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Operational Resilience Analysis of Airside Capacity at Djalaluddin Gorontalo Airport During Infrastructure Expansion

Sri Susanty Satya A.[1], Dukalang[2]

[1,2]Universitas Muhammadiyah Gorontalo

srisusantyoctober@gmail.com

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ABSTRACT

The purpose of this study was to evaluate the operational resilience of airside capacity at Djalaluddin Gorontalo Airport during a simulated infrastructure expansion phase that temporarily reduces apron capacity. The infrastructure expansion, inaugurated in February by the Governor of Gorontalo, aimed to improve the apron and taxiway facilities to allow direct embarkation of Hajj pilgrims from Gorontalo, avoiding the need to travel to Makassar or Jakarta. This development is particularly important for elderly pilgrims, whose physical condition can be adversely affected by long travel times and crowding at secondary embarkation points. Infrastructure development is essential to accommodate future aviation demand; however, construction activities can introduce temporary operational constraints that may affect airport performance, particularly at low-traffic regional airports with limited infrastructure redundancy.

The study purpose was to provide a predictive assessment of how apron capacity reduction influences operational performance and system resilience at Djalaluddin Gorontalo Airport during an infrastructure expansion phase. The study also aimed to support proactive decision-making for airport management in anticipating potential operational disruptions during construction activities.

Materials and methods. The study employed a pre-impact predictive assessment approach using historical operational data from Djalaluddin Gorontalo Airport covering the period 2023–2025. Baseline operational indicators—induding flight movements, average delay, apron utilization, and on-time performance—were analyzed using descriptive statistics. A simulation scenario was developed to model a temporary apron capacity reduction from eight to six parking stands (approximately 25%) during the construction phase. Operational impacts were evaluated through changes in delay propagation and apron utilization. A composite Resilience Index (RI) was calculated based on resilience dimensions of robustness, vulnerability, and recoverability.

Results. Baseline analysis indicates that the airport operates with an average of three daily flight movements, an average delay of 12 minutes, and an apron utilization rate of 65%, reflecting a flexible operational environment. Under the simulated apron capacity reduction scenario, average delay increases to approximately 18 minutes and apron utilization rises to around 90%. Despite these changes, the calculated Resilience Index remains at 0.85, indicating adequate capacity to absorb temporary disruptions without significant degradation of operational reliability.

Conclusions. The findings demonstrate that low-traffic regional airports may possess inherent operational flexibility that enables them to maintain service continuity during infrastructure expansion. The predictive resilience assessment framework provides a practical tool for airport managers to anticipate operational risks and implement mitigation strategies during construction phases.

Keywords: airport resilience, airside capacity, infrastructure expansion, apron utilization, regional airports

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INTRODUCTION

The global aviation industry continues to experience steady growth, particularly in emerging economies where regional airports serve as critical connectors for economic development, tourism, and social integration. In Indonesia, the expansion and modernization of airport infrastructure have become a national priority to support the country's archipelagic connectivity and economic resilience.

However, infrastructure development at operational airports presents a unique paradox: while expansion is necessary to meet future demand, the construction process itself can temporarily disrupt airside operations, potentially compromising safety, efficiency, and service reliability. This challenge is especially pronounced at tropical, low-traffic regional airports like Djalaluddin Gorontalo Airport, where limited operational slack, climatic vulnerabilities, and resource constraints converge to create a complex risk environment during infrastructure projects.

Airport engineering and planning have long been guided by international standards and best practices. Ashford et al. (2011) provide a comprehensive framework for the planning, design, and development of 21st-century airports, emphasizing the need to balance capacity, safety, and economic viability. Similarly, the International Civil Aviation Organization (ICAO) Annex 14 establishes globally recognized specifications for aerodrome design and operations, including provisions for infrastructure development phases (ICAO, 2018). At the national level, Indonesian regulations such as CASR Part 139 (Kementerian Perhubungan, 2015) and the Aviation Safety Management System regulation (Kementerian Perhubungan, 2018) mandate rigorous safety oversight during all airport activities, including construction. Despite these robust regulatory frameworks, a gap remains in practical, data-driven methodologies for assessing *operational resilience*—the ability of an airport system to anticipate, absorb, adapt to, and recover from disruptions—specifically during temporary capacity reductions caused by infrastructure expansion.

The concept of resilience, originally developed in ecological and seismic engineering contexts, has gained traction in transportation and aviation research. Bruneau et al. (2003) pioneered a quantitative framework for community seismic resilience based on four interrelated properties: robustness, redundancy, resourcefulness, and recoverability. This framework has been adapted by subsequent researchers to assess infrastructure systems under stress. In aviation, Janić (2020) proposed a structured approach for analyzing airport resilience, explicitly incorporating robustness, vulnerability, and recoverability as measurable dimensions. Omer et al. (2013) further advanced the field by developing metrics to quantify the resilience of aviation systems, emphasizing the importance of dynamic performance tracking during disruptive events. These theoretical foundations provide a valuable lens through which to evaluate airport operations during infrastructure projects, yet their application to low-traffic tropical airports remains underexplored.

Low-traffic airports, often serving regional or remote communities, exhibit distinct operational characteristics compared to high-density hubs. They typically operate with minimal schedule buffers, limited alternative infrastructure, and heightened sensitivity to weather-related disruptions—factors that can amplify the impacts of capacity constraints during construction. Tropical climates introduce additional complexities, including intense rainfall, high humidity, and rapid weather changes, which can affect both construction timelines and airside operational performance. While studies such as Cook et al. (2011) have quantified the cost impacts of flight delays at major airports, there is limited empirical research on how low-traffic tropical airports maintain operational continuity when faced with simultaneous infrastructure development and environmental stressors.

Recent research at Djalaluddin Gorontalo Airport has begun to address aspects of its operational safety and capacity. Notably, Dukalang (2025) conducted an assessment of runway ACN-PCN compatibility, providing critical insights into the structural pavement capacity and its implications for aircraft operations. This study established an important baseline for understanding the airport's physical infrastructure limits. However, operational resilience encompasses more than pavement strength; it involves the dynamic interplay between capacity, demand, scheduling, weather, and management responses during disruptive phases. The current study builds directly upon the foundation laid by Dukalang (2025) by extending the analysis from structural compatibility to *system-wide operational resilience* during a temporary apron capacity reduction scenario. By integrating the resilience framework of Bruneau et al. (2003) and the airport-specific metrics of Janić (2020), this research aims to provide a holistic, predictive assessment tool for airport managers.

Infrastructure expansion projects, such as apron extensions and taxiway developments, are essential for accommodating growth but inevitably introduce temporary constraints. During construction, parking stands may be taken offline, taxi routes altered, and ground movement patterns

disrupted. Without proactive planning, these changes can lead to increased aircraft delays, reduced schedule reliability, and heightened safety risks. Traditional capacity analysis, as outlined by Ashford et al. (2011) and ICAO (2018), focuses on steady-state conditions and may not adequately capture the transient dynamics of a construction-impacted system. A resilience-based approach, in contrast, explicitly models the system's trajectory through disruption and recovery, offering actionable insights for mitigation planning.

The study purpose was **to evaluate the operational resilience of airside capacity at Djalaluddin Gorontalo Airport during a simulated infrastructure expansion phase using a pre-impact predictive assessment methodology. Specifically, the study aimed to establish a baseline of operational performance using historical flight data from 2023–2025, simulate the impacts of temporary apron capacity reduction on key operational indicators such as average delay and apron utilization, calculate a composite resilience index incorporating robustness, vulnerability, and recoverability dimensions, and provide data-driven mitigation recommendations for airport management. By focusing on a low-traffic tropical airport, the study contributes to addressing a contextual gap in airport resilience research and offers a transferable analytical framework for regional airports undergoing infrastructure development**.

METHOD

Study participants

In the context of this airport engineering study, the "participants" refer to the operational data units and physical infrastructure elements subjected to analysis. The primary data subjects comprise historical flight operations at Djalaluddin Gorontalo Airport from 2023 to 2025, including arrival and departure schedules, aircraft types, and turnaround times. These data points serve as the baseline for normal operational performance.

The physical objects of study include the airside infrastructure components, specifically the apron parking stands, taxiways, and runway access points. Consistent with the structural assessment by Dukalang (2025), the pavement capacity (ACN–PCN) is considered a fixed operational constraint within the model. The study focuses on low-traffic flight movements, averaging approximately three flights per day, which represent the typical operational load of a regional tropical airport.

To ensure data reliability, operational records obtained from airport management were cross-checked with flight movement logs and scheduling data. Extraordinary operational anomalies, such as those associated with pandemic restrictions or major natural disasters, were excluded from the dataset to maintain consistency in baseline operational conditions.

Study organization

The research was organized into three sequential analytical phases conducted at Djalaluddin Gorontalo Airport, Indonesia. The study employed a **pre-impact predictive assessment approach** designed to evaluate operational performance prior to the implementation of actual infrastructure construction activities.

Phase 1 consisted of a **baseline operational analysis,** where historical flight data from 2023–2025 were processed to establish normal performance indicators, including On-Time Performance (OTP), average delay, and apron utilization. These indicators follow operational evaluation practices described by Ashford et al. (2011) and ICAO (2018).

Phase 2 involved the development of a **capacity reduction simulation scenario** representing temporary operational constraints during infrastructure expansion. In this scenario, apron parking capacity was reduced from eight stands to six stands (approximately 25% reduction) to simulate the temporary closure of stands during construction works. The apron capacity used in the simulation represents the design parking stand configuration of the airport rather than the current daily aircraft occupancy. The airport apron system consists of multiple stand areas, including flexible and rigid stands, but the simulation focuses on a subset of operational stands to represent typical aircraft parking usage. The apron configuration allows accommodation of both narrow-body aircraft typically serving domestic routes and occasional wide-body aircraft used for Hajj charter operations. The simulation assumes sequential aircraft stand allocation based on arrival schedules and typical

turnaround times. Operational disturbances occur when aircraft arrival intervals overlap with stand unavailability, generating delay propagation within the airside system.

Phase 3 focused on **resilience evaluation,** where operational performance under the simulated disruption scenario was compared with baseline conditions. The analysis was conducted within the framework of airport operational safety oversight and aligned with Indonesian Aviation Safety Management System regulations (Kementerian Perhubungan, 2018). This structured approach enables controlled evaluation of how infrastructure expansion constraints influence airport operational resilience.

Statistical analysis

Data analysis combined descriptive statistical techniques with quantitative resilience modeling. Baseline operational indicators—including average delay, flight movements, and apron utilization—were calculated using descriptive statistical analysis methods following the operational performance evaluation framework described by Cook et al. (2011).

To evaluate system performance under disruption conditions, a **composite Resilience Index (RI)** was calculated based on the resilience framework developed by Bruneau et al. (2003) and adapted for aviation systems by Janić (2020). The Resilience Index quantifies the ability of the operational system to maintain functionality during disturbance and recover afterward. The index is defined as the ratio between the system performance during disruption and the baseline performance over the same time interval:

$$RI = \frac{\int_{to}^{tr} Pd\,(t)\,dt}{\int_{to}^{tr} Pb\,(t)\,dt} \quad \text{..... (1)}$$

where:

- **RI** = Resilience Index
- **Pd(t)** = system performance during disruption
- **Pb(t)** = baseline system performance
- $\mathbf{t_0}$ = beginning of the disruption period
- $\mathbf{t_r}$ = recovery time

The RI value ranges from 0 to 1, where values closer to 1 indicate higher operational resilience. Performance degradation was measured through changes in average delay and apron utilization levels during the simulated capacity reduction scenario.

Additionally, a **variance-based sensitivity analysis** was conducted to identify the relative influence of operational variables—particularly apron capacity and flight intensity—on system resilience. The sensitivity evaluation followed the methodological principles described by Saltelli et al. (2000). All simulations and statistical calculations were implemented using spreadsheet-based modeling and statistical analysis tools to estimate delay propagation and capacity absorption limits under construction-related constraints.

FINDING AND DISCUSSION

The baseline operational analysis of Djalaluddin Gorontalo Airport during the period 2023–2025 indicates a stable low-traffic operational pattern. Historical records show an average of approximately three flight movements per day, reflecting the operational characteristics typical of regional airports serving peripheral areas. Under normal operating conditions, the airport experiences an average delay of approximately 12 minutes, while apron utilization remains at around 65%. These indicators suggest that the airport operates with sufficient operational buffer capacity, allowing flexibility in stand allocation and aircraft ground handling processes. The baseline operational performance is summarized in Table 1.

Table 1. Baseline Operational Performance of Djalaluddin Gorontalo Airport (2023–2025)

Operational Variable	Average Value	Interpretation	Reference
Flight movements (arrivals + departures) per day	3	Stable low-traffic operational pattern	Ashford et al. (2011)
Average delay (minutes)	12	Low operational delay indicating adequate capacity	Cook et al. (2011)
Apron utilization (%)	65%	Available operational buffer capacity	ICAO (2018)
On-Time Performance (OTP, %)	88%	Acceptable service reliability level	Cook et al. (2011)

Note: Values represent the mean operational performance derived from airport operational records during the period 2023–2025.

Table 1 shows that the airport operates significantly below its theoretical capacity limits. An average apron utilization of 65% indicates that several parking stands remain available during most operational periods, allowing the system to absorb minor disturbances without significant delay propagation. This operational buffer aligns with the characteristics of low-traffic regional airports described by Ashford et al. (2011), where lower traffic density often provides higher scheduling flexibility compared with highly congested hub airports. Furthermore, the On-Time Performance (OTP) level of 88% confirms that the current operational environment maintains an acceptable level of service reliability according to delay impact benchmarks discussed by Cook et al. (2011).

To evaluate the potential operational impact of infrastructure development, a simulation scenario was developed representing a temporary reduction in apron capacity during construction activities. In this scenario, apron capacity was reduced from eight operational stands to six stands, representing an approximate 25% reduction in apron parking availability. The purpose of this scenario was to simulate temporary stand closures during apron expansion or rehabilitation works. The comparative operational performance results between baseline conditions and the simulated capacity reduction scenario are presented in Table 2.

Table 2. Operational Performance Comparison: Normal vs. Reduced Apron Capacity

Performance Indicator	Normal Capacity (8 stands)	Reduced Capacity (6 stands)
Parking stands available	8	6
Average delay (minutes)	12	18
Apron utilization (%)	65%	90%
Resilience Index (RI)	1.00	0.85

Note: The reduced capacity scenario represents an approximate 25% reduction in apron parking stands during the simulated infrastructure expansion phase.

The simulation results indicate that the reduction in apron capacity leads to measurable but manageable changes in operational performance. The average delay increases from 12 minutes under normal conditions to approximately 18 minutes during the simulated construction phase, representing a 50% increase. Similarly, apron utilization rises from 65% to approximately 90%, reflecting the reduced availability of parking stands and increased pressure on stand allocation management. Despite this increase in utilization, the system does not reach a critical congestion threshold, and **aircraft operations remain manageable within the existing airside infrastructure framework.** The calculated Resilience Index (RI) for the disruption scenario is 0.85. According to the resilience evaluation framework proposed by Bruneau et al. (2003) and later adapted for aviation systems by Janić (2020), RI values above 0.80 indicate an adequate level of system resilience. This result suggests that the operational system of Djalaluddin Airport retains a strong ability to absorb temporary infrastructure disruptions without significant degradation of service continuity or operational safety. The results of the simulated apron capacity reduction scenario are also visualized in Figure 1, which

illustrates the comparative changes in average delay, apron utilization, and the Resilience Index between normal and reduced capacity conditions.

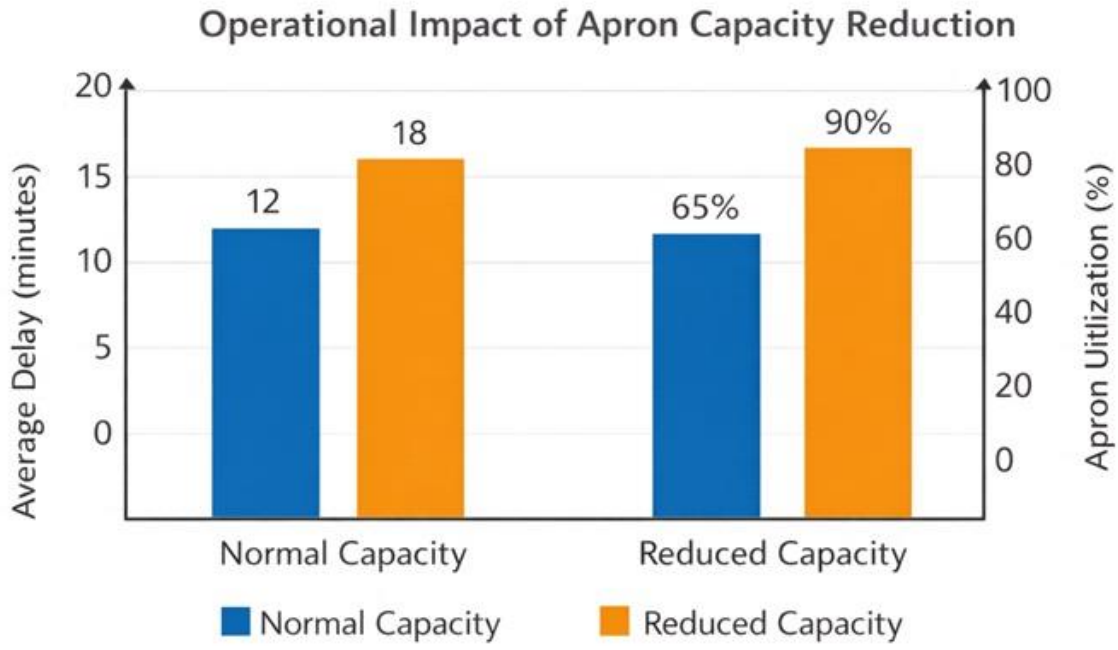


Figure 1. Impact on average delay and apron utilization under reduced apron capacity

Several factors contribute to this relatively high resilience level. First, the low daily flight intensity allows greater flexibility in scheduling adjustments and aircraft stand allocation. Unlike high-density airports where even minor disruptions may rapidly propagate through tightly packed schedules, the relatively low operational load at Djalaluddin Airport enables the system to redistribute aircraft parking assignments with minimal cascading delays. Second, the existing infrastructure still provides a limited degree of redundancy even after stand reduction, allowing airport operations to continue without reaching critical capacity saturation.

These findings complement previous infrastructure studies conducted at the same airport. Dukalang (2025) demonstrated that the runway pavement structure satisfies the required ACN-PCN compatibility for current aircraft operations, confirming the structural robustness of the primary airside infrastructure. The present study extends this structural perspective by demonstrating that the operational system itself also exhibits adequate resilience under temporary capacity constraints. This combined structural and operational robustness suggests that the airport possesses sufficient capability to maintain safe operations during moderate infrastructure expansion activities.

The sensitivity analysis further indicates that apron capacity availability plays a more dominant role than flight intensity in influencing operational resilience during the construction phase. While slight increases in flight movements could potentially increase system stress, the primary determinant of delay propagation remains the availability and management of aircraft parking stands. Effective stand allocation strategies and coordinated scheduling with airlines therefore represent critical operational mitigation measures during infrastructure development.

However, it is important to acknowledge that the simulation scenario does not explicitly incorporate environmental variables such as extreme tropical weather conditions. Airports located in tropical regions frequently experience intense rainfall and rapid weather changes that may influence both aircraft operations and construction timelines. Future studies should therefore incorporate dynamic weather-related disruption scenarios in order to provide a more comprehensive resilience assessment model for tropical regional airports.

Overall, the results demonstrate that a predictive resilience-based approach provides valuable insights for airport management when planning infrastructure expansion. By identifying potential

operational stress points prior to construction activities, airport authorities can implement proactive mitigation strategies—such as temporary schedule adjustments, improved stand allocation management, and coordinated airline operations—to maintain safe and efficient airport performance during infrastructure development phases.

CONCLUSIONS

This study evaluated the operational resilience of airside capacity at Djalaluddin Gorontalo Airport during a simulated infrastructure expansion scenario involving a temporary reduction in apron parking stands. The baseline operational analysis shows that the airport operates under a stable low-traffic environment with an average of three daily flight movements, an average delay of 12 minutes, and an apron utilization rate of approximately 65%. These conditions indicate the presence of sufficient operational buffer capacity under normal circumstances.

The simulation of a reduced apron capacity scenario, where the number of operational stands decreases from eight to six, demonstrates that the airport is capable of maintaining operational continuity despite temporary infrastructure constraints. Although the average delay increases to approximately 18 minutes and apron utilization rises to about 90%, the system remains within manageable operational limits. The calculated Resilience Index (RI) value of 0.85 indicates that the airport possesses an adequate level of operational resilience according to the resilience framework proposed by Bruneau et al. (2003) and Janić (2020).

The findings highlight that low-traffic regional airports may exhibit inherent operational flexibility that enables them to absorb moderate disruptions during infrastructure development phases. Effective apron management, flexible aircraft stand allocation, and coordination with airline scheduling are critical operational strategies that can help mitigate delay propagation during construction activities.

Future research is recommended to incorporate dynamic operational variables, particularly tropical weather disturbances and variations in flight demand, in order to develop a more comprehensive resilience assessment model for regional airports undergoing infrastructure expansion.

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