

A Conceptual Framework for Maintenance Decision-Making in a Defense System Based on Operational Readiness and Industrial Capacity

Firdah Dipi Juni Kurniawati¹

¹Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

G. Royke Deksino²

²Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

I.B. Putra Jandhana³

³Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

Ade Muhammad⁴

⁴Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

Sri Yanto⁵

⁵Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

Sulfi Indriani⁶

⁶Defense Industry Study Program, Faculty of Defense Engineering and Technology, Indonesian Defense University, Indonesia

Corresponding Author: firdah.kurniawati@tp.idu.ac.id

Abstract

This study develops a conceptual framework for maintenance decision-making in the defense sector by considering two key dimensions, namely operational readiness and industrial capacity. In practice, decision-making related to maintenance in complex systems is influenced not only by technical aspects, but also by various supporting factors such as system reliability, spare parts availability, logistics readiness, human resource competence, industrial support, technological



capability, maintenance costs, and supply chain capability. However, current approaches often have a limited scope and are insufficient in capturing the interdependencies among these factors. To address these limitations, this study proposes a framework based on Multi-Criteria Decision Making (MCDM) using the Fuzzy Analytic Hierarchy Process (FAHP). This approach was chosen because it can handle uncertainty and subjectivity in criterion assessment. The developed framework is expected to serve as a basis for establishing maintenance decision-making priorities in a more systematic manner and to provide direction for future empirical research.

Keywords: Maintenance Decision-Making; Operational Readiness; Industrial Capacity; Defense Systems; Fuzzy AHP

INTRODUCTION

In the modern defense sector, decision-making regarding operational strategy and maintenance is becoming increasingly complex. This is due to the presence of various conflicting criteria, namely operational readiness, industrial capacity, cost efficiency, and system risk levels. These conditions require an approach capable of addressing the complexity and uncertainty inherent in defense systems.

Generally, decision-making in complex environments involves evaluating various alternatives based on a number of criteria with varying levels of importance. Multi-Criteria Decision Making (MCDM) approach has been widely used to address these issues because it provides a systematic framework for evaluating alternatives and ranking them to determine decision priorities. Multi-Criteria Decision Making allows decision-makers to consider trade-offs between criteria in a more structured and transparent manner (Alharairi et al., 2025).

There are limitations to using this conventional MCDM approach, particularly when dealing with uncertainty and the subjectivity of human judgment. In practice, many decisions including those within defense systems are not always based on precise quantitative data, but rather on linguistic expert judgments such as “high,” “moderate,” or “low.” These characteristics lead to ambiguity and uncertainty that are difficult to model accurately using classical numerical approaches (Sahoo & Goswami, 2023).

To address these limitations, fuzzy set theory was introduced as an approach capable of representing uncertainty and ambiguity in the decision-making process. The integration of fuzzy logic and MCDM will result in a fuzzy MCDM method that allows qualitative assessments to be transformed into a more flexible and realistic mathematical representation. This approach has



proven capable of improving decision quality by systematically addressing subjective preferences and information uncertainty (Sahoo & Goswami, 2023).

One of the most widely used MCDM methods in this field is Fuzzy Analytic Hierarchy Process (FAHP), which is an extension of AHP method that incorporates fuzzy logic. FAHP allows for pairwise comparisons based on fuzzy values, thereby capturing uncertainties in the evaluation of criteria more accurately. This method is considered effective in addressing complex problems involving numerous criteria and uncertain preferences (Alharairi et al., 2025).

In sector of maintenance for industrial and defense systems, selecting the right strategy has a significant impact on system reliability, operational efficiency, and the sustainability of organizational performance. Several studies indicate that maintenance activities can help reduce a significant portion of operational costs and directly impact system availability and performance. Therefore, determining a maintenance strategy is not merely a technical issue, but also a complex and multidimensional strategic decision-making problem (Mossadegh Khah & Ismail Golrakhi, 2020).

Although various studies have examined decision-making methods for selecting maintenance strategies, most still focus on the general industrial sector and have not specifically considered the unique characteristics of defense systems, such as the need for high readiness, resource constraints, and the dynamics of the operational environment. Furthermore, the integration of operational readiness and industrial capacity into a single decision-making framework remains relatively limited in the literature.

Given these circumstances, this study aims to develop a fuzzy MCDM based conceptual framework for evaluating operational readiness and industrial capacity criteria to support strategic maintenance decision-making within the defense system. The main contribution of this study is the integration of operational readiness and industrial capacity into a framework for integrated maintenance decision-making in the defense sector.

LITERATURE REVIEW

In recent years, multi-criteria decision making (MCDM) has become the primary approach for addressing complex problems involving numerous alternatives and conflicting criteria. This approach provides a systematic framework for evaluating various alternatives based on the relative importance of each criterion, thereby enabling decision-makers to arrive at more rational and structured outcomes. In this sector, each criterion is assigned a specific weight based on its level of importance, which is then used as the basis for the evaluation process and the selection of



the best alternative (Alharairi et al., 2025).

One of the most widely used methods of Multi-Criteria Decision Making (MCDM) is the Analytic Hierarchy Process (AHP). This method was developed to aid the decision-making process through a hierarchical approach and pairwise comparisons, thereby enabling the identification of priorities for each criterion and alternative. The AHP method is considered superior due to its ability to systematically integrate quantitative and qualitative aspects and produce results that are easy to interpret (Liu et al., 2020). In practice, the AHP method has been widely applied in various fields, including management, engineering, and strategic decision-making.

The conventional AHP method has limitations in handling the uncertainty and subjectivity that often arise in the evaluation process. In many decision-making scenarios, decision-makers do not assign precise numerical values for comparing criteria but instead use linguistic assessments such as “more important” or “fairly important.” These limitations support the development of a method capable of addressing ambiguity through integration with fuzzy set theory.

The integration of the AHP method and fuzzy logic results in the Fuzzy Analytic Hierarchy Process (FAHP), which is designed to address uncertainty and ambiguity in human evaluations. In FAHP, comparison values are no longer expressed as exact numbers but as fuzzy numbers, such as triangular fuzzy numbers, thereby allowing for a more realistic representation of choices. This approach enables the decision-making process to be more flexible and adaptive to real-world conditions where uncertainty is a common issue (Alharairi et al., 2025).

Recent research developments indicate that the FAHP method has been widely applied across various fields, ranging from engineering and management to infrastructure systems. A literature review covering studies from 2019 to 2024 shows that FAHP is highly effective in addressing complex decision-making problems, particularly those involving multiple criteria and a high degree of uncertainty. Additionally, this method is often combined with other techniques such as TOPSIS, VIKOR, and DEMATEL to enhance the accuracy and quality of decision outcomes (Alharairi et al., 2025).

In the field of maintenance using of MCDM and FAHP approaches has also shown significant progress. Selecting a maintenance strategy is a complex issue because it involves various factors, such as system reliability, cost, safety, and resource availability. Therefore, this Multi-Criteria Decision-Making approach is considered more effective in helping experts or decision-makers determine the optimal maintenance strategy. The study shows that the use of the FAHP method in selecting maintenance strategies can improve the overall efficiency, reliability, and safety of the system (Jumanne Maulid et al., 2025).



Furthermore, other studies have also confirmed that selecting a maintenance strategy is not a simple matter as each system has different characteristics, requiring an approach that can take various criteria into account simultaneously. In this regard, the AHP and FAHP methods provide effective solutions by enabling decision-makers to prioritize strategies based on expert assessments (Mparanyi Justin, 2021).

Nevertheless, most existing research still focuses on the application of the FAHP method within the general industrial sector, such as manufacturing and infrastructure, and few studies have specifically examined its application in defense systems. The integration of operational readiness and industrial capacity within a single decision-making model remains relatively limited. This indicates a research gap that presents opportunities for the development of more comprehensive and sector-specific models.

Based on this literature review, it can be concluded that the FAHP method is a relevant and effective approach for supporting complex multi-criteria decision-making. However, further development is still needed, particularly within the defense sector, by integrating various important dimensions such as operational readiness and industrial capacity into a single, integrated analytical framework. This study will develop a conceptual framework, which is described in more detail in the following methodology section.

METHODOLOGY

This study employs a conceptual research approach aimed at developing a decision-making model framework within sector of defense system maintenance. This approach was chosen because the study does not focus on empirical testing, but rather on formulating a theoretical model capable of explaining the relationships among criteria and providing an analytical basis for decision-making. The model was developed through a review of relevant literature, particularly regarding the Multi-Criteria Decision Making (MCDM) method, the Analytic Hierarchy Process (AHP), and its extension in the form of Fuzzy AHP (FAHP). This approach allows researchers to integrate various existing concepts to produce a framework that is more comprehensive and aligned with the characteristics of defense systems.

Framework for a Decision-Making Model

The decision-making model framework developed in this study is organized into a hierarchical structure consisting of objectives, criteria, and sub-criteria. The primary objective of this model is to determine the most appropriate maintenance strategies to support defense



system readiness. At the criteria level, this study integrates two main dimensions operational readiness and industrial capacity which are considered key factors in supporting system sustainability. In addition, each criterion is divided into several sub-criteria derived from previous studies, such as system reliability, spare parts availability, logistical readiness, human resource competence, industry support, technological capability, maintenance costs, and supply chain capability. The criteria and sub-criteria used in this study, along with their supporting references, are described in detail in Table 1.

Table 1. Criteria, Sub-Criteria, and References of Maintenance Decision Model

Main Criteria	Sub-Criteria	Description	Reference
Operational Readiness	System Reliability	The ability of the system to perform its required functions under specified conditions	(Mossadegh Khah & Ismail Golrakhi, 2020)
	Spare Parts Availability	The availability of spare parts required to support maintenance activities	(Jumanne Maulid et al., 2025)
	Logistics Readiness	The readiness of logistics systems to support maintenance operations	(Mparanyi Justin, 2021)
	Human Resource Competence	The skills and expertise of personnel involved in maintenance activities	(Sahoo & Goswami, 2023)
Industrial Capacity	Industrial Support	The ability of industry to provide maintenance services and technical support	(Alharairi et al., 2025)
	Technology Capability	The level of technological capability supporting maintenance processes	(Liu et al., 2020)
	Maintenance Cost	The financial resources required for maintenance activities	(Mossadegh Khah & Ismail Golrakhi, 2020)
	Supply Chain Capability	The effectiveness of supply chain systems in supporting maintenance needs	(Sahoo & Goswami, 2023)

The purpose of establishing this hierarchical structure is to break down complex problems



into more structured components, thereby facilitating the evaluation and analysis process. A conceptual illustration of the hierarchical structure of the proposed decision-making model is shown in Figure 1.

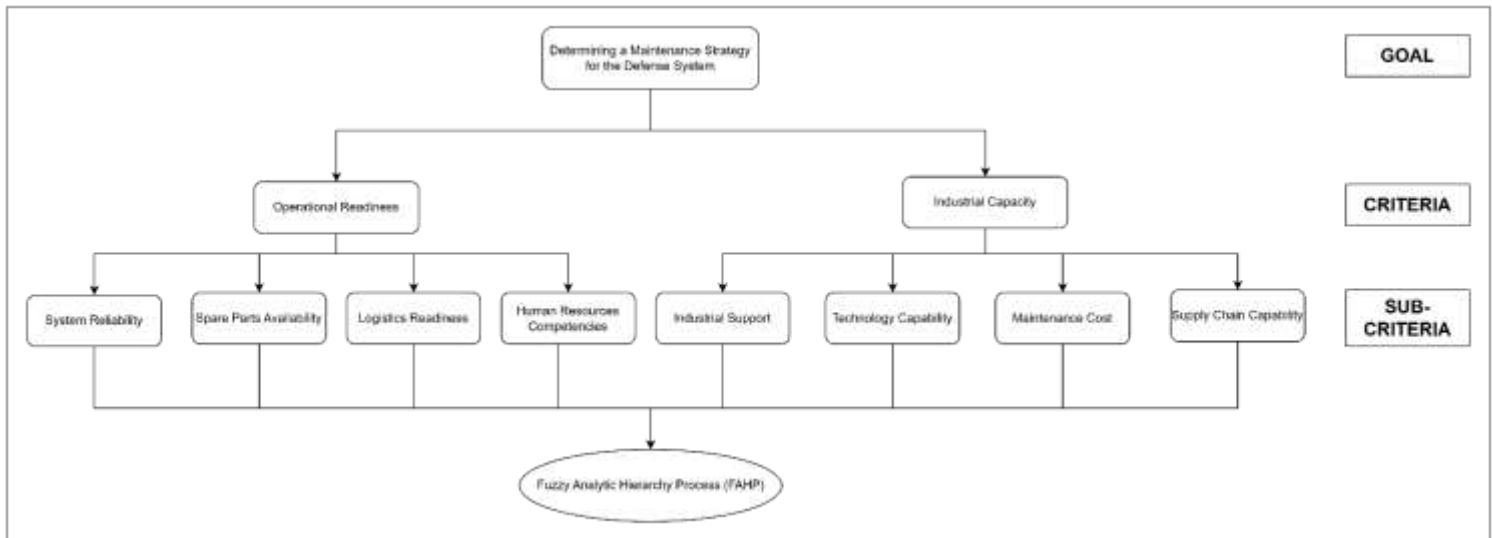


Figure 1. Hierarchical Structure of Maintenance Decision Model

Steps of the Fuzzy Analytic Hierarchy Process (FAHP)

In the analysis process, this study employs the Fuzzy Analytic Hierarchy Process (FAHP) as the primary tool for determining the relative importance weights of each criterion. The FAHP method was selected because it is better able to handle the uncertainty and subjectivity in evaluations that frequently arise in decision-making particularly in defense systems that rely heavily on expert judgment. Compared to conventional AHP, FAHP provides a more effective approach in handling such uncertainty. This stage of the FAHP method begins with the construction of a predefined hierarchical structure and continues with the creation of a pairwise comparison matrix between criteria using linguistic scales. These linguistic values are then converted into fuzzy numbers in the form of triangular fuzzy numbers to represent choices more flexibly. After that, criterion weights are calculated through the aggregation and normalization of fuzzy values, followed by a defuzzification process to obtain crisp values that can be used in the analysis. The final step in this process is to conduct a consistency test to ensure that the evaluations provided have an appropriate level of consistency. The procedural steps of the FAHP method applied in this

study are presented in Figure 2.



Figure 2. Fuzzy AHP Method Steps

The Role of Models in Research

The model developed in this study is not intended to directly generate operational decisions, but rather to serve as a conceptual framework that can be used as a basis for a more systematic decision-making process. The primary role of this model is to assist in identifying and understanding the relationships among the criteria that influence maintenance strategies, as well as to provide a more structured approach to setting priorities. Furthermore, this model is also expected to serve as a foundation for future empirical research, particularly in testing the model's validity and effectiveness in real-world cases within defense systems. Thus, this study not only makes a theoretical contribution but also opens opportunities for the development of more practical decision-making methods in the future.

RESULTS AND DISCUSSION

This section discusses the results of the development of the conceptual model proposed in this study and its implications for maintenance decision-making in defense systems. Although this study did not involve empirical testing, the results obtained are a structured and integrative model

framework that can be used as a basis for analysis and decision-making processes.

The main objective of this study is to develop a Fuzzy Multi-Criteria Decision Making (Fuzzy MCDM) model that integrates two key dimensions: operational readiness and industrial capacity. This model is structured hierarchically, allowing decision-makers to systematically understand the relationships between criteria and determine priorities based on their level of importance. This MCDM approach aligns with previous research indicating that such methods are effective in addressing complex multi-criteria decision-making problems (Sahoo & Goswami, 2023). This is particularly important in air defense systems where high operational readiness is critical.

In the defense sector, operational readiness serves as a key indicator for assessing a system's ability to perform its functions optimally. Factors such as system reliability, spare parts availability, logistical readiness, and human resource competence are critical factors that influence this level of readiness. On the other hand, industrial capacity provides external support that plays a role in ensuring the sustainability of the system through the provision of necessary resources, technology, supply chains, and maintenance services. The integration of these two dimensions offers a more comprehensive perspective compared to previous approaches that tended to separate internal and external factors, as also highlighted in studies related to FAHP- based maintenance strategies (Mossadegh Khah & Ismail Golrakhi, 2020).

The use of the Fuzzy AHP method in this model provides significant added value to the decision-making process. This method allows for the accommodation of uncertainty and subjectivity in evaluations, which frequently arise within the defense sector. By using a fuzzy approach, linguistic evaluation can be represented in a more flexible mathematical form, resulting in more realistic criterion weights that can adapt to real-world conditions. This is consistent with previous research findings stating that FAHP is capable of improving the quality of decision-making under conditions of high uncertainty (Alharairi et al., 2025; Liu et al., 2020).

Conceptually, this proposed model demonstrates that maintenance decision-making cannot be conducted in isolation but must be carried out simultaneously, taking into account the interdependencies among various factors. This is particularly critical in defense systems, where decisions made have direct implications for operational readiness and the overall effectiveness of the system. Thus, this model can contribute by filling a research gap where previous studies have not sufficiently integrated the dimensions of operational readiness and industrial capacity into a single analytical framework.

In addition, this model also has practical implications, particularly for decision-makers in the defense sector. With its hierarchical structure and systematic weighting method, this model



can serve as a tool to help determine maintenance strategy priorities in a more objective and transparent manner. This is consistent with previous research indicating that the use of the AHP/FAHP method can improve decision quality and reduce subjectivity in the maintenance strategy evaluation process (Jumanne Maulid et al., 2025; Mparanyi Justin, 2021).

This study has limitations because the proposed model has not yet been tested in real-world experiments. Therefore, these findings remain conceptual in nature and require further validation through case studies or direct field applications. Future research is expected to test this model using real-world data and expert assessments, thereby evaluating the model's accuracy and effectiveness under actual operational conditions.

CONCLUSION

This study aims to develop a conceptual framework for maintenance decision-making within the defense sector by integrating the dimensions of operational readiness and industrial capacity. Based on the results of the model development, it can be concluded that maintenance decision-making is a complex and multidimensional issue, and therefore cannot be resolved through a partial approach that focuses solely on a single aspect.

The model proposed in this study demonstrates that the integration of internal factors (operational readiness) and external factors (industrial capacity) provides a more comprehensive approach to understanding the dynamics of maintenance decision-making. Furthermore, the use of the Fuzzy Analytic Hierarchy Process (FAHP) allows for the accommodation of uncertainty and subjectivity in the assessment, resulting in a more flexible and realistic process for determining criterion weights.

Conceptually, this study contributes to the development of a decision-making approach using Multi-Criteria Decision Making (MCDM) that emphasizes the importance of integrating various interrelated dimensions. The developed model framework is expected to serve as a foundation for supporting more systematic, transparent, and structured maintenance decision-making, particularly within the highly complex environment of defense systems. This framework is intended to provide a basis for future empirical validation and practical implementation in defense maintenance decision-making.

FUTURE DIRECTIONS

This study has limitations because it is conceptual in nature and the proposed model has not yet been empirically tested. Therefore, it is recommended that future research validate this



model through real-world case studies in the field that incorporate operational data and assessments from experts in the relevant fields. Testing based on experience or observation rather than theory alone is crucial for evaluating the accuracy and effectiveness of models in supporting maintenance decision-making under real-world conditions.

In addition, future research could be conducted by integrating other MCDM methods, such as TOPSIS, VIKOR, or DEMATEL, to improve the quality of the analysis and broaden the perspectives in decision-making. This hybrid approach is expected to yield more reliable results that can be easily adapted to various conditions.

Further research could expand the scope of the model by incorporating additional factors such as operational risk, system resilience, and the increasingly complex dynamics of global supply chains. Thus, the developed model is not only relevant in a theoretical sector but also has high practical value in supporting strategic decision-making within the defense system environment.

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