

Development of A Framework for Mitigating Cost and Time Overruns in The V25 Ambulance Ship Construction Project using The ISM and ANP Approaches

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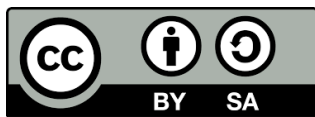
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Cost Overrun; Time overrun;
Shipyard; ISM; ANP.

Abstract

This study aimed to develop a framework for mitigating cost and schedule overruns through the integration of Interpretive Structural Modeling (ISM) and the Analytic Network Process (ANP). Data were obtained from project documentation and questionnaires administered to five experts who assessed six factors and 23 internal subfactors contributing to cost and schedule deviations. ISM was used to analyze hierarchical relationships, driving power, and dependence power, while ANP was used to construct a priority network for nine subfactors in the independent quadrant. The final priorities were derived from five subfactors (A1–A5), while A6–A9 served as control nodes within the dependency relationships. The ISM results showed that unrealistic cost planning (A6) was positioned at the most fundamental level and had the highest driving power, identifying it as a key strategic driver. The ANP results indicated that inadequate communication and coordination among relevant parties (A1) had the highest global weight of 0.348180, followed by an insufficient number of workers (A2) at 0.258313 and excessive workload (A4) at 0.172153. The integration of the two methods indicated that A6 should be addressed during the planning stage, whereas A1 should be the primary operational priority during project implementation. This study developed a cyclical mitigation framework comprising priority risk identification, mitigation implementation, monitoring, effectiveness evaluation, residual risk assessment, and decision-making. The framework was supported by early mitigation measures, a Responsible, Accountable, Consulted, and Informed (RACI) matrix, monitoring indicators, evaluation frequency, and escalation mechanisms to strengthen cost and schedule control in similar shipbuilding projects.



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INTRODUCTION

The manufacturing industry is one of the strategic sectors that plays an important role in supporting national economic growth. In a maritime country such as Indonesia, the shipbuilding industry occupies a vital position because it is directly related to maritime transportation systems, logistics distribution, inter-island connectivity, defense, and maritime-based economic development. The Government of Indonesia continues to promote the

strengthening of the national shipbuilding industry as part of its efforts to enhance the competitiveness of the national maritime industry. Deputy Minister of Industry Faisol Riza (2025) stated that the shipbuilding industry contributed 17.5% to the growth of the national manufacturing industry in the first quarter of 2025. This figure demonstrates that the shipbuilding industry has considerable potential to support national economic growth while strengthening Indonesia's position as a global maritime axis (Adryani et al., 2024).

Despite its considerable potential, the national shipbuilding industry continues to face various fundamental challenges, including high production costs, low shipbuilding efficiency, delays in project completion, and inadequate cost and schedule control. These conditions have resulted in the productivity and competitiveness of Indonesian shipyards remaining relatively low compared with those of countries with advanced maritime industries. According to (Abdelalim et al., 2025), low efficiency in construction and manufacturing projects is generally influenced by inadequate project control systems, changes in the scope of work, poor interdepartmental coordination, and management's inability to effectively control project costs and schedules (Alhammadi et al., 2024; Anandhi & Mukilan, 2017; Arantes & Ferreira, 2024; Ashtari et al., 2022).

Two major indicators of poor project performance are cost overruns and schedule overruns. These problems represent significant challenges in project management because they directly affect productivity, profitability, and corporate reputation. Zhang et al. (2022) identified cost and schedule overruns as among the most significant challenges in modern construction projects because they can adversely affect project performance and reduce the overall likelihood of project success (Gupta & Kumar, 2020; Hadžić et al., 2023; Hamidullah & Sucita, 2019; Hassan et al., 2016). In addition, Johnson and Babu (2020) emphasized that delays in project implementation are among the primary factors contributing to increased project costs because extended project durations result in the prolonged use of resources, labor, production equipment, and other operational resources (Chowdhury et al., 2019; Doloi, 2013; Dong et al., 2025; Ervianto, Wulfram, 2007).

In the shipbuilding industry, the risks of schedule and cost overruns tend to be higher than in many other construction sectors because shipbuilding projects are complex, technology-intensive, and characterized by an engineer-to-order production approach. According to Hadžić et al. (2023), shipbuilding projects involve a high degree of uncertainty because each vessel requires specific adjustments in design, materials, technology, and system integration. Consequently, even minor changes in one work package may significantly affect overall project progress, schedule, and cost. This argument is reinforced by Zadeh and Kashef (2022), who explained that increasing project complexity is associated with greater risks of delays and cost overruns because of increased technical uncertainty, changes in the scope of work, and inadequate project control (Helwande et al., 2023; Husin & Sustawan, 2021; HUSSIEN, 2025; Johnson & Babu, 2020).

In addition to project complexity, schedule delays are frequently influenced by inadequate planning and work control. Ramadhan and Waty (2025) stated that design changes contributed 56.5% to cost overruns and 40% to project delays, whereas planning errors contributed 34.5% to cost overruns and 23.1% to project delays. Similarly, Koirala et al. (2024) explained that projects experiencing schedule delays generally incur additional costs because

of the extended use of materials, labor, production facilities, and other operational resources throughout the project duration (Kerzner, 2017; Leys et al., 2013; Limantoro et al., 2023; Magalhães et al., 2021; Marzangoushi et al., 2025).

Cost and schedule overruns also occurred in the V25 Ambulance Ship construction project at a shipyard in Surabaya. The project, which included hull construction, piping and machinery system installation, major system integration, and commissioning, experienced a delay from the planned duration of 18 weeks to an actual duration of 20 weeks, representing an increase of approximately 11.1%. The delay was accompanied by a project cost overrun of approximately 31.6% of the initial contract value, particularly in hull construction (kasko), which required substantial quantities of materials and labor. These conditions indicate that delays in project implementation may contribute directly to increased costs because of the extended duration of resource utilization and associated operational expenses (Molina-Gómez et al., 2021).

Previous studies have demonstrated that cost and schedule overruns are influenced by multiple factors, including inadequate planning, changes in the scope of work, delays in material procurement, low labor productivity, and insufficient interdepartmental coordination. These factors are interrelated and therefore create complex project management challenges. However, previous studies have generally examined relationships among factors or determined their priorities separately and have predominantly focused on general construction projects. Recent studies have also emphasized that although various analytical methods have been developed to address cost and schedule overruns, the integration of structural relationship modeling with decision-prioritization approaches remains limited, particularly in shipbuilding projects. Therefore, a more comprehensive framework combining causal hierarchy analysis and priority weighting is required (Silvaniata et al., 2025). This research gap highlights the need for an integrated structural and prioritization analysis to provide a more comprehensive understanding of the factors contributing to cost and schedule overruns in shipbuilding projects.

This study employed an integrated approach combining Interpretive Structural Modeling (ISM) and the Analytic Network Process (ANP). ISM was used to identify and structure the hierarchical relationships among causal factors, thereby determining the key driving factors and dependent factors within the system. Subsequently, ANP was applied to determine the priority of each factor by considering the interdependencies among factors within the network. Integrating these two methods was expected to provide a more comprehensive analysis than applying either method independently, thereby enabling the identification of dominant factors that should be prioritized in project control and mitigation strategies.

Based on this background, this study aimed to develop a framework for mitigating cost and schedule overruns in the V25 Ambulance Ship construction project through the integration of ISM and ANP. The study sought to identify the relationships among causal factors, determine the most influential factors, and develop effective mitigation strategies to reduce the risks of schedule delays and cost overruns. In addition to contributing to the project management literature, this research was expected to provide a practical reference for shipyard companies seeking to improve the effectiveness of cost control, schedule control, and risk management in future shipbuilding projects. This integrated approach has recently been recommended because it can reveal both the structural relationships among risk factors and

their relative priorities, thereby supporting the development of more effective mitigation strategies (Silvianita et al., 2025).

METHOD

Research Object

The object of this study was the V25 Ambulance Ship construction project at a shipyard in Surabaya. The project was initially scheduled for completion within 18 weeks but experienced schedule and cost overruns. The project budget increased from IDR 430 million to IDR 566 million. Therefore, the project was selected as a case study to identify the factors contributing to these overruns and to develop mitigation strategies applicable to similar shipbuilding projects.

Research Stages

The research began with the identification of problems through field observations, initial interviews, and literature studies to obtain the factors that cause time overrun and cost overrun. The factors obtained were then validated by five experts consisting of Directors, Project Planners, Engineering, Procurement, and Skilled Carpenters. Experts are chosen because they have experience and an important role in project decision-making. The validation results were used as the basis for the preparation of the research questionnaire.

Data Processing

Data analysis was carried out using Interpretive Structural Modeling (ISM) and Analytic Network Process (ANP) methods. The ISM method is used to analyze the relationship between causal factors and compile a hierarchical structure so that it can be known which factors are the main causes and the factors that are affected. Furthermore, the ANP method is used to determine the priority level of each factor based on expert assessments through paired comparisons. The results of the ANP analysis produce priority weights that show the most dominant factors in causing time overrun and cost overrun.

Preparation of Mitigation Strategies

Based on the results of the ISM and ANP analysis, the study developed mitigation strategies to reduce the risk of delays and cost overruns in shipbuilding projects. The strategy is formulated through discussions and interviews with experts so as to produce recommendations that are in accordance with the project conditions. The final stage of research is the preparation of conclusions and suggestions as an answer to the formulation of the problem as well as input for the company and subsequent research.

RESULTS AND DISCUSSION

Interpretive Structural Modeling (ISM) Processing Results

This subchapter discusses the results of data processing using the Interpretive Structural Modeling (ISM) method to analyze the relationship between the factors that cause cost overrun and time overrun in the V25 ambulance construction project. The ISM method is used to systematically construct the structure of the relationship between elements so that it can be known which factors act as driving factors and factors that are more influenced by other elements (dependent factors).

The use of the ISM method in this study is based on the method's ability to simplify the complex relationships between variables into an easy-to-understand hierarchical model. According to Attri, Dev, and Sharma (2020), ISM is an expert judgment-based method used to identify the relationships between elements in a complex system to help decision-makers determine improvement priorities.

In this study, the ISM processing process was carried out based on the results of the assessment of five expert respondents who have experience and direct involvement in ship construction projects. An assessment was carried out on the relationship between the subfactors that cause cost overrun and time overrun, which consisted of 23 main elements from the research validation results.

Preparation of the Final Reachability Matrix

The next stage in the Interpretive Structural Modeling (ISM) method is the preparation of the Final Reachability Matrix. This matrix is obtained from the results of the development of the Initial Reachability Matrix by considering the transitivity relationship between elements.

The concept of transitivity in ISM shows that if one element affects another element, then it can occur indirectly on the next element. According to Attri, Dev, and Sharma (2020), the application of transitivity in ISM aims to describe the systemic relationships between elements so that the resulting model is able to show direct or indirect relationships in a complex system.

In this study, the Final Reachability Matrix was used to determine the driving power and dependency power of each subfactor causing cost overrun and time overrun in the V25 ambulance construction project.

Table 1. Final Reachability Matrix (FRM)

	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15	A 16	A 17	A 18	A 19	A 20	A 21	A 22	A 23
A 1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 3	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
A 4	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
A 5	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 7	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
A 8	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
A 9	1	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 10	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1
A 11	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1

	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15	A 16	A 17	A 18	A 19	A 20	A 21	A 22	A 23
A 1	1	0	1	0	1	0	0	1	0	1	1	1	1	1	1	0	0	1	0	0	0	0	1
A 2	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1
A 3	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1
A 4	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1
A 5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
A 6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
A 7	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1
A 8	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1
A 9	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0	0	0	1
A 10	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	1	1	1	0	0	0	0
A 11	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	0	0	0
A 12	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	0	0	1	1	1
A 13	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	1	1

Based on the results of the Final Reachability Matrix (FRM) in Table 4.8, there are several matrix elements that have changed their values from 0 to 1 after the implementation of the transitivity rule. These changes show an indirect relationship between factors that had not previously been seen in the initial matrix. For example, if factor A1 affects A3, and factor A3 affects A19, then it is transitively considered to affect A19. Therefore, the values in cells (A1, A19) that were originally valued at 0 changed to 1 in FRM.

Level Partitioning

The next stage in the Interpretive Structural Modeling (ISM) method is to perform level partitioning to determine the hierarchical position of each factor in the cost overrun and time overrun system. This process is carried out based on the results of the Final Reachability Matrix that have been obtained previously.

According to Attri, Dev, and Sharma (2020), level partitioning is used to identify the level of influence and dependence of each element in the system so that a hierarchical structure can be arranged that shows the cause-and-effect relationship between factors.

At this stage, several steps are taken, namely:

1. Determine the reachability set for each factor;
2. Determine the antecedent set for each factor;
3. Menentukan intersection set;
4. Factors that have a reachability set equal to the intersection set are placed at a certain level;
5. The iteration process is repeated until all factors obtain their respective hierarchy levels.

Partitioning Level Component Explanation

- The Reachability Set is a set of factors that can be influenced by a certain factor, including the factor itself.
- Antecedent Set is a set of factors that affect a certain factor, including the factor itself.
- The Intersection Set is a wedge between the reachability set and the antecedent set.

If the reachability set is the same as the intersection set, then the factor is placed at the highest level in the iteration because it is considered to be more influenced by other factors than by other factors.

Table 2. Reachability Set, Antecedent Set, dan Intersection Set

Factor	Reachability Set	Antecedent Set	Intersection Set	Lvl.
A15	{A15}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A21, A22, A23}	{A15}	15
A14	{A14, A15}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14}	{A14}	14
A18	{A18, A15}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A16, A17, A18, A19, A20, A22}	{A18}	13
A16	{A16, A18, A15}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A16}	{A16}	12
A17	{A17, A23}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A17, A21}	{A17}	12
A21	{A21}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A20, A21, A22, A23}	{A21}	12
A23	{A23}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A17, A18, A22, A23}	{A23}	12
A13	{A13, A14, A15, A18, A23}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13}	{A13}	11
A20	{A20, A18, A19}	{A1, A2, A5, A6, A9, A10, A11, A20}	{A20}	11
A22	{A22, A23}	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A18, A22}	{A22}	11
A19	{A19, A18, A15, A23}	{A1, A2, A5, A6, A7, A8, A9, A10, A11, A19, A20}	{A19}	10
A12	{A12, A13, A14, A15, A18, A23}	{A1, A2, A5, A6, A9, A10, A11, A12}	{A12}	9
A8	{A8, A9, A10, A11, A12, A13, A14, A15, A16, A18, A19, A22, A23}	{A1, A2, A3, A4, A5, A6, A7, A8}	{A8}	8
A7	{A7, A8, A9, A10, A12, A13, A14, A15, A16, A18, A19, A22, A23}	{A1, A2, A3, A4, A5, A6, A7}	{A7}	7

Factor	Reachability Set	Antecedent Set	Intersection Set	Lvl.
A9	{A9, A10, A11, A12, A13, A14, A15, A16, A18, A19, A22, A23}	{A1, A2, A6, A7, A8, A9}	{A9}	7
A5	{A5, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23}	{A1, A2, A3, A4, A5, A6}	{A5}	6
A10	{A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23}	{A1, A2, A6, A7, A8, A9, A10}	{A10}	5
A3	{A3, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A22, A23}	{A1, A2, A3, A4, A6}	{A3}	3
A4	{A4, A5, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A22, A23}	{A1, A2, A4}	{A4}	3
A1	{A1, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23}	{A1, A6}	{A1}	2
A2	{A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23}	{A2, A4, A6}	{A2}	2
A6	{A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23}	{A1, A2, A3, A4, A5, A6}	{A6}	1

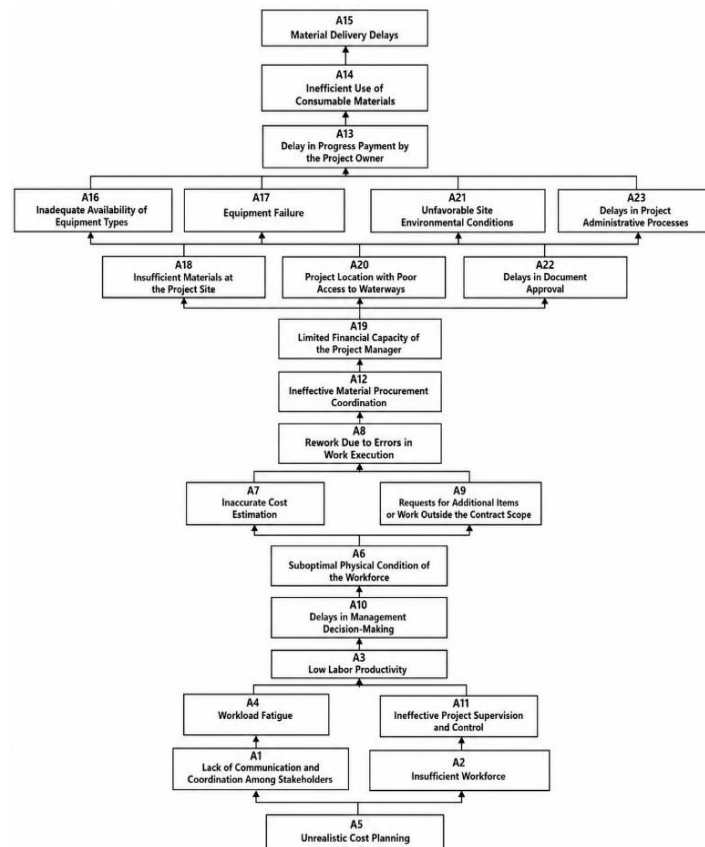


Figure 1. Hierarchical Structure of Factors Causing Project Delays Based on the ISM Method

Based on the results of the partitioning level, it can be seen that the factors causing cost overrun and time overrun have a fairly complex hierarchical relationship structure and are interrelated with each other. Factors at the lower level indicate factors that have a more fundamental influence on the project system, while factors at the top level are more influenced by other factors in the system. According to Sharma et al. (2022), factors that are at the lower level in the ISM structure are generally key driving factors that have a great influence on the emergence of other factors at the level above it (Nassar & Elbisy, 2024).

The results of the analysis showed that the A15 factor was at the highest level, namely Level 15. This shows that these factors are the ones that are most influenced by other factors in the project system. On the other hand, factor A6 is at Level 1 which indicates that it has the most fundamental influence on the system and has the potential to be the main driving factor for cost overruns and time overruns.

In addition, some factors such as A16, A17, A21, and A23 are at Level 12, while factors A13, A20, and A22 are at Level 11. This position shows that these factors act as intermediate factors that receive the influence of factors at a lower level as well as affect factors at a higher level. Thus, these factors become an important link in the spread of impact between levels in the project system.

Factors that are at the lower level need to be a top priority in project control because they have a great influence on other factors. According to Kumar et al. (2023), identification of

factors at the lower level is crucial in the risk mitigation process because controlling these factors can reduce the chain impact on the overall project system. Thus, the results of the partitioning level can help companies prioritize handling the factors that cause cost overrun and time overrun more effectively and strategically.

MICMAC Analysis

According to Attri, Dev, and Sharma (2020), MICMAC analysis is used to identify key factors in a system by grouping them into four main quadrants based on their power of influence and degree of dependency. The results of this analysis help companies in determining the priority control of the factors that are most critical to the success of the project.

In this study, the results of the MICMAC analysis were used to determine the factors that are the main driving factors (drivers), sensitive factors (linkage factors), consequence factors (dependent factors), and factors that have a small influence on the system (autonomous factors). The grouping is carried out based on the position of each factor on the MICMAC map, which is determined by the values of Driving Power and Dependence Power.

After the driving power and dependence power values of all factors are obtained, the next step is to determine the average value of each of these values. The average driving power is calculated by adding up the entire driving power value, then dividing it by the number of factors analyzed. Similarly, the average dependence power is calculated by adding up the total value of the dependent power, then dividing it by the number of factors analyzed. The average value is used as a dividing line on the MICMAC map.

1. Classification of Factors Based on Driving Power and Dependence Power

Based on the results of the Final Reachability Matrix, each factor has different driving power and dependence power values. This value is used to group the factors that cause cost overrun and time overrun into four categories of MICMAC, namely independent, linkage, dependent, and autonomous. Independent factors have a high influence on other factors but their dependence is low so they are the main factors that need to be prioritized. The linkage factor has an equally high influence and dependency so it requires special attention because changes in this factor can affect as well as be influenced by other factors. Dependent factors have a low influence but high dependency so they generally appear as a result of other factors. Meanwhile, the autonomous factor has a low influence and dependency so that the impact on the system is relatively small.

2. Discussion of Independent, Linkage, Dependent, and Autonomous Factors

The results of the analysis show that independent factors include lack of communication and coordination between parties, labor shortages, low labor productivity, excessive workload, suboptimal physical conditions of the workforce, unrealistic cost planning, inaccurate cost estimates, rework due to work errors, and the existence of additional work outside the contract. These factors are the main cause because they have a high influence on the occurrence of cost overruns and project delays.

The linkage factor consists of delays in management decision-making, ineffective project supervision, and suboptimal material procurement coordination. These factors have an equally high influence and dependency so that changes in one factor can affect other factors and vice versa. Therefore, the linkage factor needs to get special attention in project control.

Dependent factors include lack of materials in the field, inefficient use of materials, delays in material delivery, equipment limitations, equipment damage, late payment of terms, company's financial limitations, delays in document approval, and delays in project administration. These factors are generally the impact of problems on other factors. Meanwhile, the autonomous factor consists of less strategic project locations and less supportive environmental conditions. These two factors have a low influence and dependency so they are not the main factors causing cost overrun and time overrun.

Analytic Network Process (ANP) Processing Results

ANP Structure and Network

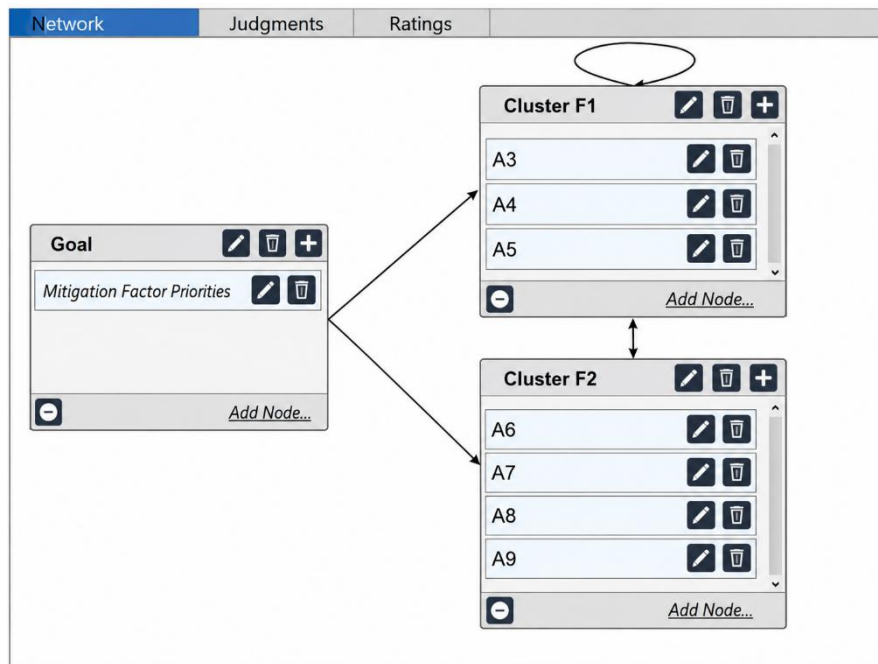


Figure 2. Network ANP

The initial stage of ANP processing is carried out by building a network model using Super Decisions software according to the relationship structure that has been designed. The model consists of two clusters, namely F1 (Labor and HR) which includes nodes A1–A5 and F2 (Management and Planning) which includes nodes A6–A9. Furthermore, the relationship of inner dependence in each cluster and the external dependence between clusters were determined based on the relationship of influence between factors in the research framework. The network model is then used as the basis for compiling paired comparisons, forming a supermatrix, and determining the priority weight of mitigation factors.

Respondent Weighting

In filling out the questionnaire, respondents had diverse backgrounds, both in terms of position, work experience, last education, and age. These differences in backgrounds show that each respondent has a different level of understanding, experience, and contribution in assessing the factors that cause cost overrun and time overrun in the V25 Ambulance Ship construction project. Therefore, it is necessary to calculate the weight for each respondent so that the assessment given can represent the level of expertise and relevance of each respondent to the object of research. This is in line with Lavasani et al. (2012), who stated that expert

weighting can be used to consider differences in respondents' characteristics and competencies in the assessment process. The following is the formula used to obtain expert weight.

$$\text{Value of Expert} = \text{PP} + \text{ET} + \text{EL} + \text{A} \quad (4.1)$$

Description:

PP = Professional Position

AND = Experience Time

THE = Education Level

A = Age of Expert

In determining expert weights, weighting categories are used with reference to research conducted by Khalila (2023). The following is a table for determining the weight of the experts:

Table 3. Weight of Members

Consitution	Classification	Score
Professional Position	Senior Academic	5
	Junior Academic	4
	Engineer	3
	Technician	2
	Worker	1
Experience Time (year)	>30	5
	20-29	4
	10-19	3
	6-9	2
	<5	1
Education Level	Phd	5
	Master	4
	Bachelor	3
	Higher National Diploma	2
	School Level	1
Age	>50	4
	40-49	3
	30-39	2
	<30	1

The following is an example of the assessment of the weighting of respondents with the position of Director. Based on the professional position category, the position can be classified into the senior group, so that the score is 5. The experience time is 20 years, so the score is worth 4. The education level taken is S1 so the score is 3. Finally, the respondent is 41 years old, so the score is 3.

The weight calculation is done using the 4.2 formula, here is an example of the weighting calculation:

$$W_j = \frac{\text{Value of Expert}}{\sum_{i=1}^n \text{Value of Expert}} \quad (4.2)$$

$$W_j = \frac{15}{49}$$

$$W_j = 0,31$$

Description:

Wj = Expert weight factor of j

The following are the results of the weighting calculation for all respondents who have filled out the questionnaire:

Table 4. Weighted Results from Respondent Data

Professional Position (PP)		Experience Time	Education Level	Age	Total	Weight
Departments	Shoes					
Director	5	4	3	3	15	0,3061
Project Planner	3	1	3	1	8	0,1633
Engineer	3	1	3	1	8	0,1633
Procurement	3	1	3	1	8	0,1633
Skilled Carpenter	1	4	1	4	10	0,2041
Total					49	1,0000

Respondent weighting was carried out to give different levels of importance to each respondent based on Professional Position, Experience Time, Education Level, and Age. The scores of the four criteria were summed and normalized so that the weight of each respondent was obtained. The weighting results showed that the Director had the highest weight of 0.3061, followed by Skilled Carpenter of 0.2041, while Project Planner, Engineer, and Procurement each had a weight of 0.1633. This weight is used in the calculation of the Weighted Geometric Mean.

Recapitulation of Questionnaire Results and Geo Mean

After the weight of each expert is obtained, the next stage is to recapitulate the results of the paired comparative assessment of all experts. The assessment is then combined using the Weighted Geometric Mean method by considering the weight of each expert's expertise. The results of the calculation resulted in a single combined value that represented the group's assessment and was subsequently used as an input in the preparation of a paired comparison matrix for each relationship in the ANP model.

Table 5. Questionnaire and Geo Mean Results

No	Comparison	Informant					Weighted Geo Mean
		Director	Project Planner	Engineer	Procurement	Skilled Carpenter	
1	F1 vs F2	1/3	1/5	1	3	5	0,9128
2	A1 vs A2	3	5	1	3	1/5	1,5683
3	A1 vs A3	5	7	3	5	1	3,4991
4	A1 vs A4	1	3	1/3	5	3	1,6274
5	A1 vs A5	7	5	3	1	5	3,9207
6	A2 vs A3	3	5	3	1	1/3	1,7406
7	A2 vs A4	1	3	1	5	3	1,9471
8	A2 vs A5	5	7	3	3	1	3,2191
9	A3 vs A4	1/3	1	3	5	3	1,3910
10	A3 vs A5	3	5	1	3	1	2,1781
11	A4 vs A5	5	3	1	1/3	3	2,0481
12	A6 vs A7	3	1	5	3	1/3	1,7406
13	A6 vs A8	5	3	7	5	3	4,3786
14	A6 vs A9	7	5	9	7	5	6,4452
15	A7 vs A8	1	3	3	5	1	1,8617
16	A7 vs A9	3	5	5	7	3	4,0704
17	A8 vs A9	1/3	1	3	5	3	1,3910
18	A1 vs A2	3	5	1	3	1	2,1781

No	Comparison	Informant					Weighted Geo Mean
		Director	Project Planner	Engineer	Procurement	Skilled Carpenter	
19	A1 vs A3	5	7	3	5	3	4,3786
20	A1 vs A4	1	3	1	5	3	1,9471
21	A1 vs A5	7	5	3	1	5	3,9207
22	A2 vs A3	3	5	3	1	1/3	1,7406
23	A2 vs A4	1	3	1	5	3	1,9471
24	A2 vs A5	5	7	3	3	1	3,2191
25	A3 vs A4	1/3	1	3	5	3	1,3910
26	A3 vs A5	3	5	1	3	1	2,1781
27	A4 vs A5	5	3	1	1/3	3	2,0481
28	A1 vs A2	5	3	1	3	1	2,3430
29	A1 vs A3	7	5	3	5	3	4,5942
30	A1 vs A4	3	1	1/3	5	3	1,9039
31	A1 vs A5	7	5	3	1	5	3,9207
32	A2 vs A3	5	3	3	1	1/3	1,8724
33	A2 vs A4	3	1	1	5	3	2,2780
34	A2 vs A5	7	5	3	3	1	3,3777
35	A3 vs A4	1	1/3	3	5	3	1,6274
36	A3 vs A5	3	5	1	3	1	2,1781
37	A4 vs A5	5	3	1	1/3	3	2,0481

The results of the assessment of all experts in each paired comparison were then combined using the Weighted Geometric Mean method by considering the weight of each expert. This method produces one combined value that represents the group's assessment for each comparison pair. These values are then used as inputs in the preparation of paired comparison matrices in ANP analysis and become the basis for the process of normalization, eigenvector calculation, and consistency testing through Consistency Index (CI) and Consistency Ratio (CR).

Pairing Comparison and Consistency Test

1. Comparison of F1 and F2 Clusters to Goals

A comparison at the goal level was made to determine the level of importance between Cluster F1 (Labor and HR) and Cluster F2 (Management and Planning) in mitigating cost overrun and time overrun. The results of the analysis showed that Cluster F1 had a weight of 0.592, while Cluster F2 was 0.408. This shows that labor and human resources factors have a greater influence than management and planning factors. Because the matrix consists of only two elements, the Consistency Ratio (CR) value is not calculated.

2. Inner Dependence Cluster F1

The analysis of inner dependence in the F1 Cluster aims to determine the priorities between labor and human resources factors. The results showed that A1 (lack of communication and coordination) had the highest weight of 0.313, followed by A2 (lack of labor) of 0.255, A4 (overload) of 0.200, A3 (low labor productivity) of 0.157, and A5 (less than optimal physical condition of labor) of 0.076. A CR value of 0.084 indicates that the assessment results have been consistent.

3. Inner Dependence Cluster F2

An analysis of inner dependence in the F2 Cluster was carried out to determine the priority of factors in the management and planning group. The results showed that A6 (unrealistic cost planning) had the highest weight of 0.514, followed by A7 (inaccurate cost estimate) of 0.282, A8 (rework) of 0.126, and A9 (additional work outside of contract) of 0.079. A CR value of 0.007 indicates that the calculation results have met the consistency requirements.

4. Outer Dependence on A6

An analysis of outer dependence on A6 (unrealistic cost planning) was carried out to determine the influence of labor factors on cost planning. The results of the analysis showed that A1 (lack of communication and coordination) had the greatest influence with a weight of 0.403, followed by A2 (lack of labor) of 0.233, A3 (low productivity) and A4 (overload) of 0.144, respectively, and A5 (physical condition of labor) of 0.076. A CR value of 0.029 indicates that the assessment results have been consistent.

5. Outer Dependence on A7

Analysis of outer dependence on A7 (inaccuracy of cost estimation) showed that A1 (lack of communication and coordination) was again the most influential factor with a weight of 0.406, followed by A2 (labor shortage) of 0.239, A3 (low labor productivity) of 0.144, A4 (overload) of 0.137, and A5 (physical condition of labor) of 0.074. A CR value of 0.043 indicates that the results of the analysis have met the consistency criteria so that they can be used as a basis for determining mitigation priorities.

Unweighted Supermatrix

Table 6. Unweighted Supermatrix

Clusters	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority of Mitigation Factors for Cost and Time Overruns
Cluster F1	0.2650 85	0.3980 94	0.4158 85	0.3856 31	0.0000 00	0.4158 85	0.4197 76	0.0000 00	0.0000 00	0.299370
	0.2868 13	0.2440 26	0.2334 78	0.2452 43	0.0000 00	0.2334 78	0.2364 41	0.0000 00	0.0000 00	0.238919
	0.1426 16	0.1297 73	0.1449 23	0.1548 72	0.0000 00	0.1449 23	0.1487 83	0.0000 00	0.0000 00	0.253017
	0.2255 44	0.1493 98	0.1300 29	0.1329 78	0.0000 00	0.1300 29	0.1180 39	0.0000 00	0.0000 00	0.206894
	0.0799 41	0.0787 09	0.0756 86	0.0839 77	0.0000 00	0.0756 86	0.0769 61	0.0000 00	0.0000 00	0.000000
Cluster F2	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.5139 16	0.5139 16	0.513916
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.2790 99	0.2790 99	0.279099

	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.1174 09	0.1174 09	0.117409
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.0895 77	0.0895 77	0.089577
Goal	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000

Based on the results of processing using Super Decisions 3.2.0 software, an unweighted supermatrix was obtained that contains the local priority weights of each inter-node relationship in the ANP network. The values in the matrix are derived from the eigenvector of paired comparison results that have met the consistency requirements. Each column represents the reference node or parent node, while the value on the row shows the relative weight of the affected node according to the relationship of inner dependence and outer dependence in the model. A value of zero indicates that there is no established influence relationship between the two nodes. Since the weight of the cluster has not been taken into account, the unweighted supermatrix is further used as the basis for the formation of the weighted supermatrix.

Weighted Supermatrix

Table 7. Weighted Supermatrix

Clusters	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority of Mitigation Factors for Cost and Time Overruns
Cluster F1	0.2650 85	0.3980 94	0.4158 85	0.3856 31	0.0000 00	0.4158 85	0.4197 76	0.0000 00	0.0000 00	0.299370
	0.2868 13	0.2440 26	0.2334 78	0.2452 43	0.0000 00	0.2334 78	0.2364 41	0.0000 00	0.0000 00	0.238919
	0.1426 16	0.1297 73	0.1449 23	0.1548 72	0.0000 00	0.1449 23	0.1487 83	0.0000 00	0.0000 00	0.253017
	0.2255 44	0.1493 98	0.1300 29	0.1329 78	0.0000 00	0.1300 29	0.1180 39	0.0000 00	0.0000 00	0.206894
	0.0799 41	0.0787 09	0.0756 86	0.0839 77	0.0000 00	0.0756 86	0.0769 61	0.0000 00	0.0000 00	0.000000
Cluster F2	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.5139 16	0.5139 16	0.513916
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.2790 99	0.2790 99	0.279099
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.1174 09	0.1174 09	0.117409
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.2500 00	0.2500 00	0.0895 77	0.0895 77	0.089577

Goal	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000
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The weighted supermatrix is obtained by multiplying each value on the unweighted supermatrix by the weight of each cluster obtained from the results of the comparison at the Goal level. This weighting process aims to make each column in the supermatrix consider the relative importance of the clusters, so that the matrix becomes stochastic (the sum of each column is equal to one). The weighted supermatrix is then used as the basis for the ranking process until it reaches a convergent condition at the supermatrix limit, which results in the global priority of each mitigation factor.

Limit Supermatrix

Table 8. Limit Supermatrix

Clusters	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority of Mitigation Factors for Cost and Time Overruns
Cluster F1	0.3481 80	0.3481 80	0.3481 80	0.3481 80	0.0000 00	0.3481 80	0.3481 80	0.3481 79	0.3481 79	0.348180
	0.2583 13	0.2583 13	0.2583 13	0.2583 13	0.0000 00	0.2583 13	0.2583 13	0.2583 12	0.2583 12	0.258313
	0.1416 59	0.1416 59	0.1416 59	0.1416 59	0.0000 00	0.1416 59	0.1416 59	0.1416 59	0.1416 59	0.141659
	0.1721 53	0.1721 53	0.1721 53	0.1721 53	0.0000 00	0.1721 53	0.1721 53	0.1721 53	0.1721 53	0.172153
	0.0796 95	0.0796 95	0.0796 95	0.0796 95	0.0000 00	0.0796 95	0.0796 95	0.0796 95	0.0796 95	0.079695
Cluster F2	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000
	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000
Goal	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.0000 00	0.000000

A1 has the highest global priority value of 0.348180 (34.82%), making it the most prioritized mitigation factor. It was followed by A2 with a weight of 0.258313 (25.83%), A4

with a weight of 0.172153 (17.22%), A3 with a weight of 0.141659 (14.17%), and A5 with a weight of 0.079695 (7.97%). The five alternatives are subfactors in the F1 Cluster (Labor and HR) so that they are the main focus in the preparation of mitigation strategies.

Meanwhile, elements A6, A7, A8, and A9 have a value of 0.000000 at the supermatrix limit. This happens because in the built ANP model, the four elements act as control nodes to produce an external dependence relationship to the F1 Cluster, so they are not counted as the final prioritized alternative. Therefore, global priorities are only generated in elements A1-A5 as the main mitigation factors that are the basis for the preparation of cost and time overrun mitigation strategy recommendations for the V25 ambulance construction project.

Global Weights and Priority Factor Rankings

The global weight of the mitigation factor is obtained from the result of the supermatrix limit, which is a condition when the value in the weighted supermatrix has reached convergence after repeated multiplication processes. The value represents the final level of importance of each factor by considering all dependency relationships in the ANP model.

Table 9. Global Weights and Priority Factor Rankings

Code	Factor	Global Weight	Presentase	Peringkat
A1	Lack of communication and coordination between related parties	0,348180	34,82%	1
A2	Shortage of manpower	0,258313	25,83%	2
A4	Overload	0,172153	17,22%	3
A3	Low labor productivity	0,141659	14,17%	4
A5	The physical condition of the workforce is less than optimal	0,079695	7,97%	5
A6	Unrealistic cost planning	0,000000	0,00%	6
A7	Inaccuracies in cost budget estimates	0,000000	0,00%	7
A8	Rework due to work execution errors	0,000000	0,00%	8
A9	Additional requests for items or work outside of contract	0,000000	0,00%	9

Based on Table 9, A1 obtained the highest global weight of 0.348180 or 34.82%, making it the most prioritized factor in mitigating cost overruns and time overruns. The next rank is occupied by A2 by 25.83%, A4 by 17.22%, A3 by 14.17%, and A5 by 7.97%. These results show that communication and coordination, labor adequacy, workload distribution, productivity, and physical condition of the workforce are the main factors that need to be controlled in shipbuilding projects.

Integration of ISM and ANP Results

The ISM results show that A6, i.e. unrealistic cost planning, is at the most basic level and is the main driving factor. This means that weaknesses in cost planning can affect labor needs, productivity, workload, and project execution. Meanwhile, the results of the ANP show that A1, namely the lack of communication and coordination between related parties, has the highest priority. This shows that A1 is the most urgent factor to control in the implementation of the project.

The difference in results does not show any contradiction. A6 is a strategic priority that needs to be improved from the planning stage, while A1 is an operational priority that needs to

be controlled immediately during the implementation of the project. Therefore, mitigation strategies must combine cost planning improvements with strengthening communication and coordination between departments.

CONCLUSION

Based on the results of this study, it can be concluded that the development of a framework for mitigating cost and schedule overruns in the V25 Ambulance Ship construction project successfully identified the key factors contributing to project delays and cost overruns through the integration of Interpretive Structural Modeling (ISM) and the Analytic Network Process (ANP). The results showed that unrealistic cost planning was the primary driving factor, whereas inadequate communication and coordination among relevant parties was the most influential operational factor during project implementation. Based on these findings, the study developed a mitigation framework structured as a risk control cycle comprising risk identification, mitigation implementation, monitoring, effectiveness evaluation, residual risk assessment, and decision-making. The framework was validated by experts and considered feasible for application to shipbuilding projects. Therefore, shipbuilding companies are advised to implement the framework gradually, establish measurable risk indicators, and integrate the framework into their project control systems to effectively minimize the risks of cost and schedule overruns.

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