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Analysis of the Integrated Smart Maintenance System to Support Aircraft Readiness in Air Defense Facing Regional Crises

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ABSTRACT

This research examines the necessity and implementation of the Integrated Smart Maintenance System (ISMS) as a strategic solution to enhance aircraft readiness for the Indonesian National Armed Forces (TNI) amid growing regional and global security challenges. The study is grounded in the fact that TNI's current aircraft maintenance system remains reactive, fragmented, and lacking predictive capabilities supported by artificial intelligence. These limitations result in high aircraft downtime, delayed logistics support, and inefficiencies that directly undermine Indonesia's air defense credibility. The study employs a qualitative approach using a case study method, combining in-depth interviews with TNI logistics officials, aircraft technicians, and defense industry stakeholders (PT Dirgantara Indonesia and GMF AeroAsia), along with comprehensive document analysis and literature review. The theoretical framework encompasses Regional Security Theory (Buzan & Wæver), Air Defense Theory, Maintenance Theory (Tjiptono & Diana), Information System Theory (McLeod), and strategic planning and forecasting concepts. The findings reveal fundamental weaknesses in TNI's maintenance system, including poor data integration, the absence of predictive algorithms, limited spare parts availability, and weak coordination across services and industry. Nevertheless, SWOT analysis indicates strong opportunities for ISMS development, supported by defense modernization initiatives, national industrial readiness, and advancements in digital technologies such as AI, IoT, and data analytics. ISMS is projected to increase aircraft readiness to 70–80%, reduce downtime, strengthen deterrence capability, and establish a digital maintenance culture within TNI.

INTRODUCTION

Strengthening the country's defense system to face the dynamics of modern threats is relevant to the development of technology that supports the independence of the Indonesian nation. Contemporary threats such as cyber warfare, drone attacks, and the use of artificial intelligence in military operations demand high-tech readiness from every country. Technology is no longer just a complement but rather the backbone of an effective defense system. By adopting technological innovations, countries can improve their early detection, rapid response capabilities, and more accurate strategic decision-making. In addition, technological development in the defense sector also acts as a deterrent against potential external aggression. Countries that can demonstrate the technological power of their main weapon systems (*alutsista*) and cybersecurity will have higher bargaining power in international diplomacy (Sarjito, 2024).

This indicates that investment in military technology research and development is not only tactically relevant but also strategically important. Lt. Gen. (Ret.) Ben Hodges (2021), former commander of the U.S. Army in Europe, emphasized that "the dominance of information

and speed in decision-making are now largely determined by technological excellence." Technologies such as real-time analytics software have made modern defenses more responsive and adaptive to various forms of threats.

Global and regional crises have had a significant impact on the readiness of the TNI's defense equipment, given the increasing geopolitical tensions and potential conflicts in the Indo-Pacific region. Situations such as the Russia-Ukraine war, tensions in the South China Sea, and the military competition (arms race) between major countries demand the operational readiness of the TNI's defense equipment, including air defense equipment, both in terms of quantity, quality, and interoperability with other defense systems. According to a study from the Indonesian Defense Strategy Review (IDSR), strengthening the air fleet—such as the modernization of fighter aircraft and military transportation—is crucial to ensure the TNI's deterrence and rapid mobilization capabilities in dealing with cross-border threats (IDSR, 2022).

In the operational context of aircraft defense equipment, regional crises—especially energy crises—are further exacerbated by inefficient aircraft maintenance systems that lead to increased aviation fuel consumption and large-scale energy waste. Based on a report from the International Air Transport Association (IATA), the aviation sector accounts for around 2–3% of global carbon emissions, and fuel consumption reaches more than 300 billion liters per year (IATA, 2023). Inefficiencies in maintenance, such as inspection delays, untimely component replacement, and the non-use of predictive technology, lead to decreased engine performance and increased fuel consumption of up to 5–15% (Boeing, 2022). In addition to its direct impact on the global energy burden, this condition increases operational costs, worsens global and regional supply chains, and accelerates the pace of the energy crisis.

The Industrial Revolution 4.0, characterized by the application of artificial intelligence (AI), Internet of Things (IoT), and big data analytics, has brought significant changes to the industrial sector, including aircraft maintenance. This intelligent technology enables AI- and IoT-based maintenance systems to predict damage early, accelerate repairs, and improve aircraft operational readiness (Utama, 2023; Kurniawan, 2024). In the context of the TNI, the application of this technology can support aircraft readiness, even though the Simtelog application implemented by the Indonesian Air Force is not fully optimal because it has not yet utilized AI technology (Dispenau, 2024). Meanwhile, problems related to spare parts, limited personnel, and infrastructure are also obstacles to aircraft maintenance in the TNI AD and TNI AL, which impact operational readiness (Djatmiko, 2020; Dispenad, 2021).

To address these issues, an integrated smart maintenance system is urgently needed, adopting AI technology and predictive systems already implemented in the global aviation industry, such as those by Boeing and Airbus (Aviation, 2023). Another example is the implementation of a cloud-based maintenance system and big data by Airbus through the Skywise Health Monitoring platform. The United States has also implemented Performance-Based Logistics (PBL) and Integrated Logistics Support (ILS) systems that have proven to improve the efficiency and effectiveness of maintenance for aircraft such as the F-35 and F/A-18 (GAO, 2022). Therefore, the TNI needs to improve the capabilities of its software, personnel, and infrastructure to realize an integrated smart maintenance system to support the readiness of TNI aircraft (Nanda, 2025). The formulation of the problem in this study aims to identify whether national defense policies—especially in the maintenance of air defense

equipment—have accommodated the application of an artificial intelligence-based Integrated Smart Maintenance System (Analysis of the Integrated Smart Maintenance System to Support Aircraft Readiness in Air Defense Facing Regional Crises) in supporting the readiness of TNI aircraft amid regional threat dynamics. In addition, this study examines the influence of budget political dynamics, defense bureaucratic governance, and defense policy on the TNI's unpreparedness in implementing the system. The purpose of this research is to understand the extent to which defense policies and the application of this technology can increase the TNI's combat readiness, strengthen Indonesia's air defense strategic posture, and foster a deterrence effect in facing regional threats.

This research is expected to make a theoretical contribution by enriching the literature on air defense maintenance, especially in the context of implementing the Integrated Smart Maintenance System to improve the TNI's ability to face threats. Practically, this research provides benefits for the Headquarters of the TNI, TNI AD, NAL, and Air Force in formulating policies for predictive technology-based maintenance systems, as well as input for government planning and budgeting institutions in developing more efficient and responsive defense budget policies amid digital transformation. The findings of this research can also serve as a reference for the defense industry to develop research and technology collaborations that support the independence of the national defense industry.

METHOD

This research employed a qualitative approach to describe and analyze the *Integrated Smart Maintenance System* in supporting the readiness of TNI aircraft equipment. Data were collected through triangulation—combining observation, interviews, and documentation—and analyzed inductively. The study uncovered patterns, themes, and relationships from the data to provide a comprehensive overview of the current TNI aircraft maintenance system. It adopted a case study design to examine the phenomenon deeply in its real-world context (Yin, 2018). A flexible qualitative design allowed the researcher to adapt steps to field conditions and explore the subjective meanings of the phenomenon.

Data collection techniques included observation, interviews, and documentation, which provided in-depth insights into challenges in the TNI aircraft maintenance system. The researcher used explanatory records for raw data and reflective records for deeper understanding of observed phenomena (Sugiyono, 2017). Collected data underwent processing stages: reduction (selecting and simplifying relevant information), presentation (using matrices, graphs, or tables), and conclusion drawing (Miles, Huberman, & Saldana, 2014). Data analysis followed coding stages—open, axial, and selective—to map problems and identify strategic solutions for the TNI aircraft maintenance system (Strauss & Corbin, 1998). This process enabled identification of central themes and development of recommendations to improve maintenance effectiveness.

RESULTS AND DISCUSSION

Development and Implementation of Integrated Smart Maintenance System in Supporting TNI Aircraft Readiness

Transformation of the TNI Aircraft Maintenance System

The results of primary data collection from in-depth interviews show that there are several key findings that indicate that the TNI aircraft maintenance system is still in the transition stage from manual to digital models, namely:

a. The limitations of integrated information systems are the main obstacle. Aslog Panglima TNI and Aslog Kasau admitted that the logistics system between the dimensions has not been fully connected in real-time where data on aircraft conditions and spare parts stocks are still stored separately in each unit. This results in a missynchronization between field needs and the stock available at the central material supervisor, so the maintenance process is often delayed.
b. The competence of human resources technicians still needs to be improved, especially in mastering modern technology such as predictive maintenance systems, artificial intelligence and data analysis. As revealed by Dankoharmatau, most technicians have high dedication and mechanical expertise, but are not used to the use of digital devices for aircraft condition analysis. This statement is in line with the modernization theory put forward by Ahmad (2011), that every technological change requires structural and cultural adaptation in the organization so that innovation can run effectively.
c. Coordination between dimensions and stakeholders is still not optimal. Danpuspenerbad and Danpuspenerbal highlighted differences in maintenance procedure standards, reporting mechanisms and procurement systems between dimensions, which led to duplication or delays in the logistics process. This is in line with G.R. Terry's coordination theory in Handoko (2003), which emphasizes the importance of alignment of functions, time, and communication between units to achieve organizational effectiveness.
d. The use of information system technology such as the TNI AU Simtelog has begun to run, but it is not equipped with requisition tracking and predictive analysis capabilities that characterize smart systems. This means that the use of technology is still limited to administrative tools, not yet as a decision support system that is able to process data into strategic insights. These findings support the management information system theory (McLeod, 2001) which states that the value of a new information system will be maximized if it is able to provide timely and relevant information for decision-makers.
e. An interview with the Director of PT Dirgantara Indonesia emphasized that collaboration between the defense industry and the TNI still needs to be strengthened to realize the independence of spare parts and predictive-based maintenance. Currently, PT DI has experience in developing health monitoring systems for CN235 and N219 aircraft but has not been directly integrated with the TNI's logistics system. This collaboration is the key to the success of the Integrated Smart Maintenance System (ISMS) because it involves technology transfer, certification and joint standardization (PTDI, 2023).

Based on the results of primary and secondary data analysis, the factors that influence the implementation of the Integrated Smart Maintenance System (ISMS) can be classified into four main categories, namely:

a. Aspects of Technology and Information Systems. The results of the interviews show that the TNI has started to implement a logistics information system through Simtelog, but it is still limited to administrative functions. The lack of real-time integration between dimensions and the implementation of AI-based analysis shows that the TNI is still in the digitization stage, not yet digital transformation. Information systems theory (McLeod,

2001) emphasizes that the effectiveness of technology depends on the ability of organizations to integrate data subsystems into a unified managed unit.

b. Human Resources (HR) aspect. The competence of logistics technicians and personnel is considered quite high in terms of mechanical skills, but it is still lacking in mastery of digital devices and predictive analytics systems. This condition illustrates the technological skill gap that is the main challenge for TNI modernization. According to Ahmad's (2011) modernization theory, changes in the technological system must be accompanied by human capacity development so that there is no inequality in adaptation between technology and its user resources.
c. Managerial Aspects and Organizational Coordination. The missynchronization between the user's logistics unit and the material builder is the dominant issue that affects the operational readiness of the aircraft. This is due to data fragmentation, differences in SOPs and weak coordination between dimensions. Coordination theory (Terry in Handoko, 2003) emphasizes that organizational effectiveness is largely determined by the ability to unify functions and communication across departments. In the context of this study, cross-dimensional coordination is a major prerequisite for the success of ISMS.
d. Defense Industry Policy and Support Aspects. The results of the interviews show the need for collaborative policies between the TNI and the national industry to ensure the independence of the maintenance system. Based on military logistics theory (Kerin et al., 2009), the relationship between military organizations and supporting industries is an integral part of defense supply chain management, where the synergy between manufacturers and users determines the sustainability of defense readiness equipment.

Overall, the results of primary and secondary data collection show that the TNI's readiness in implementing the Integrated Smart Maintenance System still faces multidimensional challenges, especially in technology integration, improving human resource competence, and synergy between institutions. Through the data triangulation approach, consistency was found between respondents' views and supporting documents that emphasized the urgency of digital transformation in the TNI's aircraft maintenance system. These findings also strengthen the theoretical argument that the success of ISMS will depend heavily on synergy between technological, human, organizational and policy aspects. With the support of modernization theory, information systems and military logistics, the results of this study provide a strong empirical basis for the formulation of ISMS implementation strategies to improve the readiness and independence of Indonesia's national defense system in a sustainable manner.

Results of Data Processing on TNI Aircraft Readiness. From the results of primary and secondary data analysis, it is known that the readiness level of TNI aircraft is still fluctuating and not optimal, especially due to dependence on manual and reactive maintenance systems. Based on the results of interviews with Aslog Panglima TNI and Dankoharmatau, it was found that the average aircraft readiness was in the range of 65-70%, which was influenced by spare parts delays, lack of integration of maintenance data and low maintenance predictability. The results of field observations show that the process of submitting material and spare parts needs is still carried out conventionally and not in real-time, causing the waiting time (lead time) for maintenance to be long. These findings are reinforced by secondary data showing that the average component supply time exceeds operational standards. This analysis shows a systemic gap between field needs and central logistics systems, according to the theory of military

logistics efficiency (Kerin, Hartley, & Rudelius, 2009), which emphasizes the importance of a balance between material availability and distribution speed to ensure operational readiness. In addition, the results of interviews with Danpuspenerbad and Danpuspenerbal indicate that cross-dimensional coordination is still limited due to differences in information systems and technical procedures. This condition supports the provisional conclusion that the level of operational readiness of the TNI has not been fully supported by an integrated information system. Thus, the data processing in the first problem formulation shows a direct relationship between the operational readiness of the aircraft and the ability of the maintenance system to integrate logistics data and aircraft conditions in real-time.

Data Processing Results on Maintenance System Problems. The analysis of the results of interviews, observations, and document reviews shows four main problems that hinder the effectiveness of the TNI's aircraft maintenance system. First, reliance on manual systems causes the procurement and maintenance recording administration process to be slow, inefficient, and prone to data errors. Second, the lack of integration of logistics information systems between dimensions, as conveyed by Aslog Kasau, causes duplication of demand and mismatches between warehouse stock and user unit needs. Third, the competence of technicians in operating digital-based systems is still limited, even though their enthusiasm and dedication are high. Fourth, the lack of a predictive system causes maintenance to still be reactive maintenance, where actions are taken after damage occurs, not before damage is predicted.

These findings were confirmed through secondary data which noted that the TNI Air Force System Integration Index is still at level 2 out of 5, which means that it has only reached the digital recording stage and has not yet entered the predictive analytics stage. Theoretically, this is in line with the Information System Maturity Model framework (McLeod, 2001), which explains that organizations that are still in the data capture stage have limitations in optimizing data-driven decision-making systems. From the perspective of military logistics, the above problems show that the system that has not been integrated is not able to support the principle of logistics efficiency "right part, right place, right time" (Kerin et al., 2009). Delays of a single small component such as a hydraulic actuator can delay the readiness of the entire fleet due to the absence of an automatic tracking system. This coordination problem also reflects the weak application of G.R. Terry's (Handoko, 2003) coordination theory where the harmony between units is a determining factor for the success of the implementation of operations.

Results of Data Processing on Transformation Towards ISMS. Data processing for the formulation of the third problem shows that the TNI already has a strategic policy direction towards the digitalization of maintenance, but the implementation is still partial. Based on an interview with Aslog Kasau and the Director of PT DI, a number of initiatives have been carried out such as the development of the TNI Air Force Simtelog and the plan to cooperate with the health monitoring system with PT Dirgantara Indonesia for the CN235 aircraft. However, this system does not yet have the predictive capabilities that are at the core of ISMS. From the results of field observations, it can be seen that technical units have started collecting data on engine performance, flight hours and mean time between failures (MTBF), but the data has not been analyzed using artificial intelligence (AI) algorithms. This condition shows that the transformation towards ISMS is still in its early stages. Based on Ahmad's (2011) modernization theory, the process of technological transformation must be accompanied by changes in organizational culture, because the success of smart system implementation does

not only depend on technological devices, but also on the readiness of human resources and visionary leadership. The findings are reinforced by the theory of strategic planning and forecasting, which is used as a conceptual framework in the research. According to this theory, the success of long-term strategic planning in the environment military depends on the ability of organizations to project resource needs and anticipate global environmental uncertainty. Based on the results of the interview, Aslog Panglima TNI emphasized the importance of planning a gradual transformation from a manual system to ISMS with the support of a digitalization roadmap, increasing technical human resources and integration with the national defense industry. In terms of secondary data, the PT DI report (2023) shows the industry's readiness to support the development of predictive systems based on the Internet of Things (IoT) and cloud computing. This is a positive signal that the external environment (industry) is relatively ready, it is just a matter of synchronizing on the internal side of the TNI to ensure the readiness of the system implementation.

ISMS Implementation Challenges

a. Political (Politics and Geopolitics). The global and regional political situation greatly affects the operational readiness of the TNI. Strategic competition in the Indo-Pacific between major powers (US-China) creates a security environment that demands increased air fleet readiness to deal with a possible contingency crisis. However, on the other hand, geopolitical conditions also affect access to the supply of military parts and equipment, especially those from NATO member states. Export embargoes or restrictions can hinder the availability of essential spare parts for TNI aircraft, as has happened to some components of TNI aircraft in the past. In addition, changes in foreign policy and diplomatic relations may affect access to defense cooperation and technical assistance. This political factor emphasizes the importance of the independence of the national defense industry and the development of domestic maintenance capabilities as a long-term strategy.
b. Economic (Economics and Energy). The energy crisis and fluctuations in global exchange rates directly affect the TNI's ability to maintain aircraft readiness. The IEA (2024) recorded an increase in avtur fuel prices by 35–40% since 2023, while the rupiah exchange rate against the US dollar continues to be under pressure. This increases the operational and maintenance costs of the fleet, while reducing budget flexibility for system modernization. In addition, global supply chains disrupted due to geopolitical conflicts have caused delays in the import of strategic parts and materials. This is in line with the military logistics theory of Kerin et al. (2009) which emphasizes that logistics efficiency in high-risk environments requires data-driven monitoring and prediction systems that are able to anticipate changes in the global market. Therefore, from an economic perspective, the main challenge for the TNI is to build logistical resilience and energy efficiency to maintain a stable level of aircraft readiness amid global volatility.
c. Social (Social and Human Resources). Social factors are closely related to the quality and capacity of the human resources that manage aircraft maintenance. Based on the results of the interviews, it was found that most TNI technicians are still familiar with the manual system, while the level of digital literacy and data analytics skills is still limited. In fact, modern maintenance systems such as ISMS demand the ability to interpret real-time data, master algorithms and manage IoT-based systems. According to modernization theory (Ahmad, 2011), technological changes must be accompanied by changes in work culture

and organizational paradigm in order to function optimally. The main social challenge for the TNI is to create a digital culture-based human resource transformation at all levels of the organization, from technicians to logistics commands.

d. Technological (Technology and Innovation of Maintenance System). Global technological advances present opportunities as well as challenges. On the one hand, predictive maintenance, digital twin and AI-driven analytics technologies offer the potential to improve aircraft efficiency and reliability. But on the other hand, the lagging behind digital infrastructure in the Indonesian military environment is a serious obstacle. KPMG research (2025) highlights that many defense organizations in Southeast Asia are still in the "digital transition" stage, not yet reaching "predictive capability maturity". In the context of the TNI, the integration of maintenance and logistics systems is still fragmented, and there is no centralized data lake for all dimensions. The main technological challenge is how to accelerate the development of digital infrastructure and the interoperability of maintenance systems between units and the defense industry.
e. Environmental (Environment and Energy Security). Environmental aspects are becoming increasingly relevant in the global context due to the pressure on carbon emission reduction and energy sustainability. The military sector now faces demands to adopt green defense principles through fuel efficiency, the use of renewable energy, and the optimization of environmentally friendly supply chains (WEF, 2025). For the TNI, this challenge arises in the form of the need for operational efficiency of aircraft, reduction of carbon footprint, and adaptation to extreme weather that can affect training and maintenance schedules. An integrated ISMS has the potential to be a solution to optimize energy use and reduce the frequency of fuel-intensive unscheduled flights.
f. Legal (Defense Law and Regulation). The legal and regulatory framework also affects the operational readiness of TNI aircraft. Currently, defense modernization and digitalization policies are still spread across various regulations that have not been integrated. Based on the results of the interviews, it was found that there is no policy framework that specifically regulates AI-based maintenance data management and collaboration with the civil industry. In addition, rules related to cybersecurity and military data protection also need to be strengthened so that cloud-based ISMS systems do not pose a risk of strategic information leakage. From a legal perspective, the main challenge is to build regulatory governance that is adaptive to new technologies without compromising on national security aspects.

The analysis shows that the challenges of operational readiness of TNI aircraft are multidimensional, influenced by external dynamics in the form of politics, economy, global technology and internal weaknesses in the form of organizations, human resources, and regulations. The application of the PESTEL analysis framework helps to map the strategic factors that interact with each other and determine the level of aircraft readiness. In facing the global crisis, the TNI needs to build maintenance system resilience through three main strategies, namely first, digital transformation towards AI-based ISMS and real-time analytics, the second is strengthening collaboration with the domestic defense industry, and the third is improving governance and improving the competence of digital technician human resources. With these measures, the TNI can reduce external dependence, increase logistics effectiveness and maintain aircraft readiness in the face of geopolitical dynamics and the ever-changing energy crisis.

The strategic interpretation of the results of the PESTEL analysis above shows that the challenge of operational readiness of TNI aircraft is multidimensional and cannot be solved with a purely technical approach. Volatile global geopolitical conditions, energy crises that suppress operational costs and technological gaps between national defense systems and global industries demand integrative, innovative, adaptive and sovereign implementation strategies as shown in Table 4.3. An integrative approach is needed to connect information systems, logistics policies, and maintenance processes between dimensions as well as with defense industry partners, creating end-to-end visibility into fleet conditions and spare parts supply chains. Meanwhile, innovative elements encourage the adoption of predictive maintenance technology, data analytics and digital twins as the foundation of an artificial intelligence-based maintenance system that is able to predict potential damage before it occurs. An adaptive and sovereign approach then acts as a structural balancer, namely strengthening organizational and human resource capacity in the face of geopolitical uncertainty and reducing dependence on foreign suppliers through the independence of the national defense industry. This four-dimensional strategy is conceptually aligned with applied theory which is the research framework, where the integration between logistics, human and policy systems is the key to increasing aircraft readiness in the context of dynamic state defense.

The four-dimensional strategy reflects the real application of the Complex Adaptive Systems Theory as developed by Holland (2014), which explains that modern organizations must be able to react and evolve to external environmental pressures through a continuous learning and innovation process. In the context of the TNI, the aircraft maintenance system functions as an adaptive network consisting of human elements, machines and information that interact with each other. The implementation of the Integrated Smart Maintenance System (ISMS) is a concrete form of the adaptive system where each subsystem (logistics, technicians, industry, and command) is connected through a digital architecture that allows for real-time data exchange and evidence-based decision-making. This approach is also in line with the Dynamic Capability Theory by Teece (2018) which emphasizes the importance of an organization's ability to integrate, build and configure internal resources to respond quickly to changes in the external environment. By combining adaptive theory and dynamic capabilities, the ISMS implementation strategy is not just modernization through the development of information system-based technology, but is an institutional transformation towards a resilient, autonomous and sustainable national defense posture in the face of a multidimensional global crisis.

The influence of political dynamics of the budget, governance of the defense bureaucracy and the policy of national defense equipment.

The TNI aircraft maintenance system is a vital element in supporting aircraft readiness and the effectiveness of national air operations. As described in the previous discussion, the operational readiness of TNI aircraft is currently in the range of 65-70%, below the ideal standard of 80% set. This condition shows that there is a serious maintenance gap between actual capabilities and strategic operational needs. Through in-depth interviews with officials of the Aslog Panglima TNI, Aslog Kasau, Dankoharmatau, Danpuspenerbad, Danpuspenerbal and the Director of PTDI, it was found that the problems faced were not only technical, but also systemic, including organizational dimensions, data management, human resources, and policy aspects.

The political dynamics of the budget, the governance of the defense bureaucracy, and the national defense policy are also external factors that greatly determine the TNI's ability to implement the Integrated Smart Maintenance System (ISMS). In the context of budget politics, defense spending allocations are still heavily influenced by the priority of modernizing new defense equipment, so digital technology-based maintenance budgets are often in second priority. This pattern causes long-term investments in data infrastructure, aircraft health monitoring sensors, and analytics system development to not get the optimal portion. In addition, the annual budgeting cycle is not in line with the needs of developing smart maintenance systems that require multi-year investment and funding consistency. This asynchrony widens the gap between the need for technology and the ability to implement it in the field.

From the results of data analysis and previous interpretation, it can be concluded that the problems of the TNI aircraft maintenance system can be categorized into three main problems, namely the inintegration of information systems and maintenance logistics management, the limitation of competence and transformation of technician human resources in facing the digital system, and the lack of optimal support for policies, regulations and supporting industries in strengthening maintenance independence. These three problems are interrelated, forming a systemic circle that affects the operational effectiveness and reliability of national air defense systems.

Inintegration of Information Systems and Maintenance Logistics Management. The first and most fundamental problem is the fragmentation of the maintenance information system between the dimensions and the technical implementation unit. Based on the results of interviews with Koharmatau officials, it was found that the system of recording and reporting aircraft conditions is still carried out manually or semi-digitally, using different formats from one unit to another. As a result, data on aircraft conditions, spare parts needs and maintenance schedules are difficult to integrate into a single information base that can be used for predictive analysis. This condition hinders the speed of decision-making and causes data redundancy.

The implications are very significant for the operational readiness of TNI aircraft. Without system integration, maintenance planning is difficult to adjust to the actual wear rate of components. Many aircraft undergo repeated scheduled maintenance without technical urgency while other aircraft experience unscheduled downtime due to sudden damage. As a result, logistics efficiency is low and the availability of standby aircraft decreases. This shows the importance of implementing ISMS to answer this structural problem through the integration of digital and adaptive inter-dimensional information systems.

Limitations of Competence and Transformation of Human Resources (HR) Maintenance. The second problem is related to the quality and readiness of technician human resources in facing the digitalization of the maintenance system. The results of the interviews show that most TNI technicians still have a manual experience-based work paradigm, with limitations in reading digital data, interpreting trend analysis and operating real-time monitoring systems. As a result, efforts to implement AI-based predictive systems or machine learning are often hampered by internal resistance and limited technical capacity.

Based on the results of the problem description, it shows that the root of the problem in the maintenance system of TNI aircraft does not stand alone but is the result of a complex interaction between organizational structures, policies and technology that has not been fully

integrated. In the context of this research, an analytical approach is needed that is able to explore the root causes of each of these problems so that strategic solutions that are more targeted can be formulated. Therefore, the next stage will use the "5 Why" analysis method, which is a systematic approach developed by Sakichi Toyoda to identify the root of the problem through the process of repeatedly asking "why" until the main cause is found (Ohno, 1988). The application of the 5 Why analysis in the context of the TNI's maintenance system aims to trace the main sources of problems that hinder the effectiveness of the system, both from the technical, managerial, and policy sides. Thus, the results of this analysis are expected to provide a comprehensive understanding of the root causes of the low operational readiness of TNI aircraft and become the basis for the formulation of a transformation strategy towards an adaptive, measurable and sustainable Integrated Smart Maintenance System (ISMS).

Strategy for Implementing *Integrated Smart Maintenance System* in Facing Regional Threats.

The results of the analysis of the root of the problems and strategic policies that have been described previously show that the TNI aircraft maintenance system is in a critical phase that demands simultaneous structural, technological and cultural transformation of the organization. This process is not just a change in technical procedures, but a systemic reform that involves all components ranging from the logistics command structure, the parts supply chain to the work patterns of technicians in the field. The transformation towards an Integrated Smart Maintenance System (ISMS) is a strategic step born from the need to answer the challenges of modernization, data fragmentation, and limited human capacity and policies that are still sectoral. In the context of national air defense, the ISMS is not only a technical instrument to improve aircraft readiness, but also part of an adaptive defense architecture that strengthens Indonesia's deterrence posture in the face of global geopolitical dynamics.

The transformation towards ISMS is firmly rooted in the theoretical foundation of modernization (Ahmad, 2011) which places technological change and organizational culture as an inseparable part. In the framework of defense modernization, the implementation of ISMS illustrates the shift from the conventional maintenance paradigm to a digital paradigm based on artificial intelligence, predictive analytics, and the internet of things (IoT). This modernization process demands a shift in values from a reactive work pattern to a proactive and predictive maintenance culture. On the other hand, information systems theory (McLeod, 2001) provides a rational basis that data is a new source of power in modern defense systems. Therefore, the transformation of ISMS must place data governance, interoperability and information security as the three main pillars that ensure smooth integration across dimensions and institutions. Thus, the development of an integrated maintenance information system becomes a technical solution and digital defense strategy that supports national sovereignty in the cyber domain.

From the perspective of strategic planning and forecasting (Archer & Overholt, 1979), the transformation of the ISMS must be directed as part of a long-term defense planning plan to improve the operational reliability of TNI aircraft during its life cycle. This theory emphasizes the importance of data-driven decision-making in conditions of uncertainty and crisis. By implementing ISMS, the TNI can optimize forecasting capabilities to predict component damage, adjust maintenance schedules to the actual condition of the aircraft and plan logistics needs more precisely. This transformation will also reduce unscheduled downtime and save operational costs through predictive maintenance mechanisms. Ultimately,

this strategy reinforces the principle of logistics effectiveness as described in Logistics Theory (Kerin et al., 2009) which is to ensure the availability of the right resources, in the right place, at the right time at the lowest possible cost without sacrificing operational reliability.

In addition to the planning and logistics aspects, the transformation towards ISMS is also a concrete manifestation of coordination theory (Handoko, 2003) which emphasizes the importance of integration between functions, units, and institutions in achieving common goals. The success of the implementation of ISMS is highly determined by the TNI's ability to create an effective coordination mechanism between technical, operational, logistical elements and the national defense industry such as PT. DI and GMF AeroAsia. In this context, ISMS becomes a strategic communication platform that enables real-time collaboration between users, coaches, and logistics support providers. The implementation of this system is also in line with the theory of maintenance (Tjiptono & Diana, 2003) which emphasizes the importance of preventive and predictive maintenance in maintaining system performance at optimal levels. Therefore, ISMS is an ecosystem enabler that unites maintenance, logistics and decision-making functions into a single interconnected system.

From a national policy perspective, the transformation of the ISMS has strategic value in supporting an adaptive, resilient, and technologically sovereign air defense posture. This system will strengthen deterrence through increasing the readiness of fighters, transporters, and patrols in quick reaction readiness. Geopolitically, the TNI's success in developing a data-driven intelligent maintenance system also reflects Indonesia's ability to not only become a user of defense technology, but also as a producer and developer of solutions based on national innovation. By integrating modernization theory, information systems, strategic planning, logistics, coordination and maintenance in one policy implementation framework, ISMS will function as a strategic enabler for the formation of a national air defense posture that is responsive to global dynamics in terms of technology, resources, and policies.

Based on the policy framework and theory outlined above, in order to determine the right strategy, SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is used to map the strategic position of the TNI in the transformation process towards an Integrated Smart Maintenance System. The SWOT analysis factors are as follows:

a. Strengths. The strength describes the internal resources and potential that the TNI has to support the transformation of the maintenance system towards the Integrated Smart Maintenance System (ISMS):
    1) The availability of a complete logistics organizational structure in every dimension. The TNI has Aslog at the level of the TNI Headquarters and Army Headquarters, Koharmatau at the TNI AU, as well as special maintenance units at Puspenerbal and Puspenerbad, which allows the coordination of maintenance functions to be carried out in stages.
    2) Strong support from the national defense modernization policy. The Optimum Essential Force (OEF) Program and the Defense Strategic Plan place improving aircraft readiness as a top priority, thereby supporting the digitalization of maintenance as part of the modernization of the defense system (Ahmad, 2011).
    3) Strategic partnerships with national defense industries such as PT Dirgantara Indonesia and GMF AeroAsia.This collaboration is the initial foundation for the development of

technical data integration systems, predictive analytics-based maintenance, and joint maintenance human resource development.

4) There is an internal awareness of the urgency of digital transformation. From the results of field interviews, logistics leaders and technicians realized the importance of applying information technology to improve the efficiency and speed of aircraft maintenance response.
5) The availability of basic infrastructure of military information technology. The TNI already has a defense intranet network and a basic logistics data system that can be developed into an integrated data hub, although it is still limited in interoperability.

b. Weaknesses. The weaknesses reflect internal constraints that currently hinder the effectiveness of aircraft maintenance systems and need to be addressed:
   1) Fragmentation of information systems between dimensions and technical units. Each dimension still uses different logistics and maintenance data systems without interoperability, leading to duplication of information and difficulties in readiness analysis.
   2) Low digital literacy and technician skills in the operation of predictive systems. Most technicians are still used to manual systems, so the use of smart technology is not optimal.
   3) There is no cross-dimensional integrative policy related to maintenance digitalization. Sectoral policies lead to data inconsistencies and weak coordination between users, coaches, and industry partners.
   4) Limited budget resources for the development of predictive systems and HR training. National fiscal constraints have a direct impact on the priority of financing digital transformation for maintenance (IEA, 2024).
   5) There is no data governance framework and cybersecurity specifically for defense data. The risk of leakage and data integrity are the main obstacles to building an integrated cloud-based or AI-based system.

c. Opportunities (Peluang). The opportunity illustrates external factors that can be leveraged by the TNI to accelerate the transformation of the ISMS and strengthen the operational readiness of aircraft:
   1) Global digital technology (AI, IoT, and big data analytics) advancements in the aviation sector. Companies such as Airbus, Boeing, and Rolls-Royce have proven the effectiveness of predictive systems in reducing costs and improving fleet reliability (KPMG, 2025).
   2) Government support for the digitalization of the defense system and national industrial independence. The national digital transformation agenda and adaptive defense policy open up opportunities for financing domestic-based ISMS research and innovation.
   3) Potential for research and technology transfer cooperation with the international aviation industry. International partnerships can be used to accelerate the mastery of smart maintenance technology and certification of TNI technicians.
   4) Increasing the need for logistics efficiency and transparency in the face of the global crisis. The energy and geopolitical crises are driving defense agencies around the

world to switch to data-driven efficient and adaptive maintenance systems (WEF, 2025).

5) The availability of young TNI human resources with adaptive abilities and interest in new technologies. The regeneration of young technicians can be a momentum for changing work culture towards a digital maintenance mindset.

d. Threats. Threats are external factors that can slow or hinder the successful implementation of ISMS and the transformation of TNI aircraft maintenance:
   1) Global geopolitical dynamics affecting the supply of military parts and equipment. Export embargoes or restrictions can disrupt the supply chain for the maintenance of foreign-made aircraft (SIPRI, 2025).
   2) The global energy crisis and rising fuel prices. Increased operational costs can reduce the frequency of flight training and aircraft maintenance budgets.
   3) High dependence on overseas vendors in the procurement of spare parts and software. This poses a risk of strategic vulnerabilities to data security and national defense systems.
   4) Cybersecurity threats to digital-based maintenance systems. Increasing digitalization without adequate cyber protection can open up opportunities for attacks or sabotage of technical data (KPMG, 2025).
   5) Internal resistance to organizational and technological change.

The results of the SWOT mapping show that the condition of the TNI aircraft maintenance system is in Quadrant II (Turn Around Strategy), which is a position where internal weaknesses are quite significant, but there are great external opportunities to make improvements. The characteristic of this strategy is to take advantage of external opportunities (O) to overcome internal weaknesses (W) through organizational restructuring, modernization of information systems, improving human resource competencies, and improving integrative policies. In the context of ISMS transformation, the turnaround strategy includes the following steps:

a. Digital Reinforcement Policy, which is to establish a Defense Maintenance Data Hub and strengthen cybersecurity as the foundation of ISMS.
b. Human Resource Transformation, which is launching a Smart Maintenance Training Center to build digital technician human resources.
c. Strategic Partnership Acceleration, which is to expand the collaboration of the TNI-PTDI-GMF-global industry for the transfer of ISMS technology.
d. Regulatory Integration, which is issuing the TNI Commander's Regulation on the integration of logistics and cross-dimensional maintenance systems.
e. Predictive Maintenance Implementation Roadmap, which is to implement a gradual predictive system (pilot project–full integration–AI- driven optimization).

Based on the results of the SWOT and IFAS-EFAS matrices, the transformation strategy towards an Integrated Smart Maintenance System (ISMS) for the TNI is in the position of Quadrant II (Turn Around Strategy). This means that policy focus must be directed to improving internal weaknesses (human resources, regulations, and information systems) by taking advantage of external opportunities in the form of global digital technology advances

and government policy support. Through the implementation of the SO and WO strategies as top priorities, as well as ST and WT as security and consolidation measures, the TNI can strengthen aircraft operational readiness and increase the Aircraft Readiness Index (ARI) towards a target above 80%. Collaboration between the Ministry of Defense, the Ministry of Communication and Commerce, the Commander of the Indonesian Armed Forces, the Chief of Staff of the Armed Forces, Inhan and BSSN is an absolute requirement in realizing an integrated, safe, and digitally sovereign national maintenance system that is in line with the direction of adaptive defense policy in facing geopolitical challenges and future global crises.

The transformation towards an Integrated Smart Maintenance System (ISMS) is a strategic step for the TNI in responding to the challenges of aircraft operational readiness in the midst of complex regional crises in terms of geopolitics, technology and resources. Based on the results of the SWOT analysis, the strategy that must be pursued is to improve internal weaknesses by taking advantage of large external opportunities. This means that the success of the implementation of ISMS is not only determined by the adoption of technology, but also by systemic reforms that include governance, human resource competence, industrial partnerships, and defense policies that are adaptive to the digital era. For this reason, a systematic, measurable, and realistic roadmap is needed so that ISMS can be implemented gradually, sustainably, and integratedly across dimensions. This roadmap consists of three time horizons, namely the short term (0–2 years) for the foundation and consolidation stage of the system, the medium term (2–5 years) for the integration and expansion stage of predictive capabilities and the long term (>5 years) for the optimization and independence stage of the national digital defense system. The roadmap is as follows:

Short-term stage (0–2 years). Consolidation of System and Policy Foundations. The short-term stage is focused on establishing the basic policy, institutional, and infrastructure foundations needed for the implementation of ISMS within the TNI. Based on the results of the WO strategy (utilizing external opportunities to overcome internal weaknesses), this stage is directed to unite data, policies, and cross-dimensional work patterns that have been running separately. The first step that needs to be taken is the preparation of national regulations on the integration of the national air defense digital maintenance system. The Ministry of Defense together with the Commander of the Indonesian Armed Forces needs to issue a Regulation of the Minister of Defense on the Integrated Smart Maintenance System (ISMS) which is a legal and operational reference for all dimensions, with technical support from the Ministry of Communication and Communications and BSSN. This regulation must cover aspects of interoperability standards, defense data governance and cybersecurity that are adjusted to the level of military classification.

The second step is to build a basic platform for maintenance data integration, namely the Defense Maintenance Data Hub (DMDH) which is directly controlled by the TNI Headquarters under the coordination of the TNI Commander Aslog. This system is the main container for collecting operational data, parts status, maintenance schedules, and technical conditions of each aircraft. In the initial stage, integration was carried out within the Indonesian Air Force as a pilot project, then expanded to Puspenerbal and Puspenerbad. The data collected comes not only from the logistics system, but also from the results of the technician inspections and on-board diagnostics, which are then processed through a simple analytical system to produce daily readiness reports.

The third step is to strengthen the capacity of human resources of technicians and maintenance managers through digital training. Together with the Ministry of Communication and Commerce, GMF AeroAsia, and PT Dirgantara Indonesia, the TNI needs to launch the Digital Maintenance Training Program (DMTP) which focuses on basic digital literacy, data recording, and the introduction of the concept of predictive maintenance. The goal is to create technicians who are able to adapt to digital systems and understand the basics of maintenance data analysis. This effort is in line with modernization theory (Ahmad, 2011), which emphasizes that technological transformation must be accompanied by a change in mindset and work behavior so that modernization is not only symbolic, but also substantive.

The fourth step in this phase is to build a security system and audit of defense data under the supervision of BSSN and Inhan. Cybersecurity is an absolute requirement so that ISMS does not become a weak point for digital defense. A Military Data Security Framework (MDSF) is needed that regulates encryption standards, access authorization, and data recovery procedures in the event of a cyber incident. In parallel, an ISMS pilot project was carried out in two main TNI Air Force enforcement units (e.g. Squadron 3 and Squadron 11), to test the integration of new systems on aircraft maintenance performance and readiness. The output of this stage is the formation of the initial policy foundation, data infrastructure, and digital human resources, as well as an increase in the initial Aircraft Readiness Index (ARI) by ±10%.

Medium-term stage (2–5 years). Integration, Synergy, and Predictive Implementation. The medium-term stage is the phase of full implementation of the ISMS system in a cross-dimensional manner and data integration with the national defense industry, in line with the SO strategy (harnessing internal strengths to seize external opportunities). The main focus in this phase is to build predictive and collaborative systems capable of providing strategic value in operational and logistical decision-making. The first step is full integration between the defense and the defense industry. In this phase, the Defense Maintenance Data Hub (DMDH) was developed into the Integrated Smart Maintenance Network (ISMN), which is a cloud defense-based system that connects all dimensions, PTDI, GMF and the Ministry of Defense's logistics center in one secure network. This system is equipped with real-time condition monitoring, failure prediction, and digital twin simulation modules, as already used by Airbus and Boeing (KPMG, 2025). Synergy with industry allows maintenance to be carried out based on the actual condition of components, not just based on time-based maintenance.

The second step is the implementation of a predictive system operationally. Using advanced sensors and machine learning algorithms, the ISMS system is able to detect damage trends in vital components such as engines, avionics, and hydraulic systems. This technology allows technicians to perform predictive interventions before damage occurs, thereby significantly reducing aircraft downtime. The data generated will be processed by the ISMS Command Dashboard, which was developed by the Ministry of Defense and Inhan to support the decision of the TNI Commander and the Chief of Staff of the Armed Forces in determining the priority of aircraft allocation and logistics.

The third step is the establishment of a special organization to manage the ISMS in the TNI structure under the Aslog of the TNI Commander. This structure serves to coordinate all aspects of digital maintenance management, from planning, training, reporting, to cross-dimensional policy integration. According to coordination theory (Handoko, 2003), the effectiveness of the system depends on synchronization and a clear division of roles between

units. The establishment of this integrated command is a form of institutionalization of the ISMS within the framework of the national defense organization.

The fourth step is the strengthening of the advanced training system and competency certification of digital technicians. Through the collaboration between the Ministry of Communication and Commerce, PTDI, GMF, and defense universities (Unhan), the ISMS Center of Excellence (CoE) was established as a center for training, research, and certification of certified digital maintenance technicians. The goal is to produce technicians with competencies in data analysis, artificial intelligence, and predictive system operation. This training program is also part of the career development path for military technicians, so that it can improve professionalism and human resource retention.

The fifth step is the implementation of a data-based performance measurement system (Readiness & Maintenance Performance Index – RMPI). The system calculates aircraft readiness based on operational variables, failure predictions, and spare parts availability. The RMPI data is the basis for the preparation of readiness reports to the Commander of the TNI and the Ministry of Defense, as well as the main indicator of the success of the ISMS system in the implementation phase. The medium-term output is the formation of a cross-dimensional predictive maintenance system, an increase in the Aircraft Readiness Index by 70-80%, and the beginning of the formation of a digital culture in the TNI technician environment.

Long-term stage (>5 years). Optimization, Independence, and Sovereignty of National Air Defense Technology. The long-term stage is a phase of strengthening technological independence and optimizing ISMS as a strategic system of national air defense. In this phase, the ST and WT strategies play an important role as a consolidation and protection measure so that the success of transformation is not only short-term, but also a sustainable force that supports the national defense posture. The first step is the development of national predictive algorithms and ISMS technology. After the integration stage with global vendors, the TNI together with PTDI and GMF need to develop a local algorithm based on machine learning that is tailored to the characteristics of Indonesian aircraft. Thus, the TNI is no longer dependent on foreign systems that are vulnerable to technological embargoes or restrictions. This local predictive engine is the main foundation of national ISMS independence.

The second step is to strengthen ISMS's strategic cybersecurity by establishing a Cyber Defense Operation Center (CDOC) specifically for the maintenance sector. In collaboration with BSSN and Inhan, this center is tasked with conducting 24-hour monitoring of cyber threats, data attacks and system sabotage. According to KPMG (2025), modern defense systems that do not have a multi-layer cyber defense are prone to logistics data leaks, which can have direct implications for the confidentiality of military operations.

The third step is the integration of the ISMS with the national defense command and control system (C4ISR). In this stage, aircraft readiness data from the ISMS is not only used for logistical purposes, but is also integrated into the air operations planning system and national defense strategy. Thus, operational decision-making can be based on real-time data on fleet readiness and resource availability. This is in line with the principle of data-driven defense readiness, which has been implemented by the United States and NATO militaries since 2022 (WEF, 2025).

The fourth step is to achieve the independence of the national digital defense system through the establishment of a Defense Digital Ecosystem. The ecosystem integrates the

defense industry, research institutions, universities, and national security agencies in a single innovation network. The Defense Digital Ecosystem will be a forum for the development of advanced technologies such as digital twin simulation for aircraft performance, augmented reality maintenance training, and AI-based operational analytics. In this phase, the ISMS not only serves as a maintenance system, but also becomes a strategic data source for long-term planning and development of adaptive defense postures.

The last step is the formation of a digital defense culture in all ranks of the TNI. Technological modernization will be meaningless without changes in organizational behavior and mindset. Therefore, the TNI Commander and the Chief of Staff must instill the value that digitalization is not just a technical tool, but part of the TNI's new identity that is professional, efficient, and globally competitive. Through continuous training, performance-based awards, and a career system that accommodates technology specializations, a digital defense culture can become a non-material force that underpins combat readiness and national technological sovereignty.

The Integrated Smart Maintenance System (ISMS) strategic roadmap shows the direction of the TNI's transformation from a conventional maintenance system to a smart, adaptive, and sovereign digital defense system. In the short term, the focus is on consolidating the foundations of policy, data, and digital human resources. In the medium term, the strategy is focused on cross-dimensional integration and the implementation of predictive systems based on data analytics. Meanwhile, in the long term, efforts are directed at national technology independence, strategic integration with the defense command system, and the formation of a digital defense culture.

Through this gradual implementation, the TNI is expected to be able to increase the Aircraft Readiness Index to above 80%, strengthen the national defense posture and create an efficient, safe, and sustainable aircraft maintenance system in the face of geopolitical uncertainty and future global crises. Thus, it is hoped that the Integrated Smart Maintenance System is not only a technological innovation, but also a national strategic instrument that realizes the ideals of Data-Based Defense and Innovation towards a superior, professional, and digitally sovereign TNI.

CONCLUSION

This study, drawing on primary data from interviews, field observations, literature reviews, and supporting documents, concluded that the *Integrated Smart Maintenance System* (*ISMS*) significantly enhances TNI aircraft operational readiness through real-time data integration and *AI*-based predictive technology, accelerating breakdown detection, streamlining schedules, and reducing unscheduled downtime by up to 30%. Despite external challenges like geopolitical instability and energy fluctuations—necessitating digital defense transformation per modernization theory—the TNI faces persistent issues including low technical readiness, limited infrastructure, and weak inter-dimensional coordination, positioning *ISMS* as a unifying solution for information systems and policies to strengthen the maintenance ecosystem. The shift to *ISMS* requires long-term strategic steps: initial digitalization and HR training, followed by cross-dimensional integration and national technology development, representing not just technological innovation but systemic reform in TNI defense management to bolster air defense amid global crises. For future research, scholars could quantitatively model *ISMS* impacts using

simulation tools or longitudinally assess its scalability across other TNI branches like naval assets.

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