Optimization of Transportation Mode Selection for EPC Project Logistics Using Analytical Hierarchy Process (AHP): A Case Study of RoRo-Based Inter-Island Material Delivery in Indonesia

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ABSTRACT

Efficient logistics management plays a crucial role in the success of EPC projects, particularly when transporting heavy fabricated components across island regions. This study aims to identify the most optimal transportation mode using the AHP based on six key criteria: cost, lead time, risk, load capacity, flexibility, and port accessibility. A hierarchical decision model was developed and assessed by seven expert respondents, with calculations performed using Expert Choice 11. The results indicate that cost, lead time, and port accessibility hold the highest priority weights, reflecting their strategic importance in EPC logistics. The synthesis of criteria and alternative weights identified Roll-on/Roll-off (RoRo) as the most suitable transportation mode, outperforming cargo ships, barges, LCTs, and truck combinations. Validation using actual project data further confirmed this result: the total delivery cost using RoRo amounted to IDR 1,126,000,000, representing a 22% savings compared to the planned budget, and only 1.66% of the total project cost significantly lower than industry benchmarks of 8–11%. The results confirm that AHP constitutes an effective and reliable approach for transportation mode selection in EPC projects. The study offers actionable managerial insights and advances the application of multi-criteria decision-making in construction logistics.

1. Introduction

In Engineering, Procurement, and Construction (EPC) projects, logistics management is one of the strategic factors that decide the success of construction implementation. Distribution involving large and heavy fabricated components should be done using a mode of transportation capable of guaranteeing timeliness, safety, and cost efficiency. Recent studies reveal that delivery activities in the construction supply chain can contribute up to double-digit percentages of the total project value [1], [2] Being an archipelagic country, Indonesia has limited port access; therefore, sea modes of transportation vary; the selection of transport modes is critical for such logistics management decisions [3].

Although several works have already defined the technical characteristics of sea modes such as RoRo, barges, and cargo ships, most of the prior studies tend to be focused on operational aspects without integrating mathematical evaluation and validation of real project data. Some studies even report that mode selection for EPC projects is often based on practical experience rather than a systematic multi-criteria approach [4], [5] On the other hand, several studies confirm that the cost of construction material distribution can be in the range of 10–18% of the total cost of a project [2], which further strengthens the urgency for a more precise and measurable method for assessing transportation modes.

Analytical Hierarchy Process (AHP) is one of the widely used methods in logistics decision-making, as it is capable of combining qualitative and quantitative data through criteria weighting and pairwise comparisons [6], [7]. The use of AHP in transportation mode selection has been recommended in a number of construction logistics studies [3],[8]. In this study, AHP was applied to evaluate six transportation mode selection criteria relevant to inter-island shipping in EPC projects: cost, lead time, risk, load capacity, flexibility, and port accessibility.

Roll-on/Roll-off (RoRo) vessels represent a critical marine transportation mode for inter-island EPC logistics due to their ability to load and unload wheeled cargo directly through ramps without requiring crane assistance, thereby minimizing rehandling activities and reducing operational risks. This mode is widely recognized for its shorter turnaround time and more predictable schedules compared to barges and cargo ships, which are more affected by tidal conditions, weather, and port equipment limitations. In EPC multisite projects, RoRo offers structural advantages because its rapid loading–unloading process supports synchronized material delivery between fabrication workshops and project sites, reducing delays in installation sequences. Prior studies on EPC logistics also highlight that transportation modes with stable lead times and lower handling risks such as RoRo tend to perform better in maintaining delivery reliability and minimizing cost deviations [3], [4], [9] These characteristics reinforce the relevance of evaluating RoRo as a primary candidate in the transportation mode selection process for this study.

This study has high practical relevance because it assesses transportation modes in a case study of the EPC project related to the delivery of 32 units of fabricated material trucks from Surabaya to Tanah Bumbu. Actual data indicates that, by using RoRo mode, the actual delivery cost is IDR 1,126,000,000, which is 22% lower than the planned budget of IDR 1,444,000,000. Moreover, the contribution of logistics costs added up to only 1.66% of the total value of the project, much less than the industry benchmark of 8–11% [2]. The integration of the AHP analysis results with actual project cost validation therefore brings significant scientific and practical contributions, especially in securing strategic decisions on transportation mode selection for multi-site EPC projects in Indonesia.

In this research, the main goal is on the first level, which is to find the optimal transport mode for the delivery of project EPC fabricated components. On the second level, six relevant criteria were determined based on the literature of project logistics and previous researches in the selection of transportation mode [7], [8]. The six criteria include cost, lead time, tonnage capacity, operational risk, operational flexibility, and port accessibility that are often determining factors in the success of heavy material delivery of inter-island EPC projects. On the third level are five real alternatives of transportation modes used in the project, namely RoRo, general cargo ship, barge, LCT, and truck combination.

2. Method

2.1. AHP Hierarchy Development

The AHP method first involves arranging a hierarchy structure that breaks down the complex problem into more structured decision elements. These include three layers, with the highest level being the goal, middle level the criteria, and the bottom level alternatives to the decision. This approach is within the principles of AHP by Saaty [6], where the hierarchy structure allows the analyst to understand the logical relationship between these elements and then execute an evaluation in a logical and methodical manner.

The development of the Analytical Hierarchy Process (AHP) hierarchy is the foundational stage that structures the decision-making problem into interconnected and measurable components. This

approach is consistent with the principles introduced by Saaty [6] who emphasized that hierarchical decomposition enables decision-makers to evaluate complex systems in a logical and systematic manner. In logistics and supply chain research, hierarchical structuring is widely adopted because it accommodates both qualitative and quantitative considerations within a unified decision model [7].

In this study, the hierarchy is organized into three levels: the decision goal, the evaluation criteria, and the transportation mode alternatives. This hierarchical structure allows the complex decision of selecting the most suitable transportation mode for an EPC project to be broken down into smaller and more manageable analytical elements. Prior studies in EPC logistics have demonstrated that transport mode selection requires a multi-criteria framework that incorporates cost, operational risk, lead time, and technical characteristics of available modes [10], [11] aligning with the structure adopted in this research.

At the highest level, the goal of the hierarchy is defined as "Selecting the Optimal Transportation Mode for EPC Material Delivery." This goal reflects the need to identify the mode that best supports the project's logistical requirements, including cost efficiency, delivery reliability, and operational feasibility.

The second level consists of six evaluation criteria, each representing a critical dimension in transportation mode performance. Cost reflects the total expenditure required for transporting materials, including shipping tariffs, handling charges, and associated logistics expenses. Lead Time captures the total duration required for the shipment to reach the project site, considering sailing schedules, loading–unloading speed, and potential delays. Risk represents the likelihood of damage, delay, or operational disruption due to weather, sea conditions, or the need for multiple handling processes. Load Capacity describes the ability of each transportation mode to accommodate the oversized or heavy fabricated components typical of EPC projects. Flexibility refers to the ease of adjusting schedules, routing, and operational handling to meet dynamic project timelines. Port Accessibility evaluates the availability, suitability, and readiness of port infrastructure to serve each transportation mode, including ramp conditions, crane availability, and berth accessibility. These criteria were selected based on EPC logistics requirements and are consistent with previous research highlighting their significance in maritime transport evaluation [8], [10].

At the third level, the hierarchy includes five transportation mode alternatives evaluated in this study: RoRo, Cargo Vessel, Barge/Tongkang, Landing Craft Tank (LCT), and Truck Combination. These alternatives represent the actual modes available and commonly used for inter-island material delivery in Indonesia's EPC logistics context. Using real, project-based alternatives ensures that the analytical outcomes from the AHP model remain applicable and implementable in practice.

This hierarchical design ensures that the decision structure is comprehensive, logically organized, and reflective of both the operational environment and the specific constraints of EPC supply chain activities. It also enables a systematic comparison across criteria and alternatives, forming the basis for subsequent pairwise evaluations and priority synthesis within the AHP framework.

To illustrate the structure of the decision-making model applied in this study, the complete AHP hierarchy is presented in the following diagram. Constructing the hierarchy is a fundamental step in AHP, as it decomposes complex decisions into a structured set of levels consisting of a goal, criteria, and alternatives—an approach emphasized in the foundational work of Saaty [6]. Recent studies in construction and logistics further highlight the importance of a clear hierarchical structure when applying AHP for transportation mode evaluation, particularly within multi-criteria and multi-constraint environments [7], [12]. The hierarchy below visualizes these elements and establishes the analytical foundation for subsequent pairwise comparisons.
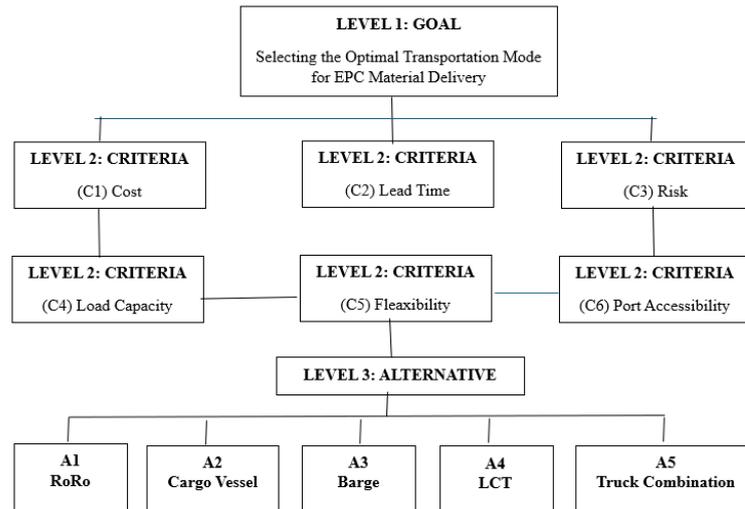
This hierarchical structure ensures that each decision component is logically organized along three levels and can be evaluated systematically through the AHP framework. Such hierarchical decomposition supports consistent comparisons and accurate priority synthesis, as recommended in the analytical procedures.

2.2. Pairwise Comparison of Criteria

After the hierarchical structure was established, the next step involved conducting pairwise comparisons between the criteria. Assessments were made using Saaty's fundamental 1–9 scale to determine the intensity of relative preference between elements. A total of seven expert respondents participated in completing the questionnaire, consisting of professionals in logistics, planning, and project management, all of whom had direct experience in selecting transportation modes for EPC projects. This multi-respondent approach aligns with recommendations in the literature to obtain more stable and representative aggregate weights [8].

All pairwise comparison values were processed using the Expert Choice 11 software, which automatically calculates eigenvector values to generate the priority weights of each criterion. The software also computes the Consistency Index (CI) and Consistency Ratio (CR) to ensure the mathematical validity of the assessments.

Where RI represents the Random Index corresponding to the matrix size [6]. A CR value ≤ 0.1 indicates acceptable consistency. Table 1 presents the pairwise comparison matrix of criteria completed by the respondents, which serves as the fundamental input for calculating the criteria weights.

Table 1.   Matrix Pairwise Comparison of Criteria

Criteria	Cost	Lead Time	Capacity	Risk	Flexibility	Acces
Cost	1.00	1.33	2.55	2.33	2.15	1.87
Lead Time	0.75	1.00	1.91	1.75	1.62	1.40
Capacity	0.39	0.52	1.00	0.92	0.85	0.73
Risk	0.43	0.57	1.09	1.00	0.92	0.80
Flexibility	0.46	0.62	1.18	1.08	1.00	0.87
Acces	0.54	0.71	1.36	1.25	1.15	1.00

The results of the pairwise comparison indicate that cost holds the highest priority weight, followed by lead time and port accessibility. In contrast, flexibility, risk, and load capacity received lower weights, although they still contribute to the decision-making process. This distribution of weights suggests that the respondents perceive cost efficiency and timeliness as the dominant factors in the delivery of materials for EPC projects—an insight consistent with findings from construction logistics research that emphasize the importance of time reliability and cost control in multi-site projects [13].

2.3. Alternative Evaluation (Mode of Transport)

The evaluation of alternatives was conducted to determine the priority ranking of each transportation mode based on the criteria weights obtained in the previous stage. At this point, each alternative was assessed through pairwise comparisons within the context of each criterion, using the same Saaty scale. The evaluation process was carried out by seven expert respondents, and all data were reprocessed using Expert Choice 11 to ensure computational consistency.

The calculation of alternative priorities followed matrix normalization procedures and the computation of local weights for each alternative under every criterion. These local weights were subsequently combined with the corresponding criteria weights through a synthesis process using the formula:

$$Global\ Priority = \sum_{i=1}^{n}(W_i \times A_i) \tag{1}$$

where W_i represents the weight of the i-th criterion and A_i denotes the weight of the alternative under the i-th criterion

Table 2 below presents the alternative weights for each criterion, which serve as the basis for calculating the global priority of transportation modes:

Table 2.   Alternative Weights per Criterion

Mode of Transport	Cost	Lead Time	Risk	Flexibility	Capacity	Accesibility
RoRo (Roll On Roll Off)	0,35	0,6	0,5	0,23	0,23	0,5
Cargo Ship	0,19	0,19	0,21	0,23	0,31	0,23
Barge	0,33	0,09	0,16	0,14	0,38	0,1
LCT (Landing Craft Tank)	0,1	0,09	0,1	0,16	0,05	0,14
Truck Combination	0,03	0,03	0,03	0,24	0,03	0,03

Table 2 displays the normalized local weights for each transportation mode, ensuring that the total weight per criterion equals 1, in accordance with AHP principles [6]. The RoRo mode obtained the highest weights in the criteria of cost, lead time, risk, capacity, and accessibility, indicating its superior suitability for EPC material delivery needs. This finding is consistent with prior studies on inter-island marine transport modes [3], [8].

Cargo ships and barges demonstrated relatively higher weights in capacity but scored lower in lead time and risk, reflecting existing research which highlights the time variability of these modes due to weather and port conditions [4]. LCTs and truck combinations received lower weights across most criteria, supporting findings that land–sea multimodal transport tends to pose greater risks related to time uncertainty and material handling [12].

To provide a clearer visualization of how each transportation mode performs across the six evaluation criteria, the alternative weights generated from the AHP model are illustrated in the following chart. This graphical representation allows for an intuitive comparison of strengths and weaknesses among all modes.
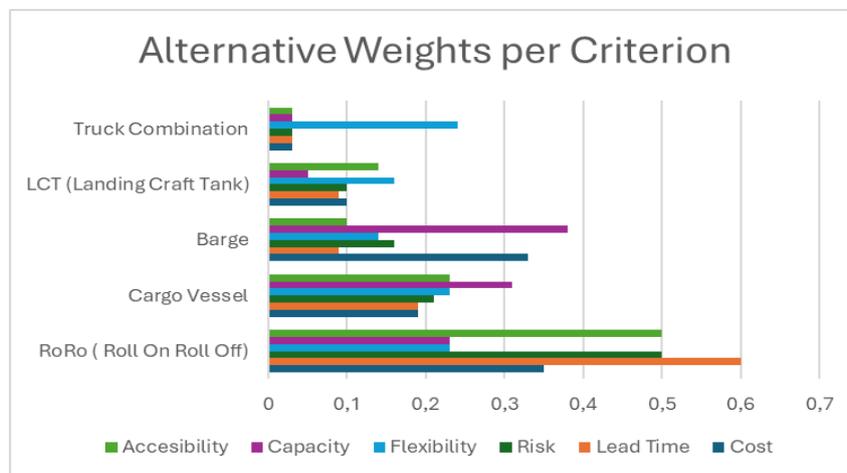
The chart demonstrates that RoRo consistently achieves the highest weights across the majority of criteria, particularly in lead time, risk, and accessibility, confirming its dominant position in the AHP evaluation. Cargo ships and barges show competitive performance on specific dimensions—cargo ships on capacity and barges on cost—yet neither surpasses RoRo in overall balance. LCT exhibits moderate performance, with relatively lower values on capacity and risk, while the truck combination alternative receives the lowest weights across all criteria, reflecting its limited suitability for long-distance inter-island material delivery. These patterns reinforce the numerical results presented earlier, highlighting that RoRo provides the most favorable trade-off among operational efficiency, reliability, and logistical feasibility for EPC material transport.

3. Results and Discussion

This section presents the analytical results derived from the AHP model and discusses their alignment with actual project performance. The results are organized into criteria-weight analysis, alternative priority ranking, and validation using real delivery cost data, followed by a discussion that connects the findings to existing literature and practical implications for EPC logistics.

3.1. AHP Criteria Weights

The pairwise comparison analysis of the six criteria produced priority weights that reflect the relative importance of each criterion in selecting transportation modes. The results processed using Expert Choice 11 indicate that the cost criterion (0.28) is the most dominant factor, followed by lead time (0.21) and port accessibility (0.15). The dominance of these three criteria aligns with previous research findings, which emphasize that cost efficiency, timeliness, and port infrastructure readiness are the most critical factors in transportation mode selection for construction and EPC projects [1], [2].

Meanwhile, flexibility (0.13), operational risk (0.12), and load capacity (0.11) ranked next in priority. These values are consistent with earlier studies that highlight operational risk and transport capacity as important, yet secondary, considerations—particularly in projects with tight deadlines that require delivery stability [3], [4].

The Consistency Ratio (CR) value of 0.07 indicates that the respondents' judgments fall within an acceptable consistency threshold. Therefore, the pairwise comparison matrix satisfies the AHP validity requirements as recommended by Saaty [6]. These findings support the characteristics of EPC projects, which are highly sensitive to time and cost deviations and thus demand transportation modes that excel in schedule reliability and delivery stability [5].

3.2. Priority Ranking of Transportation Mode Alternatives

The evaluation of five transportation mode alternatives was conducted across all criteria within the AHP model. The synthesis of criteria weights and local alternative weights resulted in the global priority scores presented in Table iii. This synthesis process adheres to the conventional AHP methodology commonly applied in transportation mode evaluations for construction and EPC projects [1], [2].

Table 3.   Global Priority Weights of Transportation Mode Alternatives

Transportation Mode	Priority Weight
RoRo	0.402
Cargo Ship	0.222
Barge	0.212
LCT	0.113
Truck Combination	0.051

These results affirm that the RoRo mode is the most suitable for the characteristics of EPC projects, primarily due to its reliability in transporting large loads, shorter delivery times, and minimal additional handling processes. This finding aligns with previous studies which emphasize that RoRo offers superior time stability and material safety in inter-island freight transportation [3], [4].

Cargo ships and barges ranked in the middle range. Although both offer high load capacity, they underperform in terms of lead time and are more sensitive to weather and port conditions. This is

consistent with studies showing that cargo and barge modes experience significant time variability due to tidal conditions and crane limitations at certain ports [5].

On the other hand, LCTs and truck combinations received the lowest priority scores due to technical limitations related to load stability, carrying capacity, and high variability in delivery times caused by multimodal transfers. These findings are in line with the literature stating that land–sea multimodal transport modes pose greater risks of material damage and higher uncertainty in delivery schedules compared to direct marine transport [11].

3.3. Validation of Mode Selection Using Actual Project Data

The validity of the AHP results was tested by comparing the transportation mode priority rankings against the actual project implementation data. The project involved the transportation of 32 trucks comprising 17 trailers and 15 medium-duty (Fuso) trucks with a total load of approximately 725 tons. All deliveries were conducted using the RoRo (Roll-on/Roll-off) mode, in combination with land transportation to reach the project site. The selection of RoRo as the actual transportation mode served as a reference point to assess the alignment between the AHP results and real-world application.

The total delivery cost allocated in the initial project budget (RAB) was IDR 1,444,000,000, while the actual cost incurred amounted to IDR 1,126,000,000 resulting in a cost efficiency of approximately 22% compared to the original budget. When compared to the total project value, the logistics cost accounted for only 1.66%, which is significantly lower than figures reported in previous studies. Literature indicates that logistics costs in construction and EPC projects typically range between 8–11% of total project value [1], [2].

The gap between this benchmark range and the actual project outcome indicates that the RoRo mode identified as the optimal choice through AHP modeling was not only mathematically superior but also operationally effective. The observed cost efficiency supports previous research findings which assert that RoRo provides scheduling stability, lower handling risks, and high suitability for transporting heavy materials across islands [3], [4].These results further reinforce the validity of the AHP method as a reliable tool for evaluating transportation modes in the context of EPC projects.

3.4. Discussion

The results of the AHP analysis indicate that the RoRo mode holds the highest global priority weight and is the most appropriate option for the logistics needs of EPC projects. RoRo's dominance in five out of six key criteria—cost, lead time, risk, load capacity, and accessibility—reflects its superior characteristics in schedule stability and minimal rehandling requirements, as also described in the studies by Sihombing [3] and Hasan [4]. RoRo operations are typically supported by major ports with higher operational standards, which enable shorter and more consistent travel times compared to other sea-based modes.

Cargo ships and barges ranked in the middle according to the AHP results. While both modes offer high load capacity, their efficiency is heavily influenced by tidal conditions and the availability of unloading equipment. The study by Santika et al. [5] highlighted the high variability in travel time associated with barge operations, as they are highly dependent on weather conditions and wave stability. Similarly, Fitrianto et al. [8] reported that transportation modes reliant on port infrastructure are at greater risk of experiencing significant delays in large-scale construction projects.

LCT and truck combinations received the lowest weights due to limitations in load capacity and the high risk associated with mode transfers (i.e., multimodal handling). Usman and Fariz [14] emphasized that land–sea multimodal transportation systems tend to have higher risks of material damage and greater delivery time uncertainty compared to direct marine modes. These findings align with the AHP results, which indicate that these two modes do not adequately meet the logistical requirements for transporting heavy materials in EPC projects.

The validity of the AHP results is reinforced by actual project data, which show that the use of RoRo transportation resulted in significant cost savings. The actual delivery cost totaled IDR 1,126,000,000—representing a 22% reduction from the budgeted cost of IDR 1,444,000,000. When compared to the total project value, the logistics cost accounted for only 1.66%, which is considerably lower than the industry benchmarks reported by Lakshana and Judson [2], as well as

Jayaruwan et al. [1], who found that logistics costs in construction projects typically range between 8–11% of total project value. This discrepancy suggests that RoRo is not only mathematically optimal based on the AHP model but also delivers substantial operational efficiency.

The consistency between the AHP results, empirical project findings, and prior literature confirms that AHP is an effective tool for supporting strategic decision-making in transportation mode selection for EPC projects. Related research by Hafni and Wibowo [15] on the integration of AHP and logistics performance also concluded that multi-criteria decision-making methods are capable of capturing the complexities of material distribution in large-scale projects with a high degree of accuracy. Accordingly, the findings of this study reaffirm that RoRo is the most suitable transportation mode for supporting the efficient distribution of construction materials across islands.

4. Conclusion

This study applied the Analytical Hierarchy Process (AHP) method to determine the most optimal transportation mode for the distribution of materials in an EPC project. The analysis revealed that cost, lead time, and port accessibility are the most influential criteria in the decision-making process. The synthesis of criteria and alternative weights identified the RoRo (Roll-on/Roll-off) mode as the best option, achieving the highest global priority score compared to cargo ships, barges, LCTs, and truck combinations. This finding is consistent with the technical characteristics of RoRo, which offers schedule stability, shorter transit times, and minimal rehandling—making it more suitable for the delivery of large-scale fabricated components in EPC projects.

The validity of the AHP results was further supported by actual project data. The use of RoRo resulted in a delivery cost of IDR 1,126,000,000, which was 22% lower than the planned budget and represented only 1.66% of the total project value. This figure is significantly below the average logistics cost reported in the literature, which ranges from 8–11% of the total project value. This demonstrates that the selection of RoRo was not only optimal in mathematical terms but also operationally efficient. The consistency between the AHP-based evaluation and actual project performance confirms that the method is capable of capturing the complexity of transportation mode assessment in EPC projects with a high degree of accuracy.

This research contributes to the advancement of multi-criteria decision-making models in construction project logistics, particularly for inter-island material distribution contexts. Furthermore, the findings offer practical insights for project managers in selecting transportation modes that are efficient, reliable, and aligned with the operational conditions of EPC projects. Future studies are encouraged to integrate additional factors such as weather variability, route simulation, or dynamic cost analysis to enhance the model's ability to reflect more complex and dynamic operational conditions.

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