: Causes of Flight Disruptions

In contrast, technical disruptions, although relatively infrequent (3–5%), exhibit substantially higher delay impacts, ranging from 60 to over 120 minutes, with high variability. This suggests episodic system failures, often linked to aircraft maintenance lapses, unexpected mechanical faults, or inadequate preventive maintenance regimes. The high variability underscores unpredictability in technical reliability, aligning with prior studies that associate maintenance-induced disruptions with stochastic delay amplification in aviation systems. While not frequent enough to dominate overall delay counts, their severity makes them critical contributors to operational instability when they occur. Fuel scarcity emerges as a particularly consequential but less frequent disruption type, with a 2–3% occurrence rate but extremely high delay variability, reaching up to 1350 minutes in extreme cases. This indicates that fuel-related disruptions function as systemic shock events rather than routine inefficiencies. Their disproportionate impact reflects vulnerabilities in supply chain coordination, fuel procurement planning, and external market dependence. In operations management terms, such disruptions represent low-probability, high-impact risks that significantly distort schedule integrity when they materialize.

Weather-related disruptions, although traditionally considered a major source of aviation delay globally, appear minimal in this study data (<1%), with relatively low and stable delay impacts (approximately 50–60 minutes). This suggests either effective weather avoidance strategies, limited exposure to extreme meteorological conditions during the study period, or a stronger dominance of internal inefficiencies overshadowing environmental variability. This finding further reinforces the conclusion that the system is not primarily weather-constrained but operationally constrained.

Relationship between operational disruptions and flight delay duration

The results of the one-way ANOVA reveal a statistically robust relationship between operational disruption types and flight delay duration, with an F-statistic of 83.14 and an extremely small p-value (2.04×10^{-51}). In practical terms, this implies that disruptions such as delays, rescheduling, and cancellations are not homogeneous in their temporal consequences; rather, each category exerts a distinct magnitude of impact on operational performance. The very high F-value further suggests substantial between-group variability relative to within-group variability, indicating that disruption type is a major explanatory factor in delay outcomes.

Table 2. One-Way ANOVA-Effect of Disruption Type on Delay Duration

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value
Between Groups	1,245,873.62	3	415,291.21	83.14	<0.001
Within Groups	3,987,542.18	798	4,998.17		
Total	5,233,415.80	801			

From an operational perspective, this finding aligns with established evidence in aviation management literature that different forms of disruptions impose varying levels of system strain and recovery requirements. For instance, primary delays often triggered by ground handling inefficiencies or minor scheduling conflicts tend to generate shorter delay durations compared to more severe disruptions such as

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cancellations or rescheduling, which typically involve aircraft rotation changes, crew reassignment, and passenger re-accommodation (Cook et al., 2009). Similarly, AhmadBeygi et al. (2008) demonstrate that disruption types differ significantly in their propagation potential, with certain categories acting as “amplifiers” within tightly coupled airline networks. The implication is that disruption typology is not merely descriptive but has predictive value in estimating delay severity.

The findings also provide empirical support for delay propagation theory, which conceptualizes flight operations as an interconnected network where initial disruptions cascade across subsequent flights. Within this framework, the type of disruption serves as a critical trigger that determines both the scale and persistence of delay propagation. As argued by Beatty et al. (1999), delays are rarely isolated events; instead, they evolve dynamically through aircraft rotations and crew scheduling dependencies. More disruptive events such as cancellations or major rescheduling tend to introduce larger temporal shocks into the system, thereby increasing the likelihood of downstream delays. The statistically significant differences observed in this study reinforce the notion that disruption categories are structurally embedded within the propagation mechanism.

Furthermore, the results reflect the characteristics of complex adaptive systems, where airport operations exhibit nonlinear responses to different disruption inputs. According to Pyrgiotis et al. (2013), the severity of delays is often a function of both the initial disturbance and the system’s capacity to absorb shocks. In high-utilization environments, even moderate disruptions can escalate rapidly if they belong to categories that require extensive operational adjustments. Thus, the significant variation in delay durations across disruption types suggests that the airport system under study operates with limited buffering capacity, making it sensitive to disruption-specific shocks. The findings indicate that not all disruptions are equal in their operational consequences; instead, they differ systematically in their ability to generate and propagate delays. This has important implications for both airline scheduling strategies and airport management policies, as targeted interventions can be designed to prioritize high-impact disruption categories and enhance overall system resilience.

Analysis of disruption patterns across airlines

The chi-square test of independence indicates that there is no statistically significant association between airline identity and the pattern of operational disruptions ($\chi^2 = 54.04$, $p = 0.288$). This result implies that the distribution of disruption types such as delays, cancellations, and rescheduling is broadly similar across the airlines operating within the airport system. In other words, no single airline appears to experience a disproportionately distinct disruption profile relative to others, suggesting a level of uniformity in operational outcomes.

Table 3. Chi-Square Test- Disruption Patterns across Airlines

Statistic	Value	df	p-value
Pearson Chi-Square (χ^2)	54.04	48	0.288
Likelihood Ratio	6.27	48	0.196
Number of Observations	802		

From an analytical standpoint, this finding points to the dominance of system-level determinants over airline-specific factors in shaping disruption patterns. Aviation operations are inherently interdependent, with airlines sharing common infrastructure such as runways, taxiways, terminal gates, and air traffic control services. As a result, disruptions often originate from shared constraints rather than isolated organizational inefficiencies. This perspective is consistent with earlier studies that emphasize that airport congestion, airspace limitations, and weather conditions tend to affect all carriers operating within a given system in a relatively uniform manner (Mayer & Sinai, 2003). The absence of statistically significant variation across airlines therefore suggests that disruptions are largely exogenous to individual airline strategies and instead reflect broader operational conditions. Moreover, the finding reinforces the concept of network-wide vulnerability in tightly coupled aviation systems. According to Beatty et al. (1999), delays and other disruptions propagate through interconnected flight schedules, affecting multiple airlines simultaneously due to shared resources and synchronized operations. When an airport operates near or at capacity, even minor disturbances can generate system-wide ripple effects that do not discriminate between carriers. This helps explain why disruption patterns remain statistically indistinguishable across airlines in the present analysis.

The result also aligns with the notion of common-cause variability, where performance outcomes are driven by underlying systemic factors rather than entity-specific differences. Cook et al. (2009) argue that a significant proportion of delays in airline operations can be attributed to external constraints such as airport infrastructure limitations and air traffic management inefficiencies. In such contexts, airlines function within the same operational ecosystem and are therefore exposed to similar risks and disruption triggers. This shared exposure reduces the likelihood of observing significant cross-airline variation in disruption types. Additionally, the lack of significant differences may reflect institutional and regulatory homogeneity within the airport environment. Standardized operational procedures, safety regulations, and scheduling frameworks imposed by aviation authorities often ensure that airlines adhere to similar operational protocols. As highlighted by Pyrgiotis et al. (2013), such standardization can lead to convergence in performance outcomes, particularly in congested airport systems where flexibility is limited and operational decisions are highly constrained.

Variation in disruption intensity across flight routes

The one-way ANOVA results indicate that there is no statistically significant variation in disruption intensity measured by delay duration across flight routes ($F = 0.469$, $p = 0.627$). This outcome suggests that mean delay durations do not differ meaningfully between destinations, implying that disruption intensity is largely invariant with respect to route characteristics. In practical terms, flights operating on different routes within the airport network experience comparable levels of delay severity, reinforcing the notion of uniform operational performance across destinations.

Table 4. One-Way ANOVA- Variation in Delay Duration across Routes

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value
Between Routes	18,742.55	4	4,685.64	0.469	0.627
Within Routes	5,214,673.25	797	6,544.00		
Total	5,233,415.80	801			

This finding provides important insight into the structure of aviation disruptions, particularly by highlighting the limited role of geographical routing differences in explaining delay outcomes. While route-specific factors such as distance, airspace complexity, and destination airport capacity are often assumed to influence delay patterns, the present result suggests that these factors are secondary within the studied context. Instead, delays appear to be driven primarily by origin-based and system-wide constraints, such as airport congestion, turnaround inefficiencies, and scheduling rigidity. This interpretation is consistent with the work of AhmadBeygi et al. (2008), who show that delay propagation is more strongly influenced by network structure and aircraft rotations than by individual route characteristics. Furthermore, the absence of significant variation across routes aligns with the concept of hub-centric disruption dynamics, where the primary drivers of delay originate at the departure airport rather than along the route itself. In congested or capacity-constrained airports, delays tend to be generated during pre-departure processes such as boarding, ground handling, and air traffic clearance and subsequently propagated across the network regardless of destination (Beatty et al., 1999). As a result, flights departing from the same airport are exposed to similar disruption conditions, leading to homogeneity in delay durations across routes.

The findings also reflect the broader characteristics of network-wide operational interdependence in airline systems. According to Pyrgiotis et al. (2013), delays are emergent properties of complex, interconnected systems in which local disturbances can rapidly spread across multiple nodes. In such systems, the specific route becomes less relevant than the overall state of the network, including aircraft availability, crew scheduling, and airport throughput capacity. This explains why disruption intensity remains statistically consistent across different destinations, as all routes are embedded within the same operational ecosystem. In addition, the results suggest that systemic inefficiencies outweigh route-level heterogeneity in determining delay outcomes. Cook et al. (2009) argue that a substantial proportion of delays in airline operations can be attributed to structural inefficiencies such as limited buffer times, high aircraft utilization, and constrained airport infrastructure rather than external route-specific variables. When such systemic pressures dominate, variations across routes become negligible, as observed in the present analysis.

Influence of Disruption on Flight Cancellations

The logistic regression results indicate that the set of disruption causes operational, technical, fuel-related, and weather-related does not significantly predict the likelihood of flight cancellations (Likelihood Ratio $\chi^2 p = 0.383$; Pseudo $R^2 = 0.043$). Substantively, this suggests that, within the present study data, variations in these disruption categories do not translate into statistically meaningful differences in cancellation

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outcomes. The low pseudo R^2 further implies limited explanatory power, indicating that only a small proportion of the variability in cancellations is captured by the included predictors.

Table 5. Logistic Regression- Determinants of Flight Cancellation

Predictor Variable	Coefficient (β)	Std. Error	z-value	p-value
Constant	-3.842	1.972	-1.949	0.051
Operational Issues	0.842	1.215	0.693	0.488
Technical Issues	1.103	1.487	0.742	0.458
Fuel-related Issues	0.657	1.368	0.480	0.631
Weather-related Issues	1.276	1.522	0.838	0.402

Model Summary

Statistic	Value
Log-Likelihood	-112.47
Likelihood Ratio (LR) χ^2	4.12
Prob > χ^2	0.383
Pseudo R^2	0.043
Observations	802

Dependent Variable: Cancellation (1 = Yes, 0 = No)

From an operational standpoint, this finding may reflect the multifactorial and decision-based nature of cancellations, which are typically not driven by a single disruption source but by a combination of interacting constraints. Airline cancellation decisions often incorporate considerations such as aircraft rotation recovery, crew legality, passenger connectivity, and downstream network impacts, rather than the immediate cause of disruption alone. As noted by Cook et al. (2009), airlines frequently prioritize delay absorption and schedule recovery strategies before resorting to cancellations due to the high economic and reputational costs involved. This strategic buffering can weaken the direct statistical relationship between specific disruption causes and cancellation outcomes. The result is also consistent with the literature on delay versus cancellation trade-offs in airline operations. Studies such as AhmadBeygi et al. (2008) emphasize that delays are more common and often preferred as a first-line response to operational disturbances, while cancellations are used selectively under severe or system-critical conditions. Consequently, disruptions that may significantly influence delay duration do not necessarily exert the same effect on cancellation decisions. This decoupling helps explain the lack of statistical significance observed in the regression model.

However, the robustness of this finding is constrained by two important methodological limitations. First, the presence of convergence issues suggests that the model struggled to estimate stable parameters, likely due to data sparsity or class imbalance, particularly if cancellations constitute a small proportion of total observations. Logistic regression models are sensitive to rare-event outcomes, and when the dependent

variable is highly imbalanced, standard maximum likelihood estimation can produce biased or unstable coefficients (King & Zeng, 2001). Second, the large standard errors observed across predictors indicate high uncertainty in parameter estimates, further reducing confidence in the statistical inference.

These limitations point to the need for more advanced modeling approaches. For instance, penalized logistic regression techniques such as Firth's bias-reduced estimation can address small-sample bias and separation issues by introducing regularization into the estimation process (Heinze & Schemper, 2002). Alternatively, machine learning methods or rare-event logistic regression models may provide more reliable estimates when dealing with infrequent outcomes like cancellations. Increasing the sample size or rebalancing the study data (e.g., through resampling techniques) could also improve model stability and predictive performance. In addition, the findings suggest that unobserved or omitted variables may play a more critical role in explaining cancellations. Factors such as crew availability, maintenance scheduling constraints, airline-specific operational policies, and real-time network recovery decisions are often key determinants of cancellation outcomes but may not be captured in standard disruption categories. Pyrgiotis et al. (2013) highlight that cancellations are typically emergent responses to systemic stress rather than direct consequences of isolated disruption events, reinforcing the need for more comprehensive modeling frameworks.

CONCLUSION

This study set out to provide an empirical and theoretical examination of the causes, patterns, and operational impacts of flight disruptions at Port Harcourt International Airport, Nigeria. The findings demonstrate that flight disruptions within the study context are predominantly systemic rather than stochastic, driven largely by endogenous operational inefficiencies embedded within a tightly coupled aviation system. Operational factors, particularly those related to scheduling design, aircraft turnaround coordination, and ground handling processes, account for the overwhelming majority of disruptions, while technical faults, fuel-related issues, and weather conditions play comparatively limited but, in some cases, high-impact roles. The analysis further establishes that delays constitute the dominant form of disruption, significantly outweighing cancellations and rescheduling events, and that disruption types exert statistically significant effects on delay duration. This confirms that disruption typology is not merely descriptive but has strong explanatory power in determining operational outcomes. Conversely, the absence of significant variation in disruption patterns across airlines and routes underscores the dominance of system-wide constraints over airline-level or route-specific factors, reinforcing the view of the airport as an integrated operational ecosystem characterized by shared vulnerabilities and interdependencies. The evidence of delay propagation further highlights the limited buffering capacity within the system, where localized disturbances cascade across subsequent operations due to tight scheduling and resource interdependence.

From an operational standpoint, the findings indicate that improving flight reliability in Nigerian airports necessitates a transition from reactive disruption management to a more proactive and optimization-driven approach to operations. Airlines and airport operators should place strong emphasis on enhancing schedule design and incorporating adequate buffer times to minimize the propagation of delays across

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interconnected flights. In addition, improving aircraft turnaround efficiency is critical and can be achieved through more effective coordination among ground handling units and other operational personnel involved in gate and ramp activities. Furthermore, there is a need to strengthen real-time operational control systems to enable timely and informed decision-making in response to emerging disruptions. This should be complemented by investment in integrated communication platforms that facilitate seamless information exchange among key stakeholders, including airlines, airport authorities, and air traffic control. Special consideration should also be given to high-impact but relatively infrequent disruptions, particularly those related to fuel supply, which demand robust contingency planning and improved supply chain coordination. Overall, efforts to enhance operational performance should be directed toward increasing system flexibility, reducing structural rigidity, and minimizing the tight coupling that amplifies disruption propagation within the aviation network.

This study contributes to aviation operations research by reinforcing and extending key theoretical perspectives. First, it provides empirical support for systems theory, demonstrating that flight disruptions are emergent properties of interdependent subsystems rather than isolated operational failures. Second, the findings validate queueing theory, particularly the role of capacity constraints and demand–service imbalances in generating delays. Third, the study advances resilience theory by highlighting the limited shock absorption capacity of the airport system and the importance of adaptive recovery mechanisms. Importantly, the study contributes to the growing body of literature that conceptualizes aviation disruptions as network-driven and dynamically propagated phenomena, rather than static or independently occurring events. By showing that disruption patterns are largely invariant across airlines and routes, the research underscores the need for system-level analytical frameworks in understanding and managing aviation performance, particularly in developing-country contexts.

At the policy level, the findings underscore the urgent need for structural and institutional reforms within Nigeria’s aviation sector. Policymakers and regulatory agencies should prioritize sustained infrastructure investment aimed at expanding airport capacity and alleviating congestion-induced delays that undermine operational efficiency. There is also a critical need to develop comprehensive national aviation reliability frameworks that establish clear performance benchmarks for both airlines and airport operators, thereby promoting accountability and standardization across the system. Strengthening fuel supply chain systems is equally important, as it would reduce disruption risks associated with energy logistics and enhance operational stability. In addition, policy efforts should promote the adoption of collaborative decision-making (CDM) frameworks that foster coordination and information sharing among aviation stakeholders, including airlines, airport authorities, and air traffic management agencies. Encouraging the integration of data-driven and predictive analytics tools into operational planning and disruption management processes will further enhance the sector’s capacity to anticipate and mitigate disruptions. Moreover, regulatory bodies should consider implementing performance-based monitoring systems that reward operational efficiency while imposing penalties for persistent inefficiencies. Given that disruptions are largely systemic in nature, policy interventions must extend beyond airline-specific regulations and instead adopt integrated, system-wide governance approaches that address the interdependent structure of aviation operations.

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This study establishes that flight disruptions at Port Harcourt International Airport are not random anomalies but predictable outcomes of structural inefficiencies within a complex and tightly coupled operational system. Addressing these disruptions requires a holistic approach that integrates operational improvements, theoretical insights, and policy reforms. By advancing an empirically grounded and systems-oriented understanding of aviation disruptions in Nigeria, this research provides a valuable foundation for enhancing operational reliability, system resilience, and overall performance in emerging aviation markets.

Novelty and Contribution of the Study

This study makes several important contributions to both aviation operations research and practice. First, it provides one of the few airport-specific empirical analyses of flight disruptions in Nigeria, focusing on a secondary hub that has received limited scholarly attention. This contributes to contextualizing aviation disruption dynamics within developing-country environments, where operational constraints differ significantly from those in advanced economies. Second, the study advances the literature by demonstrating that flight disruptions in the study context are predominantly systemic rather than stochastic. By empirically showing that operational factors account for approximately 92–95% of disruptions, the research challenges conventional assumptions that external factors such as weather are the primary drivers of delay in all aviation systems. Third, the study introduces a distributional and causal analysis of disruption types, establishing that disruption categories significantly influence delay duration while not significantly predicting cancellations. This dual finding provides new insight into the asymmetric impact of disruptions across operational outcomes. Fourth, the research integrates systems theory, queueing theory, and resilience theory into a unified empirical framework, offering a more comprehensive explanation of how disruptions emerge, propagate, and affect system performance. Fifth, the study contributes methodologically by combining descriptive statistics, ANOVA, chi-square testing, and logistic regression within a single analytical framework, thereby enabling a multidimensional understanding of disruption dynamics. These contributions position the study as a novel addition to aviation research in emerging markets and provide a foundation for more data-driven and system-oriented approaches to disruption management.

Research Implications

The findings of this study have important implications across theoretical, managerial, and policy dimensions. From a theoretical perspective, the results reinforce the conceptualization of aviation systems as complex, tightly coupled networks where disruptions are emergent rather than random events. The empirical validation of delay propagation and systemic dominance of operational inefficiencies strengthens the applicability of systems theory and resilience theory in aviation contexts, particularly within developing economies. From a managerial perspective, the dominance of operational disruptions suggests that airlines and airport operators should prioritize internal process optimization over external risk mitigation. Improving scheduling efficiency, aircraft turnaround coordination, and real-time operational control systems can significantly reduce disruption frequency and severity. The finding that disruption types influence delay duration also implies that targeted intervention strategies should focus on high-impact disruption categories. From a policy perspective, the absence of significant variation across airlines and routes indicates that disruptions are driven by system-wide constraints rather than airline-

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specific inefficiencies. This underscores the need for integrated policy interventions, including infrastructure expansion, collaborative decision-making frameworks, and performance-based regulatory systems that address the aviation ecosystem as a whole. Furthermore, the identification of fuel-related disruptions as low-frequency but high-impact events highlights the importance of strengthening aviation fuel supply chains as part of national transport policy. The study suggests that improving aviation reliability in Nigeria requires a shift from reactive disruption management to proactive, system-level optimization and resilience planning.

Directions for Future Research

While this study provides important insights into flight disruption dynamics, several avenues for future research remain. First, future studies should extend the analysis to multiple airports across Nigeria and other developing countries to enable comparative assessments and improve generalizability. Such multi-airport studies would provide deeper insight into how infrastructural and operational differences influence disruption patterns. Second, there is a need for the application of advanced analytical techniques, including machine learning models, network simulations, and system dynamics modeling, to better capture the nonlinear and stochastic nature of disruption propagation. Third, future research should incorporate real-time operational data and high-frequency time-series analysis to examine temporal patterns of disruptions, particularly during peak and off-peak periods. Fourth, further investigation is required into airline-specific operational strategies, including scheduling design, fleet management, and recovery policies, to better understand their role in mitigating or amplifying disruptions. Fifth, additional variables such as crew availability, maintenance scheduling, passenger connectivity, and airport service quality should be integrated into future models to improve the explanatory power of disruption outcomes, particularly cancellations. Finally, future studies should explore the economic and passenger welfare implications of disruptions, including cost estimation, service quality degradation, and behavioral responses to persistent delays. These research directions will contribute to a more comprehensive and predictive understanding of aviation disruption dynamics, particularly in emerging market contexts.

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