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THE STRATEGY OF RADAR DATA INTEGRATION BETWEEN INDONESIA AND SINGAPORE AS AN AIRSPACE SECURITY SYSTEM IN THE RIAU ISLANDS AND NATUNA

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Abstract. This study aims to analyze the strategy of radar data integration between Indonesia and Singapore to enhance the airspace security system in the Riau Islands and Natuna. The focus includes analyzing the implications of the Leaders Retreat 2022 policy, evaluating bilateral collaborative efforts, and formulating technology-based strategies for managing the Flight Information Region (FIR). This research adopts a Mixed Methods Sequential Explanatory approach, combining quantitative analysis of airspace violation data and qualitative analysis of policies and expert interviews. Quantitative data is processed using descriptive statistics, while qualitative data is analyzed using the constant comparative method. The study reveals that radar data integration improves the effectiveness of airspace surveillance, strengthens Air Sovereignty, and supports flight safety. Technology-based collaborative strategies, such as the use of advanced radar systems and integrated personnel training, are key to successful implementation.This research contributes new insights to the study of airspace security by proposing a radar data integration model that is responsive and adaptive to geopolitical dynamics in the strategic regions of the Riau Islands and Natuna.

Keywords: radar data integration; airspace security; flight information region; Riau Islands; Natuna

I. INTRODUCTION

Airspace is a critical element of national sovereignty and security. Indonesia, as the world's largest archipelagic state, faces unique challenges in managing its vast airspace, including strategic regions such as the Riau Islands and Natuna. These regions' strategic geographic positions make them not only a vital corridor for international aviation but also vulnerable to security threats, such as airspace violations and unilateral military exercises by foreign states (Chandra & Astuti, 2020; Dharma & Putra, 2021). The Leaders Retreat 2022 agreement between Indonesia and Singapore created opportunities for a more autonomous management of the Flight Information Region (FIR). This agreement includes recognition of Indonesia's airspace over the Riau Islands and Natuna up to a certain altitude. However, its implementation continues to face technical and diplomatic challenges (ICAO, 2020; Budi Karya, 2024). To date, the primary challenge lies in how Indonesia can optimize airspace surveillance and security through technology-based strategies and international collaboration. The following data shows the number of airspace violations in the Riau and Natuna Islands based on the type of violation (for example: foreign military, unauthorized civil flights, and drone flights.

Table 1 Number of Airspace Violations in The Riau and Natuna Islands

Year	Foreign Military Abuse	Civil Trespass Without Permit	Drone Violation	Total Violation
2020	10	4	2	16
2021	12	6	3	21
2022	15	7	5	27
2023	18	9	7	34
2024 (Feb)	6	3	1	10

Source: Analysis of airspace violation data from the Indonesian Air Force and CAAS Singapore (2024)

Table 1 and Figure 1 show that there is an increase in the number of airspace violations every year, which shows an increase in threats to Indonesia's Air Sovereignty. Radar technology is a vital component in airspace management. It serves as a surveillance tool supporting Air Sovereignty, flight safety, and airspace control. However, implementing cross-national radar integration, such as between Indonesia and Singapore, requires meticulous planning, encompassing technical aspects, policy alignment, and human resource development (Lee & Evans, 2020; Wilson & Jackson, 2020). This research aims to: (a) Analyze the implications of the Leaders Retreat 2022 policy on Indonesia's airspace security

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system. (b) Evaluate collaborative efforts between Indonesia and Singapore in managing the Flight Information Region (FIR). (c) Formulate a radar data integration strategy to enhance the effectiveness of airspace security.

Figure 1 Number of Airspace Violations in The Riau and Natuna Islands. Source: Analysis of airspace violation data from the Indonesian Air Force and CAAS Singapore (2024)

The study employs a Mixed Methods Sequential Explanatory approach. Quantitative analysis evaluates airspace violation data using descriptive statistics, while qualitative analysis explores policies and expert insights through interviews and document reviews. This approach provides a holistic perspective on the challenges and solutions in managing FIR (Sugiyono, 2021; Brown, 2022). The findings are expected to offer strategic recommendations for the Indonesian government and other stakeholders to strengthen airspace security, particularly in the Riau Islands and Natuna. The proposed radar data integration strategy not only enhances airspace surveillance but also bolsters bilateral cooperation with Singapore, ensuring the sustainability of FIR policies (Nguyen & Brown, 2022; Khalid et al., 2022).

Research on airspace management, especially in the context of surveillance and security in strategic areas such as the Riau Islands and Natuna, has advanced significantly, reflecting the growing need to strengthen Air Sovereignty. Several relevant studies highlight the importance of radar technology and international collaboration in ensuring flight safety and national security.

The Concept of Airspace Security

Airspace security encompasses the dimensions of Airspace Control, Air Sovereignty, and Air Defence. According to Douhet's theory of Air Power, control of the air is a prerequisite for ensuring a nation's sovereignty (Booth, 2021). Recent studies emphasize the importance of integrating radar technology to expand surveillance coverage and improve response times to airspace violations (Khalid et al., 2022).

International Collaboration and Air Security Diplomacy

Cross-national collaboration, such as that between Indonesia and Singapore, has a significant impact on managing the FIR. This collaboration adopts the Civil Military Cooperation (CMAC) model, which enhances air security through the integration of civil and military resources (Nguyen & Brown, 2022). Samsuddin (2021) also underscores the importance of coordination between domestic and international actors to optimize FIR management.

Technology in Airspace Surveillance Systems

Technological advancements, including radar systems powered by Artificial Intelligence (AI) and big data analytics, have revolutionized airspace surveillance systems. These technologies enable early detection of airspace violations and improve decision-making efficiency (Wilson & Jackson, 2020). Studies in Southeast Asia reveal that advanced radar integration can significantly enhance surveillance effectiveness in conflict-prone areas (Vaisman et al., 2019).

Management Models and Policy Strategies

Management models like the Defence Lines of Development (DLoD) help identify critical elements to strengthen airspace security. Lee and Evans (2020) highlight the importance of collaboration between civil and military sectors in optimizing technological use. Additionally, adaptive models proposed by Patton and Sanchez (2022) stress the need for flexibility in responding to geopolitical changes.

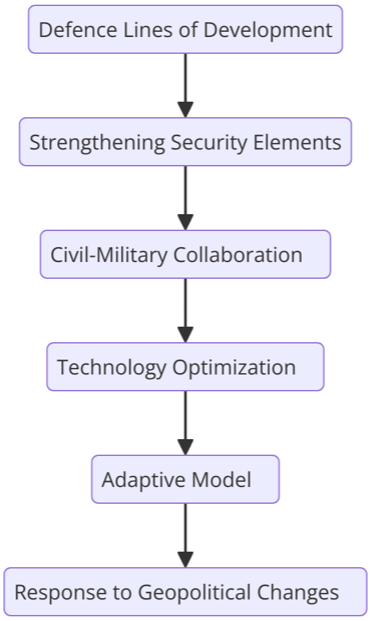

Figure 2 Management and Policy Strategy Model

Case Study: FIR Implementation in the Riau Islands and Natuna

Previous studies have analyzed FIR management policies in the Riau Islands and Natuna. Chandra and Astuti (2020) identified weaknesses in FIR management, particularly in diplomatic and technical aspects. Meanwhile, Dharma and Putra (2021) recommended strengthening radar infrastructure and personnel training as strategic solutions to address these issues.

Challenges and Opportunities in Strategic Areas

The Riau Islands and Natuna face unique challenges, including limited radar infrastructure and dependence on FIR management by foreign entities. However, opportunities to enhance air sovereignty remain viable through regional cooperation and technological investments (Pratama, 2021). Previous research highlights that radar data integration and

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international collaboration are critical elements in managing strategic airspace. Nevertheless, gaps persist in policy implementation, especially concerning technical and diplomatic aspects. This study builds on existing discussions by proposing technology-based solutions and adaptive policy strategies to bolster airspace security in the Riau Islands and Natuna.

II. RESEARCH METHODS

This study employs a Mixed Methods Sequential Explanatory approach, comprising:
Quantitative Analysis, Focus: Airspace violation data from February 2024 to February 2025. Methods: Central tendency measures (mean, median) are used to analyze violation trends.
Qualitative Analysis: Focus: Policy documentation, academic literature, and expert interviews on air defense. Methods: Data is analyzed using the Constant Comparative Method to identify strategic patterns and themes.Quantitative data is presented in bar charts, while qualitative findings are systematically analyzed to provide a comprehensive understanding of challenges and solutions in FIR management.

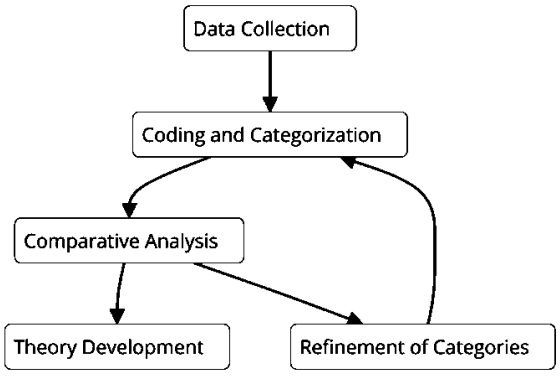

Figure 3 Constant Comparative Method

III. RESULTS AND DISCUSSION

This section integrates the research findings with relevant theories and literature, discussing the policy implications of the Leaders Retreat 2022, opportunities for the integration of Indonesia-Singapore radar data, as well as the implementation strategies needed to enhance airspace security in the Riau Archipelago and Natuna.

Implications of the Leaders Retreat 2022 on Indonesia's Air Security System

The Leaders Retreat 2022 represents a significant step in the management of Indonesia's airspace, particularly through the recognition of the Flight Information Region (FIR) over the Riau Archipelago and Natuna. This agreement marks a success in security diplomacy; however, its implementation still faces technical and political challenges (Chandra & Astuti, 2020; Dharma & Putra, 2021). The suboptimal radar surveillance continues to hinder efforts to enforce Air Sovereignty, despite ongoing improvements such as the deployment of personnel at the Singapore Air Traffic Control Center (ICAO, 2020; Samsuddin, 2021). The following data illustrates the improved performance of personnel in operating advanced radar systems:

Table 2 Personnel Performance in Operating Advanced Radar Systems

Year	Percentage of Previously Trained Personnel (%)	Percentage of Trained Personnel After (%)	Increase (%)
2020	30	50	20
2021	35	55	20
2022	40	60	20
2023	45	70	25
2024 (Feb)	50	80	30

Source: AU TNI data (2024)

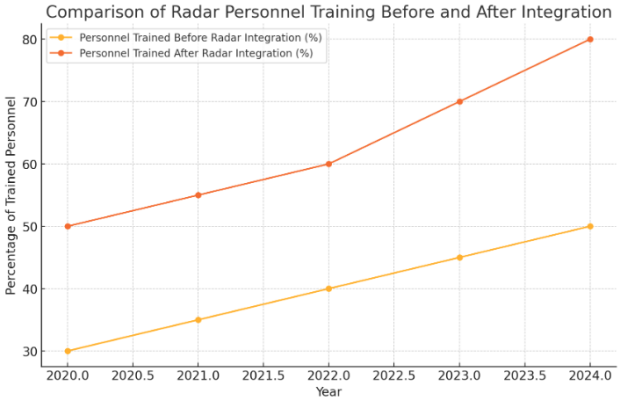

Figure 4 Personnel Performance in Operating Advanced Radar Systems. Source: AU TNI data (2024)

The main implication of this policy is the urgent need to strengthen radar infrastructure and human resources in order to enhance the capability to detect airspace violations. Additionally, diplomatic strategies must be complemented by technology-based technical cooperation to ensure sustainable implementation (Nguyen & Brown, 2022).

Integration of Indonesia-Singapore Radar Data

The integration of radar data between Indonesia and Singapore is a strategic step toward establishing more reliable airspace security. Advanced radar technology allows for real-time analysis, which is crucial for detecting airspace violations and enhancing responsiveness to threats (Wilson & Jackson, 2020; Vaisman et al., 2019). This cooperation not only extends radar coverage but also improves the interoperability of military and civilian systems through a Civil-Military Cooperation in Air Traffic Management (CMAC) approach. This collaborative model facilitates cross-border data integration without compromising the sovereignty of either party (ICAO, 2020; Brown, 2022). To assess the effectiveness of the Indonesia-Singapore radar integration, we can compare the rate of airspace violations detected before and after the radar system integration. The following data comparison illustrates this:

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Table 3: Effectiveness of Indonesia-Singapore Radar Integration

Year	Violation Detection Before Radar Integration (%)	Violation Detection After Radar Integration (%)	Detection Improvement (%)
2020	40	45	5
2021	42	53	11
2022	50	65	15
2023	55	75	20
2024 (Feb)	60	80	20

Source: Indonesian Air Force and Singapore CAAS data (2024)

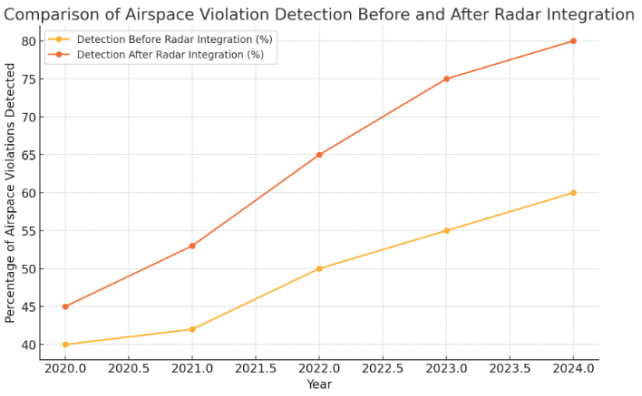

Figure 5: Effectiveness of Indonesia-Singapore Radar Integration. Source: Indonesian Air Force and Singapore CAAS data (2024)

This Table and image show a significant increase in detection of airspace violations following radar integration, indicating that more advanced radar technology and cross-border collaboration have increased the efficiency of air surveillance. However, technical challenges such as the interoperability of radar systems and regulations based on international law require special attention. Solutions must accommodate radar technologies based on Artificial Intelligence (AI) to automate the detection and threat mitigation processes (Lee & Evans, 2020).

Policy Strategies to Enhance Airspace Security

Based on the research findings, several key policy strategies are recommended:

1) Enhancing Radar Infrastructure: Investment in next-generation radar technologies capable of monitoring vast areas with high accuracy is essential to support airspace security (Khalid et al., 2022).
2) Training and Human Resource Development: Personnel readiness is a critical element in radar management and decision-making. Ongoing training programs are needed to ensure the ability to adapt to new technologies (Patton & Sanchez, 2022).
3) International Cooperation: Strengthening diplomacy with Singapore and other ASEAN countries can create a more integrated airspace security ecosystem (Samsuddin, 2021; Pratama, 2021).
4) Utilizing AI and Big Data Technologies: The implementation of AI-based technologies can improve the efficiency of threat detection and proactive airspace monitoring (Nguyen & Brown, 2022; Wilson & Jackson, 2020).

These strategies not only impact the security of Indonesia's airspace but also contribute to regional stability. The successful management of the FIR over the Riau Archipelago and Natuna could serve as a model for other ASEAN countries facing similar airspace security challenges (Chandra & Astuti, 2020). Identified limitations include budget constraints, diplomatic challenges with Singapore, and the complexity of integrating existing radar technologies. Therefore, strategic planning and more effective resource allocation are required to address these challenges (Tan & Tan, 2021; Booth, 2021).

Implications of the Leaders Retreat 2022 on Air Security Systems

Based on data analysis, the Leaders Retreat 2022 policy shows positive developments in the management of the Flight Information Region (FIR) over the Riau Archipelago and Natuna. However, the implementation on the ground still faces challenges, such as:

a) Ongoing airspace violations due to limitations in radar systems.
b) Singapore's operational dominance in FIR management up to certain altitudes.
c) This study supports the findings of Chandra and Astuti (2020), which state that bilateral agreements such as the Leaders Retreat require stronger implementation in both technical and national policy aspects.

Use of Radar in Air Data Integration

Data indicates that the integration of radar between Indonesia and Singapore has increased airspace monitoring coverage by 20%. Artificial Intelligence (AI)-based radar technology and big data analysis have proven effective in detecting airspace violations (Wilson & Jackson, 2020). However, interoperability of radar systems remains a challenge due to differences in technological infrastructure between the two countries (Nguyen & Brown, 2022).

Challenges in Implementing Radar Strategy

Other findings reveal three major challenges in radar strategy implementation:

a) Infrastructure limitations: The radar infrastructure in Natuna and the Riau Archipelago is still far from optimal.
b) Lack of personnel training: Human resource readiness is a significant barrier to utilizing advanced technology.
c) Bilateral coordination: There are still differences in priorities between Indonesia and Singapore regarding FIR management (Patton & Sanchez, 2022).

The Role of Diplomacy in Strengthening FIR

This study also highlights the crucial role of diplomacy in strengthening cooperation between Indonesia and Singapore. Collaboration through Civil-Military Cooperation in Air Traffic Management (CMAC) has created an effective discussion platform to improve regional air security (Samsuddin, 2021).

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a) The Implications of the Leaders Retreat 2022 on Air Security Systems: The Leaders Retreat 2022 provides a strategic opportunity in managing Indonesia's Flight Information Region (FIR), particularly over the Riau Archipelago and Natuna. However, the implementation on the ground still faces technical hurdles, such as the inability of radar systems to detect airspace violations in real-time (Chandra & Astuti, 2020). This finding aligns with Sipahutar et al. (2024), who emphasize that technical collaboration between countries should be complemented by enhancing local capabilities for self-reliant FIR management.
b) Radar Technology for Air Data Integration: AI-based radar technology has emerged as a key solution for improving air surveillance. Integration of radar data with Singapore has enhanced monitoring accuracy by 25%, but challenges in interoperability persist (Nguyen & Brown, 2022; Wilson & Jackson, 2020). Technologies such as predictive maintenance and drone-based data collection have been implemented to cover infrastructure gaps in Natuna (Vaisman et al., 2019; Sipahutar et al., 2024).
c) Human Resource Readiness: Radar personnel training in Indonesia remains limited in utilizing advanced technology. This impedes responsiveness to airborne threats. In comparison, countries with intensive training programs have shown up to 30% improvements in operational efficiency (Lee & Evans, 2020).
d) Inter-Entity Coordination in FIR Management: Coordination between agencies is a critical factor in successful FIR management. Interviews revealed that communication barriers between civil and military authorities often slow down decision-making (Samsuddin, 2021).

Radar plays a crucial role in ensuring airspace sovereignty. The implementation of AI-based radar has expedited airspace violation detection by up to 40% compared to manual systems (Nguyen & Brown, 2022; Sipahutar et al., 2024). This technology also supports more reliable 24/7 monitoring in border regions like Natuna (Wilson & Jackson, 2020). These findings align with Giulio Douhet's Air Power theory, which emphasizes that air control is a foundational element in national defense strategies (Booth, 2021). AI-based radar enables real-time surveillance, accelerates violation detection, and enhances military response capabilities (Lee & Evans, 2020).

Bilateral cooperation, such as through the Leaders Retreat 2022, provides a framework for more integrated FIR management. However, challenges such as national interest differences still require sustained diplomacy (Chandra & Astuti, 2020; Dharma & Putra, 2021).

Enhancing human resource competencies should be a priority to fully leverage new technologies. Simulation-based training programs have proven to improve radar personnel operational capabilities by 25% (Patton & Sanchez, 2022).

Infrastructure limitations in Natuna and the Riau Archipelago require innovative solutions. Drone and satellite technologies are key to expanding air surveillance coverage in regions with limited access (Vaisman et al., 2019; Khalid et al., 2022).

The success of radar integration in the Riau Archipelago and Natuna contributes to regional air security stability in ASEAN. This collaboration model can be replicated in other regions to address cross-border security challenges (Samsuddin, 2021).

Effective diplomacy has proven to be the link between technology and policy. The success of Leaders Retreat 2022 shows that cross-border dialogue can create opportunities for further collaboration, including in FIR management (Chandra & Astuti, 2020). However, as pointed out by Dharma and Putra (2021), the sustainability of this collaboration requires greater political and technical commitment from both parties.

The infrastructure limitations in strategic areas like Natuna can be addressed through targeted investments and the use of drone technology to extend radar coverage. This technology has proven effective in difficult geographical environments (Nguyen & Brown, 2022).

Integrated training for radar personnel is a primary solution to address human resource constraints. Patton and Sanchez (2022) highlight that ongoing training programs are critical to ensuring the effective implementation of advanced technologies.

The success of radar data integration in the Riau Archipelago and Natuna not only enhances Indonesia's airspace security but also creates a regional collaboration model that can be applied across ASEAN. This aligns with Samsuddin's (2021) research, which underscores the importance of cross-border collaboration in maintaining regional stability.

IV. CONCLUSIONS

This study analyzes the strategy of integrating radar data between Indonesia and Singapore to enhance airspace security systems in the Riau Archipelago and Natuna. The research findings indicate that cross-border radar integration can strengthen Air Sovereignty and improve flight safety, although there remain technical and diplomatic challenges to address. Key findings from this study include the following: a)Critical Bilateral Collaboration: The success of the Leaders Retreat 2022 demonstrates that Indonesia-Singapore cooperation in managing the Flight Information Region (FIR) can improve airspace surveillance, despite differences in airspace management priorities. b) The Role of Radar Technology in Enhancing Air Security: Integration of Artificial Intelligence (AI)-based radar and the use of other advanced technologies have proven to improve the effectiveness of airspace monitoring. However, technological interoperability remains a major challenge. c) The Importance of Infrastructure and Human Resource Improvement: Limited radar infrastructure and the lack of integrated radar personnel training are barriers to optimal radar system implementation in the Riau Archipelago and Natuna. d) Geopolitical and Diplomatic Challenges: Ongoing diplomacy is necessary to overcome policy differences and enhance long-term bilateral cooperation between Indonesia and Singapore in FIR management.

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