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The Effect of Turbulence Weather Information on Decision-Making of Air Traffic Controllers at Jakarta ACC

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Abstract

Safe and efficient air traffic services depend on the ability of Air Traffic Controllers (ATCs) to make timely and accurate decisions, particularly when confronted with adverse meteorological phenomena such as turbulence. This study aims to analyze the influence of turbulence weather information on the operational decision-making of ATCs at the Jakarta Area Control Centre (ACC). Employing a quantitative approach, data were collected from 77 respondents through structured questionnaires and analyzed using descriptive and inferential statistics, including validity, reliability, and linear regression tests. The findings indicate a positive and significant relationship between the provision of turbulence information (independent variable) and ATC decision-making (dependent variable), with a coefficient of determination (R^2) of 0.640. This result suggests that 64% of decision-making accuracy is influenced by the quality of turbulence information, while the remaining 36% is affected by other factors such as workload and experience. The study concludes that enhancing the timeliness, accuracy, and completeness of meteorological information is crucial to support ATCs in making precise and safe operational decisions under high-pressure and high-traffic conditions within the Jakarta Flight Information Region (FIR).

Keywords: Turbulence, Weather Information, Decision-Making, Air Traffic Controller, Jakarta ACC

INTRODUCTION

Aviation safety represents the foremost priority in the global air transport system, encompassing both technical and operational elements that must function cohesively to ensure secure and efficient flight operations. Within this context, Air Traffic Controllers (ATCs) play a crucial role in maintaining the order, separation, and flow of air traffic. One of the most influential external factors affecting ATC decision-making quality is meteorological dynamics, particularly weather phenomena such as turbulence, which can significantly impact flight safety and operational continuity (Muhammad et al., 2024). Unlike convective weather that can be visually detected, turbulence is often invisible and undetectable by conventional onboard radar systems, necessitating accurate and real-time meteorological information. Such information supports ATCs in making informed operational decisions, especially when guiding aircraft through regions with potentially hazardous atmospheric conditions (Sasmito, 2011).

The Jakarta Flight Information Region (FIR), managed by AirNav Indonesia, represents one of the busiest and most complex airspaces in Southeast Asia. It encompasses major parts of Sumatra, Java, and Kalimantan, with thousands of daily flight movements (AirNav Indonesia, 2024). Due to this high operational density, precise and timely weather information becomes indispensable for maintaining efficiency and safety in air traffic management (Saputra et al., 2015). Empirical data and recent turbulence-related incidents such as the Singapore Airlines SQ321 event (May 2024) and EVA Air BR237 (August 2024) underscore the real threat posed by atmospheric instability, emphasizing the vital role of meteorological communication between the Meteorological, Climatological, and Geophysical Agency (BMKG) and ATCs in preventing aviation hazards.

Despite the centrality of turbulence information in flight safety, limited studies have examined how ATCs utilize such meteorological data for operational decision-making, particularly within Indonesia's dense and dynamic airspace. Most existing research has focused

on technical meteorological modeling or atmospheric pattern analysis rather than the human operational aspect of decision processes in air traffic control. This research, therefore, seeks to fill that gap by empirically analyzing the impact of turbulence weather information on ATC decision-making at Jakarta ACC, focusing on decisions regarding flight level changes, rerouting, and delay management.

Accordingly, the problem formulation of this study is: *"How significant is the influence of turbulence weather information on the decision-making process of Air Traffic Controllers at the Jakarta ACC Unit?"* The objective of this research is to determine and analyze the extent to which the provision of turbulence information affects ATC decision-making accuracy and efficiency. It is expected that the findings of this study will contribute to strengthening the integration of meteorological information within Air Traffic Services (ATS) operations, improving communication protocols, and enhancing the safety management framework of Indonesia's aviation system.

RESEARCH METHODS

This study employs a quantitative research approach using a survey method as the primary data collection tool. The selection of this method is based on the research objective to examine the relationship between turbulence weather information and operational decision-making by Air Traffic Controllers (ATCs) at the Jakarta Area Control Centre (ACC) (Sugiyono, 2023). A quantitative approach allows for measurable, objective data that can be analyzed statistically to produce valid and generalizable conclusions in the context of air navigation operations. The research design is explanatory, aiming to explain how the independent variable turbulence weather information affects the dependent variable ATC operational decision-making.

The study was conducted at Jakarta ACC, which operates under the Jakarta Flight Information Region (FIR). The location was chosen due to its high traffic density, operational complexity, and frequent exposure to tropical atmospheric disturbances, including cumulonimbus formations and vertical air instability (Puteh et al., 2024). The research was carried out over a six-month period, encompassing instrument design, field data collection, analysis, and report preparation.

The population of this study includes all active ATCs assigned to Jakarta ACC, totaling 238 personnel. The sample was determined using the Slovin formula with a margin of error of 10%, resulting in a minimum of 70 respondents. To ensure representativeness, purposive sampling was applied, with criteria that respondents must be active ATCs with at least two years of experience and prior involvement in turbulence management cases. To account for potential non-responses, the total number of participants was increased to 77 ATCs.

The independent variable (X) in this study is *Turbulence Weather Information*, operationally defined by five dimensions: accuracy, timeliness, clarity of format, data completeness, and trust in information sources (Novotny et al., 2021). The dependent variable (Y) is *ATC Operational Decision-Making*, measured by observable actions such as flight level changes, rerouting, delay management, and early warnings (Klein, 2008; Simon, 1977).

Data collection employed two complementary techniques:

1. Structured questionnaires with a 5-point Likert scale distributed to the ATC respondents; and
2. Documentary studies utilizing meteorological reports and turbulence incident data from BMKG (Meteorological, Climatological, and Geophysical Agency) and AirNav Indonesia.

For data analysis, the study utilized inferential statistical methods through Simple Linear Regression to assess the magnitude and direction of influence between the variables. Prior to hypothesis testing, validity was verified using the Pearson Product-Moment correlation, and reliability was tested with Cronbach's Alpha, where $\alpha \geq 0.7$ was considered acceptable. The regression results were interpreted to determine the coefficient of determination (R^2), showing how much variation in ATC decision-making is explained by turbulence information quality. Statistical processing was conducted using IBM SPSS Statistics software (Field, 2018).

In summary, this methodology integrates structured measurement, validated instrumentation, and appropriate inferential techniques to ensure the accuracy and reliability of the research findings on the role of meteorological turbulence information in supporting operational decision-making among ATCs in the Jakarta ACC environment.

RESULT AND DISCUSSION

The results of this study describe the relationship between the provision of turbulence weather information and the operational decision-making of Air Traffic Controllers (ATCs) at the Jakarta Area Control Centre (ACC). Based on the data collected from 77 respondents through structured questionnaires, validity and reliability tests indicated that all measurement instruments were valid and reliable, with Cronbach's Alpha values for both variables exceeding 0.8, confirming strong internal consistency.

The findings from the regression analysis demonstrated a positive and significant relationship between turbulence weather information and ATC decision-making, as shown in Table 1. The coefficient of determination (R^2) of 0.640 indicates that turbulence weather information contributes 64% to the accuracy and appropriateness of ATC decisions, while the remaining 36% is attributed to other factors such as workload, coordination, and operator experience.

Table 1. Determination Coefficient (R^2)

Variable	R^2 Value	Contribution (%)
Turbulence Weather Information → ATC Decision-Making	0.640	64%

This result aligns with Simon's (1977) theory of bounded rationality, which states that decision-makers often rely on available information within limited time constraints. In the ATC operational environment, where rapid judgment is required, the accuracy and timeliness of meteorological data directly affect the efficiency of decision outcomes. When turbulence information is clear and received promptly especially through SIGMET and Pilot Reports (PIREP) ATCs are able to issue early warnings or rerouting instructions, reducing exposure to severe weather hazards (Sasmito, 2011; ICAO, 2022).

The distribution of respondent perceptions (Figure 1) also supports the statistical findings, showing that the majority of ATCs rated turbulence information from BMKG as "accurate" and "timely." Approximately 71% of respondents agreed that real-time updates significantly improved their situational awareness, allowing faster coordination among sectors within Jakarta ACC. However, 29% still perceived delays in information dissemination, primarily during peak operational periods when meteorological data transmission is congested or when communication channels are disrupted.

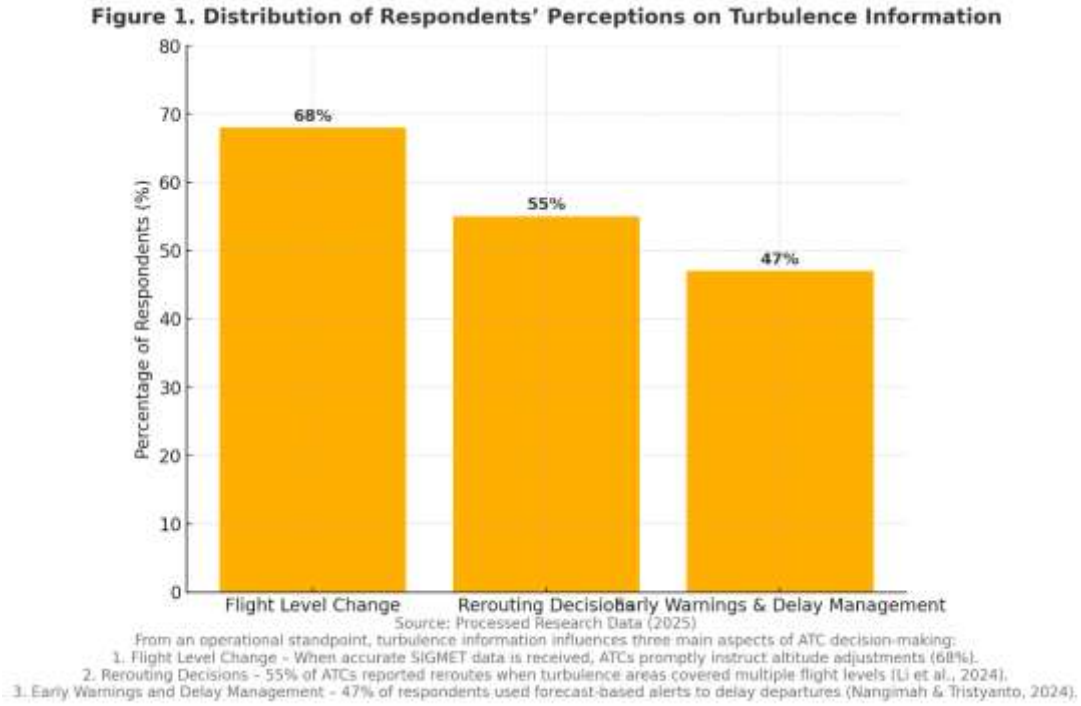

Figure 1. Distribution of Respondents' Perceptions on Turbulence Information

From an operational standpoint, turbulence information influences three main aspects of ATC decision-making:

1. Flight Level Change When accurate SIGMET data is received, ATCs promptly instruct altitude adjustments. This practice was reported by 68% of respondents as their first mitigation response.
2. Rerouting Decisions 55% of ATCs reported initiating reroutes when turbulence areas covered multiple flight levels, confirming that meteorological precision facilitates proactive route adjustments (Li et al., 2024).
3. Early Warnings and Delay Management Nearly 47% of respondents acknowledged using forecast-based turbulence alerts to delay departures or issue pilot advisories, illustrating the importance of forecast integration (Nangimah & Tristyanto, 2024).

The regression coefficient indicates that for every one-point increase in the quality of turbulence information, there is a proportional increase in ATC decision effectiveness. This demonstrates a linear correlation between the clarity and reliability of meteorological information and the precision of ATC operational responses. In practice, this means that as turbulence reports become more structured and timely, the likelihood of errors in altitude or routing decisions decreases significantly.

These findings corroborate the conceptual model proposed by Novotny et al. (2021) regarding information standardization in air traffic control, emphasizing that data format consistency (such as SIGMET coding) reduces misinterpretation and facilitates faster decision-making. Similarly, Field (2018) notes that the integration of meteorological data into human decision systems enhances situational awareness, particularly in high-density operational environments such as Jakarta FIR.

The implications of this study extend beyond statistical correlation; they reflect real-world operational improvements. The high R^2 value underscores the critical role of turbulence information as part of the Safety Management System (SMS) within AirNav Indonesia. Enhanced communication between BMKG and ATC units ensures that weather information is not merely distributed but effectively interpreted and applied. Moreover, the study highlights the need for improved digital integration of meteorological systems such as AWOS, ITWS, and ADS-B data streams, ensuring that ATCs receive automated, continuous updates.

In line with Klein's (2008) Naturalistic Decision-Making model, experienced ATCs rely heavily on pattern recognition supported by reliable data. Therefore, when turbulence information is inaccurate or delayed, decision quality deteriorates not due to skill deficiencies but due to informational constraints. This reinforces the argument that information quality serves as a cognitive amplifier, transforming raw meteorological data into actionable operational knowledge.

To summarize, the combined statistical and perceptual findings affirm that turbulence weather information has a substantial and significant effect on ATC decision-making within Jakarta ACC. The integration of real-time, accurate, and standardized meteorological data enhances decision precision, operational safety, and airspace efficiency. Future improvements should focus on optimizing data timeliness through automation and enhancing ATC interpretive training for meteorological products.

CONCLUSION

This study concludes that the provision of accurate and timely turbulence weather information has a significant and positive influence on the operational decision-making performance of Air Traffic Controllers (ATCs) at the Jakarta Area Control Centre (ACC). The regression results show that turbulence information contributes 64% to decision-making quality, emphasizing its critical role in ensuring operational safety and efficiency. High-quality meteorological data enhances ATCs' situational awareness, enabling more precise flight level changes, rerouting, and delay management during adverse weather conditions. These findings reinforce that effective integration of meteorological systems, such as SIGMET and real-time data from BMKG, within Air Traffic Services (ATS) operations significantly improves decision reliability and minimizes safety risks. Therefore, strengthening communication channels, standardizing data formats, and implementing automation in weather information dissemination are essential steps to optimize ATC decision-making and maintain safe airspace management within the Jakarta Flight Information Region (FIR).

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