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Comparative Analysis and Selection Based on AHP and Threshold Switching for LNG Crew Transportation in Remote Areas (Case Study: PT. XYZ Sorong, West Papua)

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ABSTRACT

Crew transportation plays a crucial role in ensuring the smooth operation of the Liquid Natural Gas (LNG) facility in West Papua. Current transportation relies on a combination of Dash 8 aircraft from Sorong to Babo, followed by small vessels to the LNG site. The challenges faced include dependence on weather conditions and ground infrastructure, which pose operational risks. This study aims to evaluate the effectiveness of the Fast Cruising Vessel (FCV) mode as a more efficient and reliable alternative for crew transportation. A descriptive-comparative method was used with the Analytic Hierarchy Process (AHP) approach and supported by a cost-efficiency threshold switching analysis. The assessment was conducted on eight main criteria, including travel time, cost, capacity, risk, comfort, flexibility, and infrastructure requirements. Data were obtained from technical documents and questionnaires from energy logistics practitioners. The AHP results showed that the FCV Damen Fast Ferry 4212 had the highest score (0.309), while the threshold switching calculation showed that the FCV mode resulted in cost savings of more than 80%, far exceeding the 25% threshold for modal shift feasibility. With minimal port infrastructure requirements and high flexibility, the FCV mode is considered the most technically, economically, and operationally feasible to support LNG crew rotations in remote areas. This study contributes to decision-making regarding maritime logistics strategies in remote areas, recommending FCVs as an efficient and reliable solution.

Keywords: Fast Cruising Vessel, AHP, crew transportation, descriptive-comparative method, transportation costs

ABSTRAK

Transportasi awak kapal memainkan peran krusial dalam memastikan kelancaran operasional fasilitas Gas Alam Cair (LNG) di Papua Barat. Transportasi saat ini bergantung pada kombinasi pesawat Dash 8 dari Sorong ke Babo, diikuti oleh kapal-kapal kecil ke lokasi LNG. Tantangan yang dihadapi termasuk ketergantungan pada kondisi cuaca dan infrastruktur darat, yang menimbulkan risiko operasional. Studi ini bertujuan untuk mengevaluasi efektivitas moda *Fast Cruising Vessel* (FCV) sebagai alternatif yang lebih efisien dan andal untuk transportasi awak kapal. Metode deskriptif-komparatif digunakan dengan pendekatan *Analytic Hierarchy Process* (AHP) dan didukung oleh analisis peralihan ambang batas efisiensi biaya. Penilaian dilakukan pada delapan kriteria utama, termasuk waktu tempuh, biaya, kapasitas, risiko, kenyamanan, fleksibilitas, dan persyaratan infrastruktur. Data diperoleh dari dokumen teknis dan kuesioner dari praktisi logistik energi. Hasil AHP menunjukkan bahwa FCV Damen Fast Ferry 4212 memiliki skor tertinggi (0,309), sementara perhitungan ambang batas perpindahan menunjukkan bahwa moda FCV menghasilkan penghematan biaya lebih dari 80%, jauh melebihi ambang batas 25% untuk kelayakan perpindahan moda. Dengan persyaratan infrastruktur pelabuhan yang minimal dan fleksibilitas yang tinggi, moda FCV dianggap paling layak secara teknis, ekonomis, dan operasional untuk mendukung rotasi awak LNG di daerah terpencil. Studi ini berkontribusi pada pengambilan keputusan terkait strategi logistik maritim di daerah terpencil, merekomendasikan FCV sebagai solusi yang efisien dan andal.

Kata Kunci: *Fast Cruising Vessel*, AHP, transportasi awak kapal, metode deskriptif-komparatif, transportation costs

1. Introduction

PT. XYZ LNG is one of Indonesia's national strategic energy projects located in Bay, West Papua. As a liquefied natural gas processing facility, **XYX** LNG's smooth operations depend heavily on successful crew changes from Sorong to the LNG site. Currently, the transportation system relies on a combination of Dash 8 aircraft from Sorong to Babo, followed by a sea journey by small vessel from Babo to **XYX** LNG. However, this multimodal system faces various challenges, such as dependence on weather conditions, vulnerability to runway disruptions at Babo Airport, and the risk of sea weather during small vessel travel. With increasing flight frequency, higher operational requirements, and efforts to optimize logistics, the alternative of using a Fast Cruising Vessel (FCV) directly from Sorong to XYZ LNG is being considered.

Comparing these modes is crucial, given their strategic implications for operational costs, crew rotation effectiveness, and the overall reliability of the LNG logistics system. Therefore, simulation-based research is needed to evaluate the effectiveness and efficiency of these two alternative transportation modes. Crew rotation refers to the process of changing crew members, characterized by the arrival of new crew members and the departure of existing crew members. The importance of crew rotation is to maintain crew health and safety, ensure operational continuity and consistency, ensure compliance with regulations and employment contracts, and increase employee loyalty and retention. Maintaining crew health and safety is one of the primary objectives of implementing a rotation system. The crew rotation process aims to prevent work fatigue that can endanger personnel and operational safety, making work rotation arrangements crucial (Hakola et al., 2021; Tait et al., 2021).

Ensuring operational continuity and consistency is another important reason for implementing a work rotation system. Offshore workforce productivity is significantly influenced by the work-rest cycle. Structured work rotation can increase work efficiency compared to a long-shift model without shifts. Furthermore, shift rotation supports operational continuity through the implementation of a handover process, transfer reports, and maintenance of work documentation. A rotation system enables operational continuity by maintaining documented task transitions between outgoing and incoming shifts (Ghosh et al., 2021; Hakola et al., 2021). Ensuring compliance with regulations and employment contract provisions is a crucial aspect of implementing a crew rotation system. BP, SKK Migas, and collective labor contracts regulate maximum working hours in the field. Organizations that do not implement job rotation in heavy industry show a 31% increase in labor violations. Compliance with rotation reflects adherence to labor laws, including workers' right to rest (Nieuwenhuijsen, 2003).

Increasing employee loyalty and retention is another benefit of implementing a job rotation system. From an organizational psychology perspective, a fair rotation system creates a sense of appreciation and reduces chronic stress levels. Research by Hofmann & Stetzer (1996) shows that implementing a rotation scheme increases job satisfaction and reduces employee intention to resign by up to 22%. A crew rotation scheme is a strategy for retaining qualified employees and building a healthy organizational culture (Hofmann & Stetzer, 1996). Factors such as travel time, operational costs, and the risk of choosing between sea and air transportation are parameters in this evaluation. Long travel times can cause crew fatigue, while operational costs and risks due to weather and natural conditions are important considerations in selecting the most effective mode of transportation. Based on this background, the research questions are as follows: first how does the performance of the Dash 8 + small vessel and Fast Cruising Vessel (FCV) compare based on travel time, operational costs, cost per passenger, carrying capacity, weather risk and stability, infrastructure requirements, crew comfort, and operational flexibility?. Second which transportation mode is most optimal for PT. **XYZ** LNG crew rotation based on evaluation results using the Analytic Hierarchy Process (AHP) method?.

The objectives of research are analyze and compare the effectiveness of two alternative **PT. XYX** LNG crew transportation modes, namely the Dash 8 + small vessel and the Fast Cruising Vessel (FCV), based on eight main evaluation criteria. Second conduct a mode priority evaluation using the Analytic Hierarchy Process (AHP) method to determine the most optimal transportation mode for PT. **XYX** LNG crew rotation needs. There are several research benefits such as provide a basis for consideration for **PT. XYX** LNG management in selecting the most optimal crew transportation mode based on quantitative analysis and the Analytic Hierarchy Process (AHP) method. And then support efficient and reliable crew logistics planning in remote areas, and provide implementable recommendations for the use of alternative maritime modes. And Finally serve as an academic and practical reference in multi-criteria-based transportation mode evaluation studies in the energy logistics sector, particularly in remote areas of Indonesia.

This research has several limitations, as follows: first the study only compares two alternative transportation modes: a combination of the Dash 8+ small vessel and a Fast Cruising Vessel (FCV). Next limitation is the FCVs being compared are catamarans, not monohulls or trimarans. Third, other transportation modes, such as helicopters or slow vessels, are not discussed within the scope of this research. Fourthsimulations are conducted based on operational estimation data assuming normal weather conditions in the West Papua region. And finally, the technical aspects analyzed are limited to travel time, operational costs, transport capacity, and the main risks directly related to crew transportation operations.

2. Literature Review

2.1 Logistics Transportation and Multimodal Systems

Multimodal transportation is a transportation system that combines two or more modes in an integrated manner in a single journey from the point of origin to the final destination (Rodrigue et al., 2016). Mixed or multimodal transportation is delivery by various kinds of transport: sea, road, rail or air transportation of goods in any combination. The main purpose of using multimodal transport is to reduce time and or costs in consideration of infrastructure availability. A distinctive feature of this type of transportation is the presence of a single organizational, controlling and coordinating center of the transport company (Makarova et al., 2023). It includes intermodal transportation (where the load is transported from an origin to a destination in one and the same intermodal transportation unit without the goods themselves being handled when changing modes) and combined transport (intermodal transportation of goods where the major part of the journey is by rail, inland waterway or sea and any initial and/or final leg carried out by road is as short as possible (Elbert et al., 2020).

In recent years, there has been growing attention to model and solve fleet planning problems in intermodal transportation networks. Because of environmental sensitivity as well as the overall efficiency obtained from the usage of multiple modes of transport, intermodal transportation has become a hot research topic for both practitioners and researchers in the global logistics sector (Baykasoğlu et al., 2019). Rodrigue et al. (2016) emphasizes that the trade-off between travel time, operational costs, and risk must be considered when selecting modes. The fastest mode isn't necessarily the most cost-efficient, and the cheapest mode can be less reliable if frequently disrupted by weather or technical issues. In the context of the LNG supply chain, multimodal transportation serves not only as a means of moving people or goods, but also as a strategic element supporting operational continuity. The selection and evaluation of appropriate modes will directly impact crew rotation efficiency, control logistics costs, and reduce operational risk in remote areas like **PT. XYZ**.

In practice, multimodal transportation is often used in areas with limited direct connectivity where infrastructure development is hard. For example, Makarova et al. (2023) details the implementation of multimodal transportation in the Russian Arctic, which shows that an integrated multimodal corridor is very important in supporting the region's development and utilize its mineral resources. Similarly, Frank et al. (2021) studied the implementation of hubs to aid multimodal transportation in sparse rural areas with a lacking transportation system where the results shows that there is indeed an improvements in accessibility, though the increase is limited when also considering unimodal methods.

Another example is a study by Banick et al. (2021) which takes into account multimodality in the developing world context, that is, Nepal's remote, mountainous Karnali province, when charting out accessibility. This last one is particularly relevant to this research's context, as West Papua have many high mountains and large tracts of uncut tropical rain forests and is one of the least populated areas in Indonesia (Fenner, 2019). In areas like West Papua, where **PT. XYZ** LNG is located, multimodal transportation typically involves flights to an intermediate airport like Babo, followed by sea transportation to the main site. This approach is relevant given the challenging geographic conditions and limited land transportation infrastructure. In a multimodal system, it is important to consider interchange efficiency, physical and operational compatibility, and overall system reliability (Conticelli et al., 2021; Y.-K. Lin et al., 2022; Sipetas et al., 2024). Collectively, these studies highlight that multimodal transportation plays a critical role in ensuring connectivity in geographically challenging and sparsely populated areas. However, they also reveal that its efficiency and accessibility gains are highly sensitive to local infrastructural constraints and the coordination between transport modes. Thus, it can be inferred that multimodal transportation isn't necessarily a generalized model of improvements as many previous research studies have implied (Ahlan et al., 2024; Aparicio et al., 2022; Binsfeld et al., 2025; Elbert et al., 2020; Reis et al., 2013; Seifi et al., 2014; Singh et al., 2024).

However, despite the increasing popularity of multimodal transport and the amount of study incorporating it, multiple studies show that in many real-world contexts its theoretical benefits are offset by transfer costs, delays, regulatory/coordination complexity, or weak infrastructure. For example, Zgonc et al. (2019) shows that unimodal road transport can be more efficient than intermodal options for shorter haul distances because of drayage cost. Similarly, the unimodal delivery scheme is more predictable, as the number of constituent elements in it is smaller than in the multimodal system. It is one of its major advantages (Rossolov et al., 2017). Multimodal systems are also not as simple as adding another mode of transport into the network. Karam et al. (2023) has found that without proper preparations and infrastructure that address the barriers related to multimodal systems, it is very possible that unimodal systems are more efficient. It also needs to be noted that most of the advantages found in multimodal systems studies, such as the one mentioned above, are found when rail transport is involved in some ways, which is not the case in this study. These findings support the idea that in some settings (especially remote or with limited infrastructure), unimodal systems may offer better reliability, lower overhead, and higher operational simplicity.

2.2 Crew Transportation Modes in the LNG Industry

Crew transportation refers to the planning, arrangements, and execution of moving personnel (crew members) from their home or base to duty locations (and back), between duty segments, or between assignments, including the associated logistical, regulatory, time, and cost considerations. It often includes non-working travel (deadheading), accommodation, regulatory constraints (rest times, certifications), and scheduling requirements (Al-Mekhlafi et al., 2021; El-Thalji, 2024; D.-Y. Lin & Tsai, 2019; Wen et al., 2021). Crew transportation plays a crucial role in maintaining the smooth operation of LNG projects, especially in remote areas like **PT. XYZ** LNG in West Papua. Reliable transportation directly impacts logistical efficiency, work productivity, safety, and project operational costs (Al-Mekhlafi et al., 2021; Radwanski & Rutkowski, 2022). In large-scale projects with rotational staffing systems, timely crew change is essential for maintaining production continuity. Transportation disruptions such as flight cancellations, vessel unavailability, or weather-related delays can cause cascading operational downtime, particularly when specialized technical personnel are involved (Graham, 2010). In offshore and remote energy industries, even short disruptions in crew mobility or negative effects towards crew conditions caused by transportation have been reported to increase overtime costs, reduce maintenance efficiency, and elevate safety risks due to worker fatigue or overextension (Aria et al., 2024; Hystad et al., 2013; Redutskiy et al., 2022). These challenges highlight that crew transportation is not merely a logistical task but a strategic component of operational reliability, where the choice of mode directly affects the project's cost structure and risk exposure.

Geographical challenges such as difficult-to-access terrain, extreme weather, and limited infrastructure (runways, docks, vessels) require that transportation mode selection consider reliability, punctuality, and safety (Gössling et al., 2023; Rodrigue et al., 2016; Zhang et al., 2021). At **PT. XYZ** LNG, commonly used modes include chartered aircraft (Dash 8), Fast Crew Vessels (FCVs), and multimodal (air-sea) combinations. Each mode has advantages and limitations depending on the weather, travel time, and capacity. Multimodal transportation, for example, is often time-efficient but relies on more infrastructure. Furthermore, crew comfort is also a crucial consideration. Less comfortable modes can cause fatigue and reduce work readiness. Phillips et al. (2017) emphasized that travel fatigue impacts safety and productivity. Given these challenges, the selection of crew transportation modes in the LNG industry must consider the balance between technical efficiency, infrastructure readiness, and overall crew working conditions.

2.3 Transportation Mode Evaluation Criteria

Crew transportation plays a crucial role in maintaining the operational continuity of LNG projects, particularly in remote areas like **PT. XYZ** LNG. This is because transportation systems can increase the productivity and quality of life at the same time if they are planned and managed properly (Tuzkaya, 2009). Reliable transportation is essential to ensure smooth crew rotations, maintain efficiency, and avoid downtime due to delays or disruptions during crew changes (Bailey et al., 2017; Chen & Huang, 2018). Transportation in crew rotations isn't as simple as moving people or goods from point A to point B, but also have to take into accounts other additional factors such as the crew's working hours, rest periods, crew roles, availability, worker health, types of contract and payment, as well as influence of weather and forecast-uncertainty (Rippel et al., 2021). When designing a crew transportation system, several key components must be evaluated: cost, travel time, carrying capacity, operational risk, and crew comfort. The choice of transportation mode should balance technical aspects with user experience. Costs include direct costs (such as mode rental, fuel, crew salaries) and indirect costs (such as reduced productivity due to rotation delays) (Fale et al., 2025). Cost evaluations should reflect their impact on the overall efficiency of the operation (Sinha & Labi, 2007). Meanwhile, travel time and schedule accuracy are crucial factors in supporting a consistent work cycle, as even the fastest mode can become inefficient if frequently delayed (Rodrigue et al., 2016). These criteria represent a balance between technical efficiency and human-centered considerations that needs to be addressed in the micro operational priorities and the macro managerial priorities.

Cost encompasses both direct expenses, such as charter fees, vessel costs, fuel, and personnel, and indirect impacts, including productivity losses from rotation delays or inefficient scheduling. This is because the most cost efficient decisions are associated with the biggest risks. Conversely, the safest decisions require the highest investments/costs (Dalgic et al., 2015). Travel time and schedule reliability directly influence project continuity, even fast modes may become inefficient when prone to delay or cancellation (Krüger & Vierth, 2015). Carrying capacity affects both the scalability and resilience of crew rotation systems, particularly when limited transport frequency magnifies the importance of per-trip efficiency (Dalgic et al., 2015; Wei et al., 2022). Operational risk involves exposure to disruptions caused by adverse weather, maintenance schedules, or intermodal transfers in multimodal systems. Each added transfer point increases complexity and potential for failure, a concern particularly acute in remote operations where contingency options are limited (Radwanski & Rutkowski, 2022; Zheng et al., 2021) . Finally, crew comfort is vital for sustaining safety and productivity (Aria et al., 2024). Extended travel under uncomfortable conditions can cause fatigue and reduce post-arrival performance. Specifically for sea transport, this can be caused by the vibration, noise, and movement of the ship (Rüpke & Athanassiou, 2024). Recent studies have confirmed that user-oriented criteria such as comfort, flexibility, and perceived reliability are very important in mode selection for the users themselves, which could have an effect on the larger managerial decisions (Hansson et al., 2019; Hu et al., 2015; Vledder et al., 2023).

In terms of operational risk related to transportation mode choice in air-sea transportation in remote areas, some common challenges include: bad weather disrupting flights, airport runway maintenance, disruptions to sea travel due to high waves, and the complexity of changing modes in a multimodal system (Fabiano et al., 2004). Reliance on more than one mode on a single route also increases the likelihood of logistical failure. Crew comfort is equally important. Noisy, unergonomic, or excessively long modes of transportation can cause physical and psychological fatigue, impacting safety and productivity (Phillips et al., 2017). Sekmen et al. (2023) used AHP to analyze user preferences for various transportation modes in urban areas, confirming that criteria such as comfort and flexibility are highly influential in the mode decision-making process. These variables were selected as the basis for evaluation based on the practical and operational considerations that most influence the success of crew rotations. Cost and time reflect logistical efficiency, capacity reflects the carrying capacity per trip, while risk and comfort reflect sustainability and safety aspects in field implementation. By systematically evaluating all these components, companies can design transportation modes that are more optimal, efficient, and suited to the geographical and operational challenges in LNG areas such as **PT. XYZ**.

2.4 Alternative Modes of Transportation

2.4.1 Dash 8 mode + Small ship

The current mode of transportation used for **PT. XYZ** LNG crew rotation is a multi-modal system that combines flights on a Dash 8 aircraft from Sorong to Babo, followed by a sea journey on a small boat to the LNG site. The Dash 8 is a turboprop aircraft with a capacity of 37–70 passengers, designed for short-haul routes and small airports. The small boats used have a limited capacity of around 15–20 passengers per trip. The main advantage of this mode is the overall speed of travel, as flights are relatively short and sea connections only last about an hour. However, this mode is highly dependent on infrastructure, particularly the Babo Airport runway, which is frequently disrupted by weather or maintenance. Furthermore, switching from air to sea increases logistical and operational risks, particularly in adverse weather conditions.

2.4.2 Fast Cruising Vessel (FCV) Mode

Fast Cruising Vessel (FCV) FCVs are medium- to large-capacity fast vessels designed for medium-distance direct ocean voyages and are often used for passenger ferries, crew rotations, or rapid logistics in archipelagic regions. In the context of the **PT. XYZ** LNG project, FCVs are a strategic alternative to replace the current multimodal (air-sea) transportation system, with the aim of simplifying routes, increasing capacity, and reducing reliance on air infrastructure. A single mode reduces logistical complexity compared to combined modes (Archetti et al., 2022). The main advantages of FCVs lie in direct connectivity (single-mode), operational cost efficiency, and greater carrying capacity. FCVs also offer scheduling flexibility because they are not dependent on airports or flight slots. However, the main limitation of this mode is its sensitivity to sea conditions, particularly high waves above 2.5 meters, which can cause delays or cancellations.

The FCV discussed here is a catamaran hull. A catamaran hull is a vessel with two parallel hulls connected by a main deck. Besides catamarans, there are other hull types, namely monohulls and trimarans, which consist of one main hull and two side hulls. Matthews et al. (2024) showed that catamarans have better stability in medium sea conditions, while Samuel et al. (2015) noted that catamarans have lower water resistance than monohulls, contributing to fuel efficiency and greater passenger comfort due to better stability. Meanwhile, research conducted by Tupan and Luhulima (2021) concluded that trimarans have the lowest drag compared to catamarans and monohulls. Furthermore, trimarans also have the lowest fuel consumption after catamarans and monohulls.

1. Damen Fast Ferry 4212
The FCV used as the main reference in this study is the Damen Fast Ferry 4212, made by Damen Shipyards Group (Netherlands). This aluminum vessel has a length (Length Overall) of 42.2 meters, a width (Breadth) of 11.6 meters, a depth (Draught) of 1.5 meters, with a maximum speed of up to 40 knots. The technical passenger capacity reaches 450 people, but in the **PT. XYX** LNG operational scenario it is only maximized to around 50-60 crew per trip to maintain comfort and space efficiency. The advantages of the Damen FF 4212 include high stability in the open sea, large carrying capacity with a modular design, suitable for small ports such as Sorong and LNG Jetty, relatively efficient fuel consumption and operational costs.

2. Incat Wave Piercing Catamaran Hull 090
Incat is an Australian manufacturer known for its high-speed wave-piercing catamaran designs. The Incat hull 090 has a length (Length Overall) of 36.6 meters, a width (Breadth) of 9.9 meters, and a depth (Draught) of 1.8 meters. This ship is capable of reaching speeds of up to 32 knots, with a passenger capacity of 409 passengers. The main advantage of Incat is that due to the ship's size, capacity, and lower speed, it consumes

less fuel. However, viewed from another angle, the Incat ship at a lower speed will make the journey longer, and its smaller size and limited capacity will reduce crew comfort.

3. Austal 45
Austal, Also from Australia, it is one of the largest FCV manufacturers in the world. The Austal 45 has a length (Length Overall) of 45.24 meters, a width (Breadth) of 12.3 meters, and a depth (Draught) of 2 meters. This ship can reach up to 38 knots and carries 452 passengers. The advantage of the Austal 45 is its large size, which improves crew comfort. However, its speed is not the best among the ships compared, and its fuel consumption is high, the highest among them.

In general, the comparison between Fast Cruising Vessels for Damen, Incat, and Austal is presented in Table 1.

Table 1. Comparison between FCV

Criteria	Damen FF4212	Incat Hull 090	Austal 45
Maximum speed	± 40 knots	± 32 knots	± 38 knots
Passenger capacity	Reach 450 pax	Reach 409 pax	Reach 452 pax
Ship Stability	Good	Good	Good
Port needs	Medium (small port)	Medium (small port)	Medium (small port)
Operating costs	Efficient	More Efficient	High
Field suitability	Very Suitable	Less suitable, speed factor	Less suitable, high operational costs

Processed by the author based on ITS Tekno Sains. (2019). Feasibility study on fast cruising vessel reliability and capability from Sorong to PT. XYZ LNG

2.5 Previous Research and Research Gaps

Several studies have demonstrated improvements in logistical performance when switching to more direct or unimodal systems. For example, a study regarding logistics service providers who transport freight over long distances found that while multimodal systems reduce cost, a unimodal system have lower delivery time, and that again the highest reduction in cost is found in rail transport (Wolfinger et al., 2019). Unimodal transport is advantageous for short transportation distances because no additional transhipment costs and time durations occur, resulting in lower administrative effort compared to multimodal transport (Kogler & Rauch, 2018). After all, the uncertainty of the duration of transportation operations between nodes is a significant obstacle to perform route optimization of a multimodal transportation network to guarantee reliable delivery times (Taran et al., 2023). Infrastructure limitations and budget constraints also significantly reduce the theoretical advantages of multimodal systems, something very relevant when talking about transportation for remote areas like LNG projects.

In addition to operational studies, several studies have also shown that the AHP method is effective in evaluating transportation modes. AHP allows for an objective assessment of alternative modes based on criteria such as cost, time, capacity, and risk, as discussed by Vaidya & Kumar (2006) and Forman & Gass (2001). Akhrouf et al. (2024) demonstrated that AHP can be used as a basis for priority-based transportation investment decisions, which is relevant in the context of strategic projects such as LNG crew transportation in remote areas. AHP has also been used to examine risk factors in transportation in petroleum supply chain, and that integrating environmental metrics into benchmark performance standards, such as the SCOR model considering congestion, poor infrastructure conditions, and human error as key risk factors in formulating risk mitigation policies for the local supply chain actors (Mohamed Said et al., 2024). These findings reinforce the relevance of applying FCV and the AHP method to evaluate crew transportation modes in LNG projects like **PT. XYZ**. However, to date, no studies have explicitly compared FCV and multimodal modes in the Indonesian LNG context using a combined AHP and threshold switching approach. Applying this integration to crew transportation in remote LNG operations provides not only a multi-criteria prioritization framework but also an economic validation based on cost-efficiency thresholds, offering a more comprehensive basis for decision-making. It also adds to the discussion about the comparison and benefits of choosing between multimodal and unimodal transportation systems and can provide further insights into how and when multimodal or unimodal transportation is better compared to the other. As far as the researchers' knowledge, research regarding mode of transport evaluation in the context of crew transportation in remote areas, specifically for LNG projects and like, is still few and far between.

2.6 Analytic Hierarchy Process (AHP) Method

Analytic Hierarchy Process (AHP)is a multicriteria decision-making method developed by Thomas L. Saaty. AHP helps in prioritizing and selecting the best alternative when a decision involves multiple criteria, both quantitative and qualitative (Saaty, 1980; Saaty & Vargas, 2012). This method uses a pairwise comparison approach to determine the relative weight of each element in the decision hierarchy structure. Assessment is carried out based on a scale of 1-9 that describes the relative importance of each element. The main stages of AHP include: first develop a hierarchical structure: from objectives to criteria to alternatives, conduct pairwise comparisons between elements at each level, calculate priority weights using the eigenvector method, test the consistency of the assessment using the Consistency Ratio (CR) and finally sum the final scores to determine the best alternative.

In the past decade, the Analytic Hierarchy Process (AHP) has been recognized as one of the most widely applied decision-making methods in the transportation and logistics sector due to its simplicity, process transparency, and ability to generate consistent weights (Kabashkin, 2023; Moslem et al., 2023). Although some criteria may be conceptually interrelated, the hierarchical structure used in AHP still provides a practical analytical framework that is easier for decision-makers to understand compared to more complex methods such as ANP (Ishizaka & Mu, 2023). Another advantage of AHP is the availability of a consistency test (Consistency Ratio), which serves to verify the quality of expert judgments and is rarely present in alternative methods such as TOPSIS (Broniewicz et al., 2020). If the panel of experts is relatively homogeneous and experienced, the uncertainty in their assessments can be minimized, making the use of classical AHP without fuzzy numbers a reasonable choice. In line with Baric (2021), fuzzy approaches are more suitable when there is significant ambiguity in expert judgment. Furthermore, when the Consistency Ratio is sufficiently low (<0.1), the assessments can be considered reliable, and classical AHP may be regarded as adequately representative for deriving weights and prioritizing alternatives. These strengths underline the suitability of AHP for evaluating multi-criteria problems in logistics and transportation.

In the context of logistics and transportation, AHP is highly relevant because it is able to handle decision-making involving multiple criteria with different weights such as cost, time, capacity, risk, and comfort. AHP provides a systematic and objective approach in evaluating crew transportation modes, such as the comparison between Dash 8 + small vessels and FCVs in the Tangguh LNG project. The AHP method has been widely used in the evaluation of energy distribution transportation modes. Hruška, Kmetík, and Chocholáč (2021) proved that AHP is effective in determining the best mode based on a combination of operational, technical, and economic criteria in fuel distribution logistics. In the study of Ebrahimi and Bridgelall (2020), a combination of Fuzzy Delphi and AHP methods was used to capture passenger perceptions and preferences, which shows that this method is able to accommodate subjective complexity in transportation mode selection.

2.7 Threshold Switching Concept

Threshold switching refers to the minimum threshold of cost efficiency that must be achieved for a change in transportation mode to be considered strategically and economically feasible. This approach is commonly used in logistics decision-making to assess the feasibility of modal shifts from a financial perspective. According to Chopra and Meindl (2019), a minimum cost savings of 25% can be used as a benchmark for the feasibility of switching in a logistics system. If the efficiency offered by the new mode exceeds this threshold, then the modal shift is considered economically rational. This concept is based on an idea first proposed by Payne et al. (1993), which stated that decision-makers only initiate change once the perceived benefits (ΔU), such as improved reliability and time efficiency, surpass the switching cost (C), including additional investment, risk exposure, and transitional downtime. In PT. XYZ's case, this 'switching cost' includes new vessel procurement, certification, changes in crew scheduling systems, and regulatory coordination with SKK Migas and local authorities. The behavioural threshold, therefore, is not merely financial, it represents the operational tipping point where persisting with the existing multimodal approach becomes less efficient and riskier than transitioning to an integrated marine logistics system. Thus, the Threshold Switching concept explains the timing of change decisions within the company's marine operations: switching is justified only when the FCV model's efficiency, predictability, and crew comfort significantly exceed the total switching burden.

Rieskamp & Otto (2006) also proposed the strategy selection learning (SSL) theory that examines how people select strategies. According to SSL, people possess a repertoire of cognitive strategies to solve the inference problems they face. Through feedback, these unobservable cognitive strategies, instead of stimulus-response associations, are reinforced. From their strategy repertoire, people are most likely to select the strategy they expect to solve the problem well. These strategies' expectancies change through reinforcement learning depending on the strategies' past performances. This is part of the bigger principles that appear to guide learning which strategy to select. First, heuristics and their underlying core capacities can be (partly) hardwired by evolution. The second selection principle is based on individual learning. Third, heuristics can be selected and learned by social processes, as in imitation and explicit teaching of heuristics. Finally, the content of individual memory determines in the first place which heuristics can be used, and some heuristics' very applicability appears to be correlated with their "ecological rationality" (Gigerenzer & Gaissmaier, 2011). SSL decomposes participants' performances into three components: an initial preference parameter, a learning rate parameter, and an error parameter (Mata et al., 2011).

This concept of threshold switching is also based on Damodaran's (2009) concept of hurdle rate. Damodaran stated that investments in projects should only be made when they yield a return greater than the minimum acceptable hurdle rate. The hurdle rate should be higher for riskier projects and reflect the financing mix used - owners' funds (equity) or borrowed money (debt) Returns on projects should be measured based on cash flows generated and the timing of these cash flows; they should also consider both positive and negative side effects of these projects. Hurdle rate itself is a minimum financial metric and include the user's cost of capital and a premium corresponding to a significant subjective assessment of unsystematic project risk used to measure the viability of potential projects. This is achieved by conducting feasibility analyses to inform decision makers during the early stages of development projects. For projects to proceed, the forecasted profitability determined through feasibility analyses must meet or exceed the minimum requirements of firms (Moorhead et al., 2024). Equation (1) is used to calculate the percentage savings.

$$\text{Threshold Saving (\%)} = ((\text{Previous Cost - Current Cost}) \;/\; \text{Previous Cost}) \text{ x } 100\% \quad (1)$$

This formula captures PT XYZ's economic rationale for switching by quantifying how much OPEX reduction or value-for-money improvement the FCV must deliver to justify the transition. Factors include reduced fuel and aviation costs, lower downtime risk during bad weather, and minimized crew layover time at the shorebase (Sorong). The threshold saving becomes the measurable economic signal that aligns behavioural intent (to switch) with PSC-driven cost recovery logic. In the context of this research, threshold switching is used as a complement to AHP evaluation to provide a quantitative basis for selecting a more efficient mode of transportation. The use of this concept, which combines Payne's idea of decision making and the hurdle rate concept with the AHP Operational Prioritization, forms a more thorough and unified marine logistics decision model compared to a more one-dimensional model. This theoretical foundation ensures that decisions regarding vessel mode transition are rational, economically defensible, and operationally aligned with PT. XYZ'S excellence standards. It transforms the transition from being a purely cost-driven argument into a strategic logistics optimization model, reflecting the company's long-term commitment to efficiency, reliability, and sustainability in LNG operation.

3. Methodology

This study uses a descriptive-comparative approach to compare the effectiveness of four alternative crew transportation modes in supporting **PT. XYX** LNG operations in West Papua. Furthermore, for multi-criteria decision-making, the Analytic Hierarchy Process (AHP) method was used to determine the most optimal mode based on eight evaluation criteria. The primary focus of this study was to compare the existing mode, which combines flights using a Dash 8 aircraft and a small vessel, with the alternative of direct sea transportation using a Fast Cruising Vessel (FCV) from Sorong to the LNG site. The objects studied in this study included four alternative modes: the Dash 8 + small vessel as the existing mode, and three FCV variants: the Damen Fast Ferry 4212, the Incat Hull 090, and the Austal 45. Each alternative was analyzed based on eight key evaluation criteria reflecting technical, economic, and operational aspects: travel time, operational costs, cost per passenger, carrying capacity, weather risk and stability, infrastructure requirements, crew comfort, and operational flexibility.

The rationale for selecting the AHP has been elaborated in the literature review section. In summary, AHP was chosen over other multicriteria decision-making methods such as ANP, TOPSIS, and fuzzy AHP because the decision criteria in this study are hierarchically structured and largely independent, expert judgments were consistent and quantitative, and the method provides transparency through the Consistency Ratio. As the expert panel was relatively homogeneous and experienced, classical AHP was deemed sufficient without the need for fuzzy extensions. These considerations make classical AHP the most suitable and interpretable tool for the structured evaluation of transportation modes in this research. The study involved three respondents, consisting of practitioners and academics with at least five years of experience in energy logistics and maritime transportation. Respondents were selected purposively, considering their involvement in operational planning or LNG transportation projects in eastern Indonesia. The data used in this study came from two primary sources. Secondary data was obtained through literature and technical document reviews, including the FCV study report from ITS (2019), vessel specifications from manufacturers, and academic references on maritime transportation and logistics in remote areas. Meanwhile, primary data was collected through questionnaires distributed to energy logistics and transportation experts with experience in the LNG sector. The questionnaires were structured using a pairwise comparison format to support the application of the AHP method.

Data analysis was conducted in two stages. The first stage involved operational simulations to compare each mode in terms of travel time, carrying capacity, and cost per trip, assuming normal weather conditions in Bintuni Bay. The second stage involved applying the AHP method to determine the most optimal mode based on the preference weights for each criterion. The AHP process begins with the development of a hierarchical decision structure, followed by pairwise comparisons between elements, calculation of priority weights (eigenvectors), and consistency testing using the Consistency Ratio (CR) value, which is considered valid if ≤ 0.10. Finally, the weight of each criterion is multiplied by the preference score of each mode, resulting in a total score that serves as the basis for selecting the best alternative. Furthermore, to strengthen the methodological contribution, this study does not rely solely on the AHP but integrates it with threshold switching analysis. This combination is rarely employed in LNG-related transportation studies in Indonesia, particularly in remote area crew logistics, where economic feasibility is as critical as technical and operational performance. To assess feasibility, a threshold-switching cost analysis is conducted, which measures the extent to which the new mode's cost efficiency exceeds the minimum feasibility threshold of 25%. The savings of more than 80% in the FCV mode compared to the existing mode strengthens the justification for selecting the direct sea mode as a strategic logistics solution for Tangguh LNG.

4. Results and Discussion

4.1 Operational Simulation of Transportation Modes

The evaluation of **PT. XYX** LNG crew transportation modes was conducted based on eight key criteria. The following discussion integrates simulation data, operational study results, and professional technical references from the high-speed maritime transportation industry and LNG projects. The Dash 8 + small vessel mode completes the Sorong-Babo-LNG Site trip in approximately 1.5-2 hours. Meanwhile, the Damen FF 4212 FCV requires approximately 4.5 hours of direct sailing from Sorong to the LNG Jetty. Despite the longer time, the FCV has the advantage of route simplicity and avoids the risk of changing modes (transit). Under real-life operational conditions, the FCV is considered sufficiently responsive to support weekly crew rotations.

Simulations from the report indicate that the operational costs of the Dash 8 + small vessel reach IDR 180 million per trip, compared to only IDR 100 million per trip for the FCV, resulting in savings of up to 44%. Damen vessels are more fuel efficient than Incat and Austal, making them more economical for daily routes under 200 miles (Haase, 2016). Assuming 60 crew members are transported per trip, the cost per person for an FCV is only around IDR 1.67 million, significantly lower than the IDR 9 million per person for the Dash 8 + small vessel mode. This demonstrates significant economic efficiencies that support mode switching.

The Dash 8's capacity is 37–70 passengers, depending on the variant, and the small vessel can accommodate only about 20. The Damen FF 4212 can accommodate up to 450 passengers, and in the **PT. XYZ** LNG configuration, it can accommodate approximately 60 passengers per trip, in line with projected annual crew rotation requirements (**PT. XYX**, 2023). Air and sea transportation (Dash 8 and small vessel) face dual risks: adverse weather in the air and high seas. FCVs face a single risk, namely sea waves exceeding 2.5 m. Based on the Wave Climate Study (**PT. XYZ** Berau, 2017), the average sea state in Bintuni Bay is level 3–4, which is still suitable for operation by the Damen FF 4212, Austal 45, and Incat hull 090. The coomparison Matrix of alternative transportation modes can be seen in Table 2.

Table 2. Comparison Matrix of Alternative Transportation Modes

Parameter	Dash 8 + Small Ship	FCV Damen	FCV Incat	FCV Austal
Traveling time	45 minutes (air) + 1 hour (sea)	4-5 hours (sea)	7.5 hours (210 NM)	5.53 hours (210 NM)
Operational Cost	Rp.180 mio/trip	Rp.100 mio/trip	Rp.75 mio/trip	Rp.120 mio/trip
Cost per Pax	Rp.9 mio	Rp.1,67 (ITS 2019)	Rp.1,5 mio (est. 409 pax)	Rp.2 mio (est. 450 pax)
Transport Capacity	37–70 pax (Dash 8), 15–20 pax (boat)	450 pax	396 pax	446 pax
Weather risks	Height (air and sea), Heavy rain and visibility	Moderate (sea), Wave height >2.5 m	Moderate (sea), Wave height >2.5m	Moderate (sea), Wave height >2.5m
Infrastructure	Babo Airport + small boat dock	Sorong Pier + LNG Jetty	Sorong Pier + LNG Jetty	Sorong Pier + LNG Jetty
Crew Comfort	Direct, One mode	Direct, One mode	Direct, One mode	Direct, One mode
Operational Flexibility	Babo runway maint.multimodal coord	High waves	High waves	High waves

The Dash 8 requires a runway at Babo Airport and a small vessel terminal. The Damen FCV requires only a standard dock in Sorong and the LNG Jetty. Based on IMO MSC.1/Circ.1331 standards, the Damen FF 4212 can operate in small and simple ports, unlike the Incat and Austal, which require larger facilities. Small vessels are not designed for long-distance comfort: they are cramped, open, and prone to shaking. Damen FCVs offer spacious cabins, ergonomic seating, good ventilation, and crew rest areas. This improves crew working conditions on site and reduces the risk of operational fatigue (Phillips et al., 2017). FCVs can be scheduled more flexibly because they are not dependent on flight slots, do not require airport authority, and can be adjusted to operational conditions. In emergency situations (urgent crew changes), FCVs can be mobilized more quickly. This aligns with the dynamic nature of LNG operations.

Based on simulation results, the Fast Cruising Vessel (FCV) mode offers the advantage of direct connectivity from Sorong to Tangguh without the need for transit or changing modes. Although sea travel times are longer than air travel and small vessels, FCVs provide greater flexibility and reduce dependence on land infrastructure such as Babo Airport. However, FCVs still carry the risk of operational delays during high sea conditions. Therefore, operational mitigation measures, such as weather forecast-based scheduling and the availability of alternative transportation backups, are necessary during implementation. Table 4.2 below presents a comparison between the two alternative transportation modes based on key parameters, as reported by ITS (2019).

3.1 Evaluation Based on AHP Method

In this study, the Analytic Hierarchy Process (AHP) method was used to evaluate alternative transportation modes for Tangguh LNG crew. The decision hierarchy structure is structured in three levels, as shown in Figure 1. This structure serves as the basis for organizing the assessment process and multi-criteria-based decision-making.

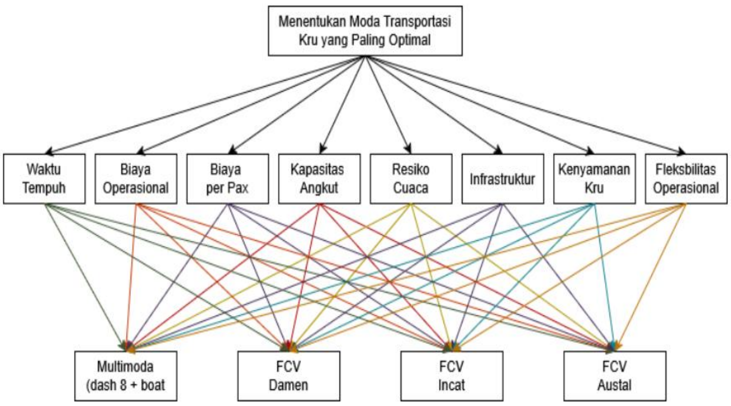

Figure 1. Decision Hierarchy Structure

The assessment was conducted using eight main criteria and a pairwise comparison approach by expert respondents (see Table 3). The assessment results were then quantitatively processed to obtain the weight for each criterion and the total score for each alternative mode. The comparison results are displayed in the pairwise comparison matrix in Table 3, then normalized to obtain the eigenvector as the final weight of each criterion in Table 4. Travel Time is considered the most important (0.289) because it is vital to maintain labor availability in large-scale projects in remote areas. Transportation delays can cause significant downtime, especially if specialist labor is involved (Graham, 2010).

Table 3. Pairwise Comparison Matrix

Criteria	WT	BO	BP	KA	RC	IF	KK	FO
WT	1.000	7.000	5.000	5.000	5.000	5.000	5.000	3.000
BO	0.143	1.000	1.000	0.143	0.200	1.000	0.333	0.333
BP	0.200	1.000	1.000	0.143	0.200	0.333	0.333	0.333
KA	1.000	7.000	7.000	1.000	5.000	3.000	3.000	5.000
RC	0.200	5.000	5.000	0.200	1.000	3.000	1.000	1.000
IF	0.200	1.000	3.000	0.333	0.333	1.000	0.333	0.333
KK	0.200	3.000	3.000	0.333	1.000	3.000	1.000	3.000
FO	0.333	3.000	3.000	0.200	1.000	3.000	0.333	1.000
TOTAL	3.276	28.000	28.000	3.352	13.733	19.333	11.333	14.000

Table 4. Normalized Pairwise Comparison Matrix

Criteria	WT	BO	BP	KA	RC	IF	KK	FO	Eigen Vector
WT	0.305	0.250	0.179	0.298	0.364	0.259	0.441	0.214	0.289
BO	0.044	0.036	0.036	0.043	0.015	0.052	0.029	0.024	0.035
BP	0.061	0.036	0.036	0.043	0.015	0.017	0.029	0.024	0.033
KA	0.305	0.250	0.250	0.298	0.364	0.155	0.265	0.357	0.281
RC	0.061	0.179	0.179	0.060	0.073	0.155	0.088	0.071	0.108
IF	0.061	0.036	0.107	0.099	0.024	0.052	0.029	0.024	0.054
KK	0.061	0.107	0.107	0.099	0.073	0.155	0.088	0.214	0.113
FO	0.102	0.107	0.107	0.060	0.073	0.155	0.029	0.071	0.088

Table 5. Assessment Criteria Consistency Matrix

Criteria	WT	BO	BP	KA	RC	IF	KK	FO	Weight	Eigen Vector	λ Per element
WT	0.289	0.243	0.163	0.281	0.541	0.270	0.566	0.264	2.616	0.289	9.058
BO	0.041	0.035	0.033	0.040	0.022	0.054	0.038	0.029	0.291	0.035	8.408
BP	0.058	0.035	0.033	0.040	0.022	0.018	0.038	0.029	0.272	0.033	8.357
KA	0.289	0.243	0.228	0.281	0.541	0.162	0.339	0.440	2.522	0.281	8.990
RC	0.058	0.173	0.163	0.056	0.108	0.162	0.113	0.088	0.921	0.108	8.516
IF	0.058	0.035	0.098	0.094	0.036	0.054	0.038	0.029	0.441	0.054	8.150
KK	0.058	0.104	0.098	0.094	0.108	0.162	0.113	0.264	1.001	0.113	8.842
FO	0.096	0.104	0.098	0.056	0.108	0.162	0.038	0.088	0.750	0.088	8.517

The consistency test for pairwise comparisons of the assessment criteria in Table 5 yielded a Consistency Ratio (CR) of 0.061. A CR value of less than 0.10 indicates that the assessment is consistent and acceptable for further analysis. Each alternative mode (Multimodal Dash 8 + small vessels, FCV Damen, Incat, Austal) was compared based on the criteria shown in Tables 6, 7, 8, 9, 10, 11, 12, and 13.

Table 6. Comparison of Alternatives for Travel Time Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	3.00	5.000	5.000	0.577	0.662	0.536	0.357	0.533	0.533	0.819	0.638	0.333	2.323	4.359
FD	0.333	1.000	3.000	3.000	0.192	0.221	0.321	0.357	0.273	0.178	0.273	0.383	0.333	1.167	4.275
FI	0.200	0.333	1.000	3.000	0.115	0.074	0.107	0.214	0.128	0.107	0.091	0.128	0.200	0.525	4.116
FA	0.200	0.200	0.333	1.000	0.115	0.044	0.036	0.071	0.067	0.107	0.055	0.043	0.067	0.270	4.055
Total	1.733	4.533	9.333	14.000	1.000	1.000	1.000	1.000	1.000	0.924	1.237	1.191	0.933		

Table 7. Comparison of Alternatives for Operational Cost Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	0.143	0.143	0.143	0.045	0.085	0.032	0.016	0.045	0.045	0.079	0.030	0.028	0.181	4.059
FD	7.000	1.000	3.000	5.000	0.318	0.597	0.670	0.547	0.533	0.312	0.550	0.639	0.965	2.465	4.486
FI	7.000	0.333	1.000	3.000	0.318	0.199	0.223	0.328	0.267	0.312	0.183	0.213	0.193	0.901	4.234
FA	7.000	0.200	0.333	1.000	0.318	0.119	0.074	0.109	0.155	0.312	0.110	0.213	0.193	0.828	4.291
Total	22.000	1.676	4.476	9.143	1.000	1.000	1.000	1.000	1.000	0.982	0.921	1.095	1.378		

Table 8. Comparison of Alternatives for Cost per Passenger Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	0.143	0.143	0.143	0.045	0.085	0.032	0.016	0.045	0.045	0.079	0.030	0.028	0.181	4.059
FD	7.000	1.000	3.000	5.000	0.318	0.597	0.670	0.547	0.533	0.312	0.550	0.639	0.965	2.465	4.486
FI	7.000	0.333	1.000	3.000	0.318	0.199	0.223	0.328	0.267	0.312	0.183	0.213	0.193	0.901	4.234
FA	7.000	0.200	0.333	1.000	0.318	0.119	0.074	0.109	0.155	0.312	0.110	0.213	0.193	0.828	4.291
Total	22.000	1.676	4.476	9.143	1.000	1.000	1.000	1.000	1.000	0.982	0.921	1.095	1.378		

Table 9. Comparison of Alternatives for the Carrying Capacity Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	0.333	0.333	0.333	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.400	4.000
FD	3.000	1.000	1.000	1.000	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	1.200	4.000
FI	3.000	1.000	1.000	1.000	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	1.200	4.000
FA	3.000	1.000	1.000	1.000	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	1.200	4.000
Total	10.000	3.333	3.333	3.333	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		

Table 10. Comparison of Alternatives for Weather Risk Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FD	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FI	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FA	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
Total	4.000	4.000	4.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		

Table 11. Comparison of Alternatives for Infrastructure Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FD	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FI	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
FA	1.000	1.000	1.000	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	1.000	4.000
Total	4.000	4.000	4.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		

Table 12. Comparison of Alternatives for Crew Comfort Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	3.000	7.000	7.000	0.618	0.643	0.583	0.583	0.607	0.607	0.690	0.571	0.571	2.439	4.020
FD	0.333	1.000	3.000	3.000	0.206	0.214	0.250	0.250	0.230	0.202	0.230	0.245	0.245	0.922	4.007
FI	0.143	0.333	1.000	1.000	0.088	0.071	0.083	0.083	0.082	0.087	0.077	0.082	0.082	0.327	4.002
FA	0.143	0.333	1.000	1.000	0.088	0.071	0.083	0.083	0.082	0.087	0.077	0.082	0.082	0.327	4.002
Total	4.000	4.667	12.000	12.000	1.000	1.000	1.000	1.000		0.982	1.074	0.979	0.979		

Table 13. Comparison of Alternatives for Operational Flexibility Criteria

Criteria	Paired Comparison				Normalized				Eigen Vektor	Consistency Check				Weight	λ Per element
	MM	FD	FI	FA	MM	FD	FI	FA		MM	FD	FI	FA		
MM	1.000	0.333	0.333	0.333	0.100	0.167	0.074	0.029	0.093	0.098	0.160	0.070	0.070	0.399	4.071
FD	3.000	1.000	3.000	3.000	0.300	0.500	0.670	0.265	0.434	0.294	0.481	0.631	0.631	2.038	4.234
FI	3.000	0.333	1.000	7.000	0.300	0.167	0.223	0.618	0.327	0.294	0.160	0.210	0.210	0.875	4.158
FA	3.000	0.333	0.143	1.000	0.300	0.167	0.032	0.088	0.147	0.294	0.160	0.210	0.210	0.875	4.158
Total	10.000	2.000	4.476	11.333	1.000	1.000	1.000	1.000	1.000	0.979	0.963	1.122	1.122		

Table 14. Alternative Evaluation

Mode Transportation	Assestment Criteria								Matrix Multification	Rank Alt
	WT	BO	BP	KA	RC	IF	KK	FO		
Dash 8+Boat	0.533	0.045	0.045	0.100	0.250	0.250	0.607	0.098	0.303	2
FCV Damen	0.273	0.550	0.550	0.300	0.250	0.250	0.230	0.481	0.309	1
FCV Incat	0.128	0.213	0.213	0.300	0.250	0.250	0.082	0.210	0.204	3
FCV Austal	0.067	0.193	0.193	0.300	0.250	0.250	0.082	0.210	0.185	4
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	

The final calculation is performed by summing the results of the eigenvector multiplication (table 4) and the alternative preference scores for each criterion (tables 6, 7, 8, 9, 10, 11, 12, and 13). Table 14 shows that the final score for the Damen FCV has the highest score (0.309), thus concluding that the Damen FCV Fast Ferry 4212 is the best alternative among all the modes analyzed. Based on the results of the AHP analysis and operational data, the Damen FCV Fast Ferry 4212 is the most optimal mode of transportation to support PT. XYZ LNG crew rotation, both from a technical, economic, and operational perspective. These findings indicate that the use of the Damen FCV as the primary mode for the crew rotation process, compared to an unstable multimodal system, will improve logistics efficiency, crew comfort, and operational resilience in the PT XYZ LNG supply chain. These results are highly significant and have a positive impact on the formulation of a more reliable and cost-effective long-term logistics strategy for LNG operational management in remote areas.

The Damen FCV excels in terms of operational costs, infrastructure, and comfort. This vessel is suitable for small ports like LNG Jetties and has an ideal configuration for regular crew rotation. The Incat FCV has the lowest speed of the three, but does not require extensive infrastructure because its size still allows it to operate in small ports like LNG Jetties. The Austal FCV has the largest size and capacity of the three, making it superior in terms of comfort, especially compared to the Damen FCV. However, the trade-off is its higher fuel consumption. The ship's slightly different size allows it to dock at the same ports, especially small ports like LNG Jetties.

Threshold switching analysis is used to assess the feasibility of switching modes of transportation based on cost efficiency. Referring to the minimum savings threshold of 25% (Chopra, 2019), a new mode is considered feasible if it can save more than that threshold. Although the difference in AHP scores itself is relatively small (0.309 compared to 0.303), the threshold switching analysis also demonstrates a highly significant cost-saving potential, with the cost per passenger of the existing Dash 8 + small vessel mode reaching IDR 9 million while the Damen FCV is only IDR 1.67 million. This represents an efficiency gain of more than 81%, far exceeding the feasibility threshold of IDR 6.75 million. Such results not only strengthen the AHP findings but also provide strong justification that the mode transition remains worth considering, as the economic benefits far surpass the minimum threshold typically adopted as the basis for investment or operational change decisions in LNG crew logistics. The results show that perhaps in remote regions where infrastructure is difficult and only air or sea transport is viable, unimodal transportation is more viable. While this result contradicts the dominant conclusions of the literature, it can also be interpreted as showing the importance of the availability of rail transport, and that the benefit of multimodality is pretty marginal without it in some situations such as crew transportation in remote areas. Other than being a useful managerial consideration for PT XYZ, it also shows that even small priority shifts captured by AHP can yield disproportionately large managerial benefits when threshold switching theory is used during the analysis.

4. Conclusion and Suggestions

This study aims to compare two PT. XYZ LNG crew transportation modes: a Dash 8 aircraft + small vessel and a Fast Cruising Vessel (FCV), based on eight evaluation criteria. The Analytic Hierarchy Process (AHP) method was used to determine the optimal multi-criteria mode. The main results indicate that the Damen Fast Ferry 4212 FCV is the best alternative, with the highest score in the AHP analysis (0,309), particularly in terms of cost per passenger, crew comfort, operational flexibility, and compatibility with port infrastructure in West Papua. This mode also provides cost savings of over 80%, far exceeding the 25% switching feasibility threshold. Based on these results, it can be concluded that: first, The Damen FCV offers more efficient and reliable direct connectivity than existing modes that rely on multimodal transportation. Second, Dash 8 + small vessel faces higher risks related to weather and airport infrastructure, as well as capacity constraints. Third, The main FCV risk related to extreme sea conditions can be mitigated through schedule management and early warning systems. And finally, the use of FCVs addresses the main research problem: this mode is considered the most optimal across eight assessment aspects based on the results of the AHP and time-cost analysis.

The implications of this study encompass both operational and managerial-strategic dimensions. First, the cost efficiency of using FCV can save operational costs significantly. Second, the reliability of using FCV can strengthen the crew rotation process and reduce the dependency of Babo airport, which experiences frequent bad weather situations. The third is about maintaining the crew condition. Selecting the most comfortable transportation mode can increase employee productivity upon arriving on the site. Fourth, it was found that employing threshold switching theory in conjunction with the common AHP method can yield further insights into mode of transport decision making. Fifth, contradicting the common conclusions of the literature regarding the superiority of multimodality, this study can act as evidence in support of using unimodal transportation systems in some cases such as crew transportation in remote areas. Sixth, this study covers the gap in study regarding modes of transportation evaluation in the context of crew transportation for remote areas. Lastly, this study can be a consideration for SKK Migas and the government to formulate the logistics strategy with value-for-money-based, particularly for the national strategic project in the remote area.

This study is limited by the assumption of normal weather and the use of operational estimation data. Other modes, such as helicopters or slow ships, were not analyzed. Furthermore, this study only considers one case as its main data point, so generalizability might still be limited to other companies in different sectors, situations, and regions. Further studies are recommended to test FCV operational scenarios under more scenarios, such as extreme weather conditions, with different vehicle assortments, and develop dynamic cost models based on time and season, using the new framework within this study or to incorporate other theories, because it is possible that similar to how incorporating threshold switching theory can add new insights to common AHP method analysis, other theories can perhaps also yield new insights.

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