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AN ANALYTICAL HIERARCHY PROCESS (AHP) APPROACH FOR SELECTION OF OFFSHORE SUPPLY BASES: KEMAMAN VERSUS TOK BALI IN MALAYSIA

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ABSTRACT

This paper explores and identifies a key element in the offshore supply chain and the oil and gas industry, the offshore logistic system, which includes offshore supply bases. This shore supply base is the logistics hub for all drilling and oil and gas activity. It functions as a central warehouse and a forward base for supplying cargo and needed supplies to offshore installations, and it offers critical services to facilitate offshore operations. Because of its advantageous position in Southeast Asia, Malaysia has become a prominent participant in the worldwide oil and gas sector. The nation's offshore supply bases, with oil and gas platforms operating in different locations along the eastern shores, have become crucial centres for the sector. This study aims to identify the key factors in supply base selection by oil and gas operators by performing a comparative analysis of two significant offshore supply bases in Malaysia, specifically Kemaman and Tok Bali. The analytical hierarchy process (AHP) has been used for stakeholders to make multi-criteria decisions. The method will prioritise four main criteria for supply base selection: Geographical location of Offshore Supply Base, Infrastructure and facilities, services provided and charges, and Regulatory considerations were used with twelve sub-criteria to ascertain which supply base is most favourably situated to meet the increasing demands of the oil and gas industry in the region, all of which determine the operational efficiency and cost-effectiveness of offshore operations. The analysis revealed that the Geographical component is the most significant, followed by Facilities and infrastructure, Service and costs, and Regulatory, respectively. Based on the score, the attribute with the highest level of importance is the Distance to MTJDA & MVCAA (Northern Section) Oil & Gas Platform. This is followed by Service, Berth facilities, Distance to the oil and gas Platform at Terengganu Water (Southern Section), Outsourced / Inland Area, Warehousing, Storage Facilities, Crew Change, Customs, Charges, Port Authority, and ISPS compliances in that order. The findings of this study will aid oil and gas companies and players in making informed decisions regarding the selection of onshore supply bases. By examining the factors influencing the choice of supply base and their respective advantages, companies can make informed decisions that contribute to their overall success in a competitive global market.

Introduction

The exploration and production (E&P) activities in the offshore oil and gas industry necessitate robust logistical support to ensure the smooth and efficient operation of various tasks such as seismic surveys, drilling, pipeline installation, platform installation, and production operations. Central to this logistical framework are offshore supply bases, which serve as critical hubs for the transhipment of essential materials, equipment, and personnel between onshore facilities and offshore units (Syuhaida, 2020) (Syuhaida, 2019) (Hassan, 2013). These bases play a pivotal role in maintaining the continuity and productivity of offshore operations by providing a wide range of services and facilities tailored to the needs of the oil and gas sector. In Malaysia, two prominent supply bases, Kemaman Supply Base (KSB) and Tok Bali Supply Base (TBSB), exemplify the strategic importance of such facilities. KSB, located on the east coast of Peninsular Malaysia, is the region's largest fully integrated oil and gas supply base, offering comprehensive logistical support and various specialised services.

In contrast, TBSB, situated on the northeast coast, serves as a newer, yet increasingly vital, supply base catering to the North Malay Basin, the Malaysia-Thailand Joint Development Area (MTJDA), and the Malaysia-Vietnam Commercial Arrangement Area (MVCAA) as shown in Figure 1. Several factors, including geographical location, infrastructure and facilities, services offered, and regulatory compliance, influence the selection of an appropriate supply base. These factors collectively determine the operational efficiency, cost-effectiveness, and overall success of offshore oil and gas operations. The existing research on the oil and gas industry largely focuses on the problem with offshore platform vessel planning at the supply base, an example of an integrated approach for facility location and supply vessel planning with time windows (Amiri et al., 2019b), Optimal fleet composition and mix periodic location-routing problem with time windows in an offshore oil and gas industry: A case study of National Iranian Oil Co, (Amiri et al., 2018b). Even the research by Duffy (1979) surveyed the Northern North Sea offshore oil and gas supply base. Moreover, most research concentrates on developing the Port logistics service quality and customer satisfaction (Le et al., n.d. 2109). There is a limited number of studies about offshore supply bases in Malaysia, and researchers have published a limited number of articles. Further, the motivations of this study are the notion that understanding the dynamics of supply base selection is crucial for energy companies aiming to optimise their logistical chains and enhance productivity in a competitive global market. This paper identifies the key factors in the supply base selection by the oil and gas operator and company. Furthermore, it aims to explore the functions and significance of offshore supply bases, focusing on KSB and TBSB. By examining and identifying the factors influencing the choice of supply base and their respective advantages, this review provides insights into the strategic considerations that underpin effective offshore logistics management.

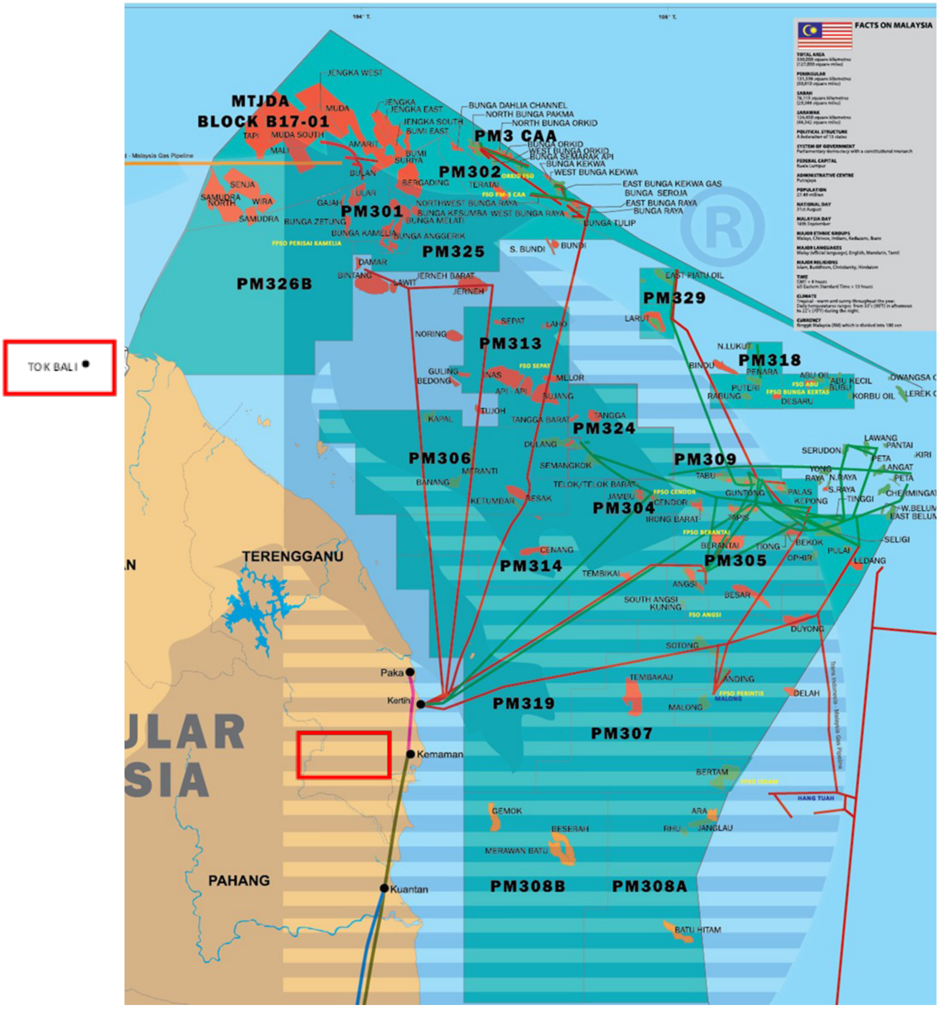

Figure 1: Overview of Oil and Gas Location in East Coast Peninsular Malaysia

Sources: MSGOC

Literature Review

Offshore Supply Base

An offshore supply base is the onshore logistical hub for various offshore exploration and production (E&P) activities, including seismic surveys, drilling, pipeline installation, platform installation, and production operations. The offshore support facility is a transhipment point for various items such as tools, equipment, mud, cement, manpower, consumables, water, fuel, and more. In simpler terms, "in other words" refers to a crucial component of the logistics system. Its main tasks involve the transportation of essential materials and supplies, as well as the return of used materials and equipment, between offshore units and an onshore supply base. These activities are carried out according to a predetermined delivery schedule (Aas *et al*., 2007) (Amiri *et al*., 2018). Furthermore, an offshore supply base also comprising of, at the very least, a jetty, lay-down areas, warehouses and a range of support buildings which support cargo handling activities (Kaiser 2010, p.2780) and it serves as a hub for the coordination, organisation, and deployment of offshore supply vessels (A.-S. Milakovic *et al*., 2014).

Kemaman Supply Base (KSB)

Kemaman Supply Base is situated on the east coast of Peninsular Malaysia. It is the largest fully integrated oil and gas supply base in Peninsular Malaysia and a one-stop shop for oil and gas companies operating in the region. It is important in supporting offshore oil and gas exploration and production activities. It is located in the Kemaman district of Terengganu, Malaysia. The base opened in 1982 and has since grown to 200 hectares, with an additional 60 hectares reserved for future expansion. KSB is a privately owned port that operates under the jurisdiction of Kemaman Port and requires pilotage services from the Kemaman Port Authority. Clause 29A of the Port Authorities Act 1963 states that all vessels navigating within the Kemaman Port Pilotage District must be piloted. However, subject to terms and conditions, the Kemaman Port Authority may grant a pilotage exemption to a Master of Supply vessel and crew boat regularly calling at Kemaman Port. Furthermore, International Ship and Port Facility Security (ISPS) compliance allows KSB to run its operations smoothly without any disruption. The Royal Customs of Malaysia uniquely license the entire area of KSB under the Petroleum Supply Base scheme. This means that taxes and duties for imported oilfield equipment entering KSB and subsequently going to offshore locations are deferred. The Kemaman Supply Base is home to over 200 support service companies and Petroleum Arrangement Contractors (PACs) catering to various oilfield needs, offering various oilfield trade specialities. It supplies marine fuel products and lubricants at Kemaman Supply Base for Offshore Support Vessels (OSV) and power equipment on Oil and Gas (O&G) platforms in the offshore East Coast of Peninsular Malaysia. KSB also provides berthing facilities for OSV. With a length of 360 mtr, a maximum draft of 8.0 mtr, and a maximum deadweight of 8,000, it can occupy a maximum of 10 vessels at one time with a double bend configuration, plus another two (2) vessels at the finger jetty. However, the maximum number of vessels that can carry out the cargo operation is only seven (7) at a time. This operation will combine with the mooring and unmooring services and manpower for cargo operations. The Kemaman Supply Base is owned and operated by Pangkalan Bekalan Kemaman Sdn Bhd (PBKSB), a subsidiary of the EPIC Group. Most of the companies KSB serve operate the platform in the area off Terengganu water. Voyage Distance from Kemaman Supply Base to the offshore rig platform in the Terengganu water is a shorter distance to Kelantan water, Malaysia-Thailand Joint Development Area (MTJDA) and Malaysia-Vietnam Commercial Arrangement Area (CAA) as shown in Figure 1. This can benefit the oil company that operates in Terengganu Water in terms of travelling time and fuel costs.

Tok Bali Supply Base (TBSB)

Tok Bali Supply Base (TBSB) is located on the northeast coast of Peninsular Malaysia or more specifically in Pasir Puteh Kelantan which aims to provide a safe and professional one-stop centre for Production Sharing Contract ("PSC") and services companies. TBSB was commercialised and officially operated by TB Supply Base Sdn Bhd in September 2014. The dominance shares have been owned by AZRB by its subsidiary, Matrix Reservoir Sdn Bhd (MRSB) is the owner of Tok Bali Supply Base ("TBSB"), which received full government approvals in January 2015 and commenced operation (Phase 1) in July 2015 as focusing for Oil & Gas sector. TBSB has been licensed under the Malaysian Customs Act 1967 under Section 77B (Petroleum Supply Base). As a new emergence of the supply base in peninsular Malaysia, they are focusing on three gateways of oil and gas exploration and production, namely the North Malay Basin (NMB), Malaysia-Thailand Joint Development Area (MTJDA) and Malaysia – Vietnam Commercial Arrangement Area (MVCAA). To cater for the prolonged demand and become a successful supply base operator, they would accommodate and offer all necessities by creating opportunities and providing new service options covering downstream and upstream support, both local and foreign port users. Because it is ideally located to serve companies operating in the North Malay Basin, Malaysia-Thailand Joint Development Area and Commercial Arrangement Area (CAA) between Malaysia and Vietnam. Tok Bali Supply Base is expected to create savings for Production Sharing Contract ("PSC") customers, especially those PSCs that are currently operating at the Malaysia-Thailand Joint Development Area ("MTJDA") and Malaysia-Vietnam Commercial Arrangement Area ("CAA"), due to shorter vessel voyage as compared to Kemaman Supply Base ("KSB"). Among the services that TBSB offers are fuel and water, mechanical handling equipment, a bonded warehouse, customs and immigration and office space. TB Supply Base provides an integrated support service and facilities and can provide cost-efficient services to clients. Moreover, all-weather 473 meters of berthing facilities, with fuel bunker, potable water, liquid mud and dry bulk off-take points conveniently slotted alongside the berth, could accommodate 5 supply vessels and 3 crew boats at any one time. The land distance to MTJDA and CAA from Tok Bali Supply Base is only 160km compared to 360km from KSB. The shorter vessel voyage also translates to lesser fuel requirements and lower operational costs for the PSCs.

Factors Affecting the Selection of Supply Base

A supply base is a customised harbour designed specifically to meet the requirements of the offshore exploration and production business. In recent years, energy corporations have delegated numerous activities deemed secondary to their main operations, such as logistics (de Wardt 1990; Aas *et al.* 2008). However, energy businesses still decide internally on the supply base selection rather than relying on sub-contractors like service companies, OSV operators, or freight forwarders. Kaiser (2010) has highlighted several crucial variables for supply base selection in the Gulf of Mexico, including distance to port, port capability and specialisation, transit time, and operator facilities. Given the absence of any specific additional studies on the selection of supply bases, it would be advantageous to examine the broader literature on inter-port competition and port selection to assess its applicability to the choice of supply bases. The field of port literature has extensively examined many service-related and economic elements that significantly impact the decision-making process of shippers and ship owners. The conventional perspective on port selection focused mainly on the individual physical characteristics of a port, such as its terminal infrastructure, equipment, efficiency, frequency of sailings, costs, quality of services, availability of value-added activities, and port security. Additionally, it took into account the port's safety and environmental policies and the accessibility of its hinterland (Bruno and Guy, 2006). Recently, it has been acknowledged that the emphasis on individual physical characteristics of ports does not accurately represent the current state of global supply chains. Ports are rapidly recognised as crucial connections within competitive global supply networks (Robinson 2002).

Geographical location of Offshore Supply Base

The geographical location of an offshore supply base significantly influences transportation costs and efficiency (Øyvind & Stein, 2009). For example, a supply base near the offshore rig installation results in lower transportation costs due to easier vessel access. On the other hand, a supply base located far away may incur higher transportation and logistics costs. Furthermore, it can impact delivery lead times, affecting operational efficiency, productivity, and overall supply chain complexity (Koilo, 2023). Additionally, the surrounding onshore area of the supply base is to be considered. For example, the industrial area nearby and local supplier resources. Access to the sources can help reduce lead times and improve overall operational efficiency. Furthermore, evaluating the infrastructure and transportation network in the surrounding area is essential to ensure smooth and timely delivery of materials and equipment to the offshore rig (Röben *et al.*, 2008). By considering these factors, companies can optimise their supply chain operations and ultimately enhance productivity and cost-effectiveness in their offshore operations and overall logistics chain by choosing the right location for an offshore supply base.

Infrastructure and Facilities

The resources needed for a supply base include berthing space, cranes, loading/unloading equipment, storage facilities, and maintenance workshops. These resources should be efficient and accessible for the efficient movement of goods and personnel. Accessible transport links, including road, rail, and air, are essential for moving goods and personnel efficiently. On-site accommodation, security measures, and facilities for waste management and environmental protection are also essential (Roben *et al*., 2010). A well-equipped supply base is essential for ensuring smooth operations in the oil and gas industry. The base must have a reliable supply of essential materials and the necessary infrastructure to support transportation and maintenance activities (Danish, 2019). Accessibility and security measures are also key considerations to ensure the safety and efficiency of operations. A supply base is very important in supporting the success of oil and gas operations by providing a range of services and facilities.

Service Provided and Charges

The supply base normally accommodates the vessel for berthing. This includes piloting services, vessel mooring and unmooring, crew change facilitation, and transportation services. Additional services may include bunkering, fresh water supply, and provision of necessary vessel supplies (Razack *et al*., 2018). With the efficient service provided, vessels can quickly and easily resupply and continue their operations without delay. This ensures that vessels can maintain their schedules and complete their voyages promptly. The streamlined process of receiving essential services at offshore supply bases also helps to reduce downtime and increase productivity for shipping companies (Amiri *et al*., 2019). This comprehensive range of services contributes to smooth and efficient vessel operations in these areas. Understanding service charges is crucial for consumers as it directly impacts their willingness to pay. Consumers' perceptions of convenience, including transaction and access convenience, play a significant role in their decision-making process (Leonard *et al*., 2002). The importance of convenience in services strongly correlates with consumers' willingness to pay, highlighting the need for businesses to understand and address service charges to attract and retain customers (L. *et al*., 2004).

Regulatory Considerations

Ensuring regulatory compliance with local laws, environmental standards, customs clearance processes, and safety requirements on offshore supply bases is essential for safeguarding the security of the transportation of products and persons. Implementing security measures is essential to adhere to regulatory standards like the ISPS code and others to guarantee the safety of operations within these facilities (Bichou, 2008). Failure to adhere to these standards can result in serious consequences, including fines, legal action, and even the suspension of operations. Additionally, non-compliance with security measures can lead to reputational damage and loss of business opportunities. Therefore, offshore supply bases must prioritise regulatory compliance and safety to maintain the integrity and efficiency of their operations. By prioritising regulatory compliance, they can also build trust with their clients and stakeholders, ultimately enhancing their competitiveness in the industry.

Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed by Saaty (1980) as a technique to address complex decision-making situations, including multiple criteria (Timor and Sipahi 2005). It has been used for MCDM by stakeholders with varying preferences for transhipment port selection by global carriers (Lirn *et al*., 2004). An advantageous characteristic of this strategy is its ability to manage qualitative and quantitative data effectively (Kuo *et al*., 2002; Timor and Sipahi, 2005). AHP is useful for decision-makers to analyse complicated problems, particularly those involving subjective judgment. It helps decision-makers comprehend the decision-making model's structure, enhancing their understanding of the challenges at hand. AHP, or Analytic Hierarchy Process, is a method that breaks down a complicated problem into a hierarchical structure consisting of goals, criteria, sub-criteria, and alternatives (Saaty, 1990; Triantaphyllou and Mann, 1995:35; Wang *et al*., 2004). The implementation of the AHP approach will be discussed in the methodology below.

Methodology

The research methodology first involves reviewing the literature and interviewing the supply base operator to obtain information on the use of the AHP method in formulating and selecting the best factor for the selection of the supply base (Marzouk & Sabbah, 2021). To identify the factors in the selection of the supply base, interviews were conducted to obtain information related to each supply base, other than finding out from the online resources and literature for comparison, as shown in Table 2. After identifying the factor, a set of questionnaires was completed and answered by five experts from this sector. All interviewees have over 10 years of experience in the supply chain and oil and gas industry. Table 1 shows the demographic profile of interviewees in this study. Based on the judgment of these experts, pair-wise comparisons were made between Criterion groups and between sub-factors in each group to determine their weights. A quantitative measure of their importance was obtained. Then, selecting the highest score will be the best option. This result is an "apples to apples," quantitative comparison of your choices (Munier & Hontoria, 2021).

Table 1: Interviewees demographic

Interviewee	Year of experiences	Role in the company	Country	Current Company
I1	14	Marine Executive	Malaysia	Port Operator
I2	16	Operation manager	Malaysia	Shipping Agency
I3	15	Marine Safety Executive	Malaysia	Oil and gas operator
I4	20	Operation Manager	Malaysia	Oil and gas Operator
I5	18	Manager Marine	Malaysia	Shipping company and Oil and gas contractor

Step 1: *Identifying the factors.*

The first step is to review the related literature studies and interview experts (Kuo et al., 2002) to describe the decision problem with multiple criteria and attributes used for its solution. Then, comparative development interventions for the two offshore supply bases were presented, as mentioned in Table 2.

Table 2: Comparative development interventions for the two offshore supply bases

Factor in selecting Supply Base	*Kemaman Supply Base (KSB)*	*Tok Bali Supply Base(TBSB)*
Geographical		
Distance to Rig platform	Approximately 360km from MTJD and CAA (northern part) of the oil and gas platform. Approximately 200km from Terengganu water (southern part) Oil & Gas platform.	Approximately 160km from the oil gas platform's MTJD and CAA area (northern part). Approximately 370km from Terengganu water (southern part) Oil & Gas platform
Inland Area	In the vicinity of Teluk Kalong industrial area.	In the vicinity of Tk Bali Industrial Park.

Infrastructure & Facilities		
Berthing	All weather straight 360 mtr berth and 2 finger jetty can accommodate 7 vessels at one time.	All weather "U" shape jetty with a length of about 473m can accommodate 7 vessels simultaneously.
Storage	Liquid mud plant, Dry bulk plan, Marine gas oil storage	Liquid mud plant, Dry bulk plan, Marine gas oil storage
Warehousing	Total 43 unit	A total of 12 units with 100% utilisation
Crew change	Completed with CIQ facilities	Completed with CIQ facilities
Service & Charges		
Service	Cargo loading & unloading Pilotage & towage Stevedoring-manpower Material Handling Equipment Weight bridge Schedule Waste Management Security - Provide round-the-clock security and also specific security services for individual client Fresh Water and fuel oil Bunkering	Cargo loading & unloading Pilotage & Towage Stevedoring-manpower Material Handling Equipment Weight bridge Schedule Waste Management Security - Provide round-the-clock security and also specific security services for individual client Fresh Water and fuel oil Bunkering
Charges	Marine services such as pilotage, towage, port dues, harbour dues and vessel dues as per Kemaman Port Tariff Other charges are as per KSB tariff since they are private entities.	All the charges are under the Tok Bali tariff since they are private ports.
Regulatory Compliances		
Custom	licensed under the Malaysian Customs Act 1967 under Section 77B (Petroleum Supply Base)	licensed under the Malaysian Customs Act 1967 under Section 77B (Petroleum Supply Base)
Port Authority	MSO 1952, Port Authority Act 1963 Kemaman Port.	MSO 1952, Directly under Marine Department Malaysia
ISPS	In compliance with ISPS	In compliance with ISPS

Step 2: *Develop the Hierarchical Structure of Decision Problem*

The problem is divided into its criteria (level 1), as depicted in Figure 6, with each possible sub-criteria (level 2) arranged into many hierarchical levels (Ho 2008). The criteria for evaluating location possibilities are determined based on information from relevant papers and the expertise of domain specialists. Numerous factors influence the decision-making process when choosing a site. However, certain criteria are deemed crucial because they are essential for correctly evaluating numerous location possibilities. In this study, the evaluation of two potential supply bases takes into consideration the following criteria: geographical location (C1), infrastructure and facilities (C2), service quality and charges (C3), and regulatory compliances (C4). Each entity is broken down into its individual properties. The attributes of the criterion 'geographical' encompass the distance to the MTJDA & MVCAA (Northern Section) Oil & Gas Platform (C1.1), the distance to the Oil & Gas Platform at Terengganu Water (Southern Section) (C1.2), and the outsourced/inland area (C1.3). The features of the criterion 'Infrastructure & Facilities' include Berth facilities (C2.1), Warehousing (C2.2), Crew Change (2.3), and Storage Facilities (2.4). The attributes of the criterion 'Service & Charges' are as follows: Service (3.1) and Charges (3.2). The elements of the criterion "Regulatory Compliances" include Custom (C4.1), Port Authority (C4.2), and ISPS compliances (C4.3).

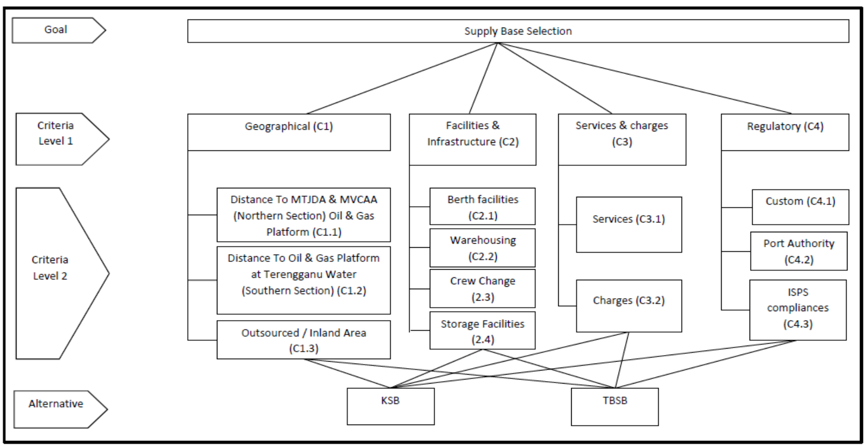

Figure 6: The hierarchical structure of supply base selection

Step 3: *Evaluating the elements by pairwise comparison to obtain weights of elements*

The weights of the AHP model's elements at each level are calculated by performing pairwise comparisons (Timor and Sipahi 2005). Decision makers will compare the importance of the elements at each level in a pairwise fashion based on their prior knowledge or experience (H. Ho, C. Chang & C. Ku, 2011). "For instance, every criterion in the second level is compared at each time concerning the goal, while every attribute of the same criterion in the third level is compared at a time concerning the corresponding criterion"(Ho, W. 2008). Furthermore, each pair of alternatives in the last level of the hierarchy is compared concerning the decision criterion and the sub-criterion. A questionnaire that allows for pairwise comparison of each pair of elements in the hierarchical model can be given to the decision-makers to determine the weight of the elements. A rating scale called the Saaty Scale (Saaty 1982) is used to measure the weights of the elements in the pairwise comparison. A questionnaire survey was designed to collect data from the decision-makers. The data collected were from the pairwise comparison of all the suggested elements in the hierarchical model. Five decision makers were gathered for an interview session and given the questionnaire survey to fill out.

Each question in the survey was a pairwise comparison of two elements at the same level. One example was "How important is Criterion 1 compared to Criterion 2?". This applied to all the criteria and sub-criteria. As for the alternatives, each was pairwise compared against one another as for how well the first alternative met the sub-criteria against its pair. For example, "How well does Alternative 1 meet Criterion 5 compared to Alternative 2?" The pairwise comparison was done using the Saaty Scale (Saaty 1982), as shown in Table 4. In this case, the average result from all the decision-makers was gathered to determine the relative weight of the factors. Table 3 shows the result of the interviewer's example of the relative weight scale for factor facility and infrastructure.

Table 3: Average relative weights by interviewers for Sub Criterion Facilities & Infrastructure C2

Criterion	C2.1-C2.2	C2.1-C2.3	C2.1-C2.4	C2.2-C2.3	C2.2-C2.4	C2.3-C2.4
I1	4	2	1	1	1	1
I2	6	1	2	0.333	1	3
I3	1	4	1	4	1	0.25
I4	4	2	1	0.5	1	0.5
I5	3	3	2	3	1	3
AVE	3.6	2.4	1.4	1.7	1	1.4

Table 4: 9-point intensity of relative weight (importance or well-being) scale

Definition	Scale	Significance
Equal importance / Equally good	1	Two preferences contributed equally to the decision
Moderate importance of one factor over another / Weakly	3	Experience and judgements slightly favour one preference over the other
Strong or essential importance / Strongly	5	Experience and judgements strongly favour one preference over the other
Very strong importance / Very strongly	7	A preference is strongly favoured and its dominance is demonstrated in practice
Extreme importance / Absolutely better	9	The evidence favouring one preference over the other is of the highest possible order of affirmation
Intermediate value between the two adjacent judgments	2, 4, 6, 8	Intermediate value between the two adjacent judgments
Reciprocals for inverse comparison		Reciprocals of the above nonzero numbers

Source: Adapted from Saaty (1982)

Pair-Wise Comparisons

The elements of each level are compared pairwisely concerning the next upper-level element in terms of their importance. Moving from the top to the bottom of the hierarchy, the pairwise comparisons at a given level can be reduced to multiple square matrices.

$C = [C_{ij}]_{xnx}$ as is the following:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

The matrix which has reciprocal properties $R = \left[\frac{1}{C_{ij}}\right]_{xnx}$ are represented as

$$\begin{bmatrix} \frac{1}{C_{11}} & \frac{1}{C_{12}} & \frac{1}{C_{31}} \\ \frac{1}{C_{21}} & \frac{1}{C_{22}} & \frac{1}{C_{32}} \\ \frac{1}{C_{31}} & \frac{1}{C_{32}} & \frac{1}{C_{33}} \end{bmatrix}$$

In AHP, Saaty (1980) suggested that a scale of relative importance from 1 to 9 is used to make subjective pairwise comparisons (see Table 4). First, all pairwise comparison matrices are formed. Then, the vector of weights, , is computed based on Saaty's eigenvector procedure. The calculation of the weights involves two steps: (1) forming a normalised pair-wise matrix and (2) creating a weighted matrix (Chen 2006). The scale of the relative importance is defined in Table 4 according to the Saaty 1–9 scale for pairwise comparison.

After the pair-wise comparison matrix, is done, the normalised by equation (1) (Chen 2006), in which each element in the matrix is divided by its column total to generate a normalised pair-wise matrix (Bunruamkaew 2012).

$$X_{ij} = \frac{c_{ij}}{\sum_{i=1}^{n} c_{ij}} \begin{bmatrix} X_{11} & X_{12} & X_{31} \\ X_{21} & X_{22} & X_{32} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \quad (1)$$

for all j = 1, 2, . . . , n.

Step 4: *Calculating weights of all elements in the hierarchical model*

The priority weight of criterion, sub-criteria, and alternatives is derived using the eigenvector approach mentioned before. Firstly, a matrix is generated to compare each criterion with one another, and then the resulting matrix is standardised to provide a consistent format. To ascertain the priority of a particular criterion (or sub-criterion or alternative), the relative weights are computed by averaging the pairwise comparisons of the pertinent values. The weight of each element was determined using the eigenvector approach, as described by equation (2). This method involves dividing the sum of the normalised column of the matrix by the number of criteria employed (n) to obtain a weighted matrix (Bunruamkaew 2012).

$$W_{ij} = \frac{\sum_{j=1}^{n} x_{ij}}{n} \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} \tag{2}$$

for all i = 1, 2, . . . , n.

Step 5: *Consistency check*

In order to obtain a consistency vector, the pair-wise matrix is multiplied by the weights vector as equation (3)

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{23} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} C_{11} \\ C_{21} \\ C_{31} \end{bmatrix} \tag{3}$$

Then, it is achieved by dividing the weighted sum vector by criterion weight (Bunruamkaew 2012).

$$\begin{aligned} Cv_{11} &= \frac{1}{W_{11}}[C_{11}\,W_{11} + C_{21}W_{21} + C_{13}W_{31}] \\ Cv_{21} &= \frac{1}{W_{21}}[C_{21}\,W_{11} + C_{22}W_{21} + C_{23}W_{31}] \\ Cv_{31} &= \frac{1}{W_{31}}[C_{31}\,W_{11} + C_{23}W_{21} + C_{33}W_{31}] \end{aligned} \tag{4}$$

There is a relationship between the vector weights, 9, and the pairwise comparison matrix, as shown in the following equation (5) (Chen 2006).

$$C_W = \lambda_{max} W \tag{5}$$

The value of $\lambda_{max} W$ the maximum eigenvalue of the comparison matrix (Mikhailov and Tsvetinov 2004), is an important validating parameter in AHP. It is used as a reference index to screen information by calculating the estimated vector's consistency ratio (CR) (Chen 2006). is obtained by averaging the value of the consistency vector, formulated using equation (6) (Bunruamkaew 2012).

$$\lambda = \sum_{i=1}^{n} Cv_{ij} \tag{6}$$

In order to calculate the CR, the consistency index (CI) for each matrix of order *n* can be obtained from equation (7) (Chen, 2006).

$$CI = \frac{\lambda_{max-n}}{n-1} \tag{7}$$

The consistency ratio *CR* for the decision makers' judgements was calculated and checked using the equation 8:

$$CR = \frac{CI}{RI} \tag{8}$$

Where *RI* is the random consistency index obtained from a randomly generated pairwise comparison matrix. Table 5 shows the values of the RI for matrices of order 1 to 9 (Saaty 1980). If the result of *CR* is < 0.1, the result of the alternative is considered valid. Any higher value at any level (CR>.01) indicates that the decision makers' judgements warrant re-examination (Bunruamkaew 2012); thus, the AHP procedure should be reviewed and revised.

After determining the CR, create an aggregate measure of the pairwise comparisons of all individuals involved in a decision problem, the individual assessments are averaged using equation (9)

$$C_{ij}^{hp} = \sqrt[q]{\prod_{q=1}^{q} C_{ij}^{q}}, \tag{9}$$

where C_{ij}^{q} is an element of matrix *C* of an individual q(q = 1, 2, 3, …,*Q*), and C_{ij}^{hp} is the average/the sum of a collection of numbers divided by the count (arithmetic mean) of all individuals . The group *CR* is calculated according to equations (7) and (8) (Saaty 1982; Chen 2006). Table 6 - 10 presents the results of the pairwise comparison, priority weight and CR for the Criteria and sub-criteria.

Table 5:Random index for N = 9

Random Index (RI)									
N	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Saaty 1980

Table 6: Pairwise comparison matrix and weights for the main criterion

Criterion	C1	C2	C3	C4	Priority Weight
Geographical C1	1	2.1	2.6	2.9	0.4209
Facilities & Infrastructure C2	0.48	1	3	2.5	0.2946
Service & charges C3	0.38	0.33	1	3	0.1806
Regulatory C4	0.34	0.40	0.33	1	0.1039
CR: 0.0898					

Step 6: *Calculating the final score for selecting the Supply Base*

Table 11 summarises the priority weight assigned to each criterion, sub-criterion, and alternative in selecting a supply base, together with their corresponding scores. The utilisation of a pair comparison matrix determines the priority weight. In this analysis, two options are assessed based on their priority weight in terms of the number of decision elements, including criteria and sub-criteria. The priority weight for alternatives is determined based on the performance of each alternative relative to individual sub-criteria. As previously stated, the score for each sub-criterion is determined by multiplying the priority weights inside that sub-criterion. Subsequently, the values are consolidated into a comprehensive score by calculating the average of the total score (T-Score) for each choice, where the T-score is the score for each alternative by multiplying the Priority weight of the main criterion with the sub-criterion and weight of the alternative relative to the sub-criterion, to facilitating the decision-making process.

To calculate the overall score for KSB, use the following calculation.

[C1 PV x C1.1 PV x KSB C1.1 S] + [C1 PV x C1.2 W x KSB C1.2 S] + [C1 PV x C1.3 PV x KSB C1.3 S] + [C2 PV x C2.1 PV x KSB C2.1 S] + [C2 PV x C2.2 W x KSB C2.2 S] + [C2 PV x C2.3 PV x KSB C2.3 S] + [C2 PV x C2.4 PV x KSB C2.4 S] + [C3 PV x C3.1 PV x KSB C3.1 S] + [C3 PV x C3.2 W x KSB C3.2 S] + [C4 PV x C4.1 PV x KSB C4.1 S] + [C4 PV x C4.2 PV x KSB C4.2 S] + [C4 PV x C4.3 PV x KSB C4.3 S] = 0.679

Table 11: Priority Weight and score for Criterion, sub-criterion and alternative

Criterion	Priority Weight	Sub-Criteria	Priority Weight	Score (S)	Alternative	Priority Weight	T.Score (S)
Geographical C1	0.4209	C1.1	0.4306	0.1812	KSB TBSB	0.1295 0.8705	0.0235 0.1577
		C1.2	0.2928	0.1232	KSB TBSB	0.8352 0.1648	0.1029 0.0203
		C1.3	0.2766	0.1164	KSB TBSB	0.8571 0.1429	0.0998 0.0166
	CR for sub-criterion C1: 0.0819						
Facilities & Infrastructure C2	0.2946	C2.1	0.4237	0.1248	KSB TBSB	0.8485 0.1515	0.1059 0.0189
		C2.2	0.1959	0.0577	KSB TBSB	0.8333 0.1667	0.0481 0.0096
		C2.3	0.1875	0.0552	KSB TBSB	0.7500 0.2500	0.0414 0.0138
		C2.4	0.1929	0.0568	KSB TBSB	0.8438 0.1562	0.0480 0.0089
		CR for sub-criterion C2: 0.0907					
Service & charges C3	0.1806	C3.1	0.8000	0.1445	KSB TBSB	0.8485 0.1515	0.1226 0.0219
		C3.2	0.2000	0.0361	KSB TBSB	0.3289 0.6711	0.0119 0.0242
		CR for sub-criterion C3: 0.000					
Regulatory C4	0.1039	C4.1	0.4977	0.0517	KSB TBSB	0.7500 0.2500	0.0388 0.0129
		C4.2	0.3099	0.0322	KSB TBSB	0.7222 0.2778	0.0233 0.0089
		C4.3	0.1923	0.0200	KSB TBSB	0.6667 0.2333	0.0133 0.0067
		CR for sub-criterion C4: 0.0510					
CR for main criterion = 0.0921							
FINAL SCORE					KSB TBSB	0.679 0.321	68% 32%

Results and Discussion

The analysis of the offshore supply base selection criteria in Table 11 reveals that the component with the highest significance is 'Geographical' (0.4209). The three key criteria are 'Facilities & Infrastructure' (0.2946), 'Service & charges'(0.1806) and ' Regulatory' (0.1039). Based on the score, the attribute that holds the highest level of importance is the " Distance to MTJDA & MVCAA (Northern Section) Oil & Gas Platform", accounting for (0.1812). The prioritised attributes are as follows: (2) Service (0.1445), (3) Berth facilities (0.1248), (4) Distance To Oil & Gas Platform at Terengganu Water (Southern Section) (0.1232), (5) Outsourced / Inland Area (0.1164), (6) Warehousing (0.0577), (7) Storage Facilities (0.0568), (8) Crew Change (0.0552), (9) Custom (0.0517), (10) Charges (0.0361), (11) Port Authority (0.0322), and last ranked (12) are ISPS compliances with the score of (0.0200). The AHP ranked KSB as the most suitable supply base to be selected with a weight of 0.679 presented of 68%. The other offshore supply base, known as the Tok Bali Supply base, has a weight of 0.321 presented at 32%. While KSB dominates the overall situation, not all elements are in its Favor. Analysing the distance variable, the MTJDA & MVCAA (Northern Section) Oil & Gas Platform (C1.1) data indicates that TBSB has a higher weight of 0.8705 than KSB, which only weighs 0.1295. It was found that Oil and gas operators in the northern section of the MTJDA & MVCAA sector selected TBSB as a logistical base for their offshore operations. This is due to the proximity of the location compared to KSB. It was discovered that operators in the southern region or the offshore area of Terengganu selected KSB as their target. This demonstrates the significant impact of the location distance factor and corroborates the findings of previous investigations. Another contributing element to TSBS's victory over KSB is the difference in charges (C3.2), with TSBS having a weight of 0.6711 and KSB having a weight of 0.3289. It was discovered that a significant number of respondents preferred TBSB over KSB. This indicates that the potential rates charged by TBSB are more dependable and competitive. The other outcome in the selection of supply base between KSB and TBSB that can be compared based on the sub-criterion is displayed in Table 11 above.

Conclusion and Implication

This study offers a comprehensive analysis of the offshore supply base. The text provides additional details on integrating offshore supply bases inside the oil and gas supply chain. The objective is to validate the efficacy of the Analytic Hierarchy Process (AHP) for selecting an appropriate offshore supply base in East Coast Peninsular Malaysia. The alternatives for evaluating the Analytic Hierarchy Process (AHP) approach were determined by analysing pertinent research on the criteria and sub-criteria in the hierarchical model, as well as utilising literature and interview data and have intended to show an expert's point of view for "Factors Affecting the Selection of Supply Base. Offshore supply bases are essential elements of the logistics network that support the oil and gas sector's exploration and production (E&P) activities. These supply bases serve as crucial centres, enabling the smooth movement of materials, equipment, and personnel between facilities on land and platforms in the sea. From the findings and discussion, the literature study emphasises the crucial function these bases play in guaranteeing smooth operations and the significance of strategic base selection. The Kemaman Supply Base (KSB) and the Tok Bali Supply Base (TBSB) in Malaysia exemplify the substantial improvement in operational efficiency that can be achieved through the integration and strategic positioning of supply bases. KSB, the largest fully integrated supply base in Peninsular Malaysia, provides a wide range of services, strong infrastructure, and a strategically advantageous location for firms operating off the Terengganu coast. TBSB, while newer, provides critical support to operations in the North Malay Basin, MTJDA, and MVCAA, offering logistical advantages due to its proximity to these areas. Its proximity to these locations gives it logistical benefits. location, infrastructure and facilities, service offerings, and regulatory compliance. Having a supply base close to offshore installations can decrease transportation costs and transit times. Additionally, advanced infrastructure and extensive services guarantee streamlined and effective operations. Furthermore, adherence to regulatory requirements is essential for preserving operational integrity and mitigating legal and reputational hazards. Ultimately, the performance of offshore exploration and production (E&P) activities heavily relies on offshore supply bases such as KSB and TBSB. Energy organisations can achieve optimal logistical operations, increased productivity, and cost-effectiveness by thoroughly evaluating location, infrastructure, services, and regulatory requirements. Well-managed supply bases will continue to be crucial to operational success in the evolving offshore oil and gas industry. However, this study may have constrained the criteria and sub-criteria used to assess offshore supply bases, neglecting other pertinent considerations such as environmental effects, technical improvements, and long-term sustainability. Relying solely on literature reviews and expert interviews can induce biases. The limited sample size and lack of diversity among the experts interviewed may restrict the applicability of the findings. Moreover, emphasising the East Coast of Peninsular Malaysia implies that the results may not be relevant to other areas of distinct geopolitical, economic, and environmental circumstances. Furthermore, the dynamic character of the oil and gas business, which is affected by volatile oil prices, regulatory modifications, and technical progress, could potentially affect the applicability of the study's results in the long run. Although AHP is a resilient method for making decisions, it largely depends on the discernment and coherence of the decision-makers. Variations in decision-making can impact the dependability of the outcomes. In order to conduct a thorough evaluation of offshore supply bases, future studies should consider a broader range of variables, such as environmental sustainability, technical advancements, and long-term strategic advantages. By employing a mixed-method approach that integrates quantitative data, such as performance indicators and cost analysis, with qualitative insights, a more comprehensive understanding can be achieved. Enhancing the generalizability of the findings can be achieved by incorporating a broader and more varied selection of industry experts. Performing comparative analyses across several geographical areas can aid in identifying universal standards for selecting a supplier base and highlighting region-specific aspects that impact decision-making. Conducting longitudinal studies to monitor the performance of certain supply bases over time can offer valuable insights into the long-term effects of strategic supply base selection and the flexibility of the criteria employed. Integrating the Analytic Hierarchy Process (AHP) with other decision-making frameworks and advanced analytical approaches such as fuzzy logic and multi-criteria decision analysis can improve the strength and dependability of the evaluation process. An examination of the impact of developing developments in the oil and gas sector, such as the increasing use of renewable energy, digitisation, and automation, on the criteria for choosing offshore supply bases can offer valuable insights for the future. A more thorough understanding of the consequences of supply base selection can be obtained by incorporating input from a wider array of stakeholders, such as regulatory authorities, local communities, and environmental organisations.

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Table 4: 9-point intensity of relative weight (importance or well-being) scale

Definition	Scale	Significance
Equal importance / Equally good	1	Two preferences contributed equally to the decision
Moderate importance of one factor over another / Weakly	3	Experience and judgements slightly favour one preference over the other
Strong or essential importance / Strongly	5	Experience and judgements strongly favour one preference over the other
Very strong importance / Very strongly	7	A preference is strongly favoured and its dominance is demonstrated in practice
Extreme importance / Absolutely better	9	The evidence favouring one preference over the other is of the highest possible order of affirmation
Intermediate value between the two adjacent judgments	2, 4, 6, 8	Intermediate value between the two adjacent judgments
Reciprocals for inverse comparison		Reciprocals of the above nonzero numbers

Source: Adapted from Saaty (1982)

Table 5:Random index for N = 9

Random Index (RI)									
N	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Saaty 1980

Table 6: Pairwise comparison matrix and weights for the main criterion

Criterion	**C1**	**C2**	**C3**	**C4**	**Priority Weight**
Geographical C1	1	2.1	2.6	2.9	0.4209
Facilities & Infrastructure C2	0.48	1	3	2.5	0.2946
Service & charges C3	0.38	0.33	1	3	0.1806
Regulatory C4	0.34	0.40	0.33	1	0.1039
CR: 0.0898					

Table 7: Pairwise comparison matrix and weights for Sub Criterion Geographical C1

Sub Criterion C1	**C1.1**	**C1.2**	**C1.3**	**Priority Weight**
Distance To MTJDA & MVCAA (Northern Section) Oil & Gas Platform (C1.1)	1	2.0	1.6	0.4306
Distance To Oil & Gas Platform at Terengganu Water (Southern Section) (C1.2)	0.49	1	1.4	0.2928
Outsourced / Inland Area (C1.3)	0.86	0.69	1	0.2766
CR: 0.0819				

Table 8: Pairwise comparison matrix & weights for Sub Criterion Facilities & Infrastructure C2

Sub Criterion C2	C2.1	C2.2	C2.3	C2.4	Priority Weight
Berth facilities (C2.1)	1	3.6	2.4	1.4	0.4237
Warehousing (C2.2)	0.28	1	1.8	1	0.1959
Crew Change (2.3)	0.42	0.57	1	1.6	0.1875
Storage Facilities (2.4)	0.71	1	0.65	1	0.1929
CR: 0.0907					

Table 9: Pairwise comparison matrix and weights for Sub Criterion Service & charges C3

Sub Criterion C3	C3.1	C3.2	Priority Weight
Service (3.1)	1	4	0.8000
Charges (3.2)	0.25	1	0.2000
CR: 0.000			

Table 10: Pairwise comparison matrix and weights for Sub Criterion Regulatory C4

Sub Criterion C4	C4.1	C4.2	C4.3	Priority Weight
Custom (C4.1)	1	2.1	2.1	0.4977
Port Authority (C4.2)	0.48	1	2.1	0.3099
ISPS compliances (C4.3)	0.48	0.48	1	0.1923
CR: 0.0510				

Table 11: Priority Weight and score for Criterion, sub-criterion and alternative

Criterion	Priority Weight	Sub-Criteria	Priority Weight	Score (S)	Alternative	Priority Weight	T.Score (S)
Geographical C1	0.4209	C1.1	0.4306	0.1812	KSB TBSB	0.1295 0.8705	0.0235 0.1577
		C1.2	0.2928	0.1232	KSB TBSB	0.8352 0.1648	0.1029 0.0203
		C1.3	0.2766	0.1164	KSB TBSB	0.8571 0.1429	0.0998 0.0166
	CR for sub-criterion C1: 0.0819						
Facilities & Infrastructure C2	0.2946	C2.1	0.4237	0.1248	KSB TBSB	0.8485 0.1515	0.1059 0.0189
		C2.2	0.1959	0.0577	KSB TBSB	0.8333 0.1667	0.0481 0.0096
		C2.3	0.1875	0.0552	KSB TBSB	0.7500 0.2500	0.0414 0.0138
		C2.4	0.1929	0.0568	KSB TBSB	0.8438 0.1562	0.0480 0.0089
		CR for sub-criterion C2: 0.0907					

Service & charges C3	0.1806	C3.1	0.8000	0.1445	KSB TBSB	0.8485 0.1515	0.1226 0.0219
		C3.2	0.2000	0.0361	KSB TBSB	0.3289 0.6711	0.0119 0.0242
		CR for sub-criterion C3: 0.000					
Regulatory C4	0.1039	C4.1	0.4977	0.0517	KSB TBSB	0.7500 0.2500	0.0388 0.0129
		C4.2	0.3099	0.0322	KSB TBSB	0.7222 0.2778	0.0233 0.0089
		C4.3	0.1923	0.0200	KSB TBSB	0.6667 0.2333	0.0133 0.0067
		CR for sub-criterion C4: 0.0510					
CR for main criterion = 0.0921							
FINAL SCORE					KSB TBSB	0.679 0.321	68% 32%

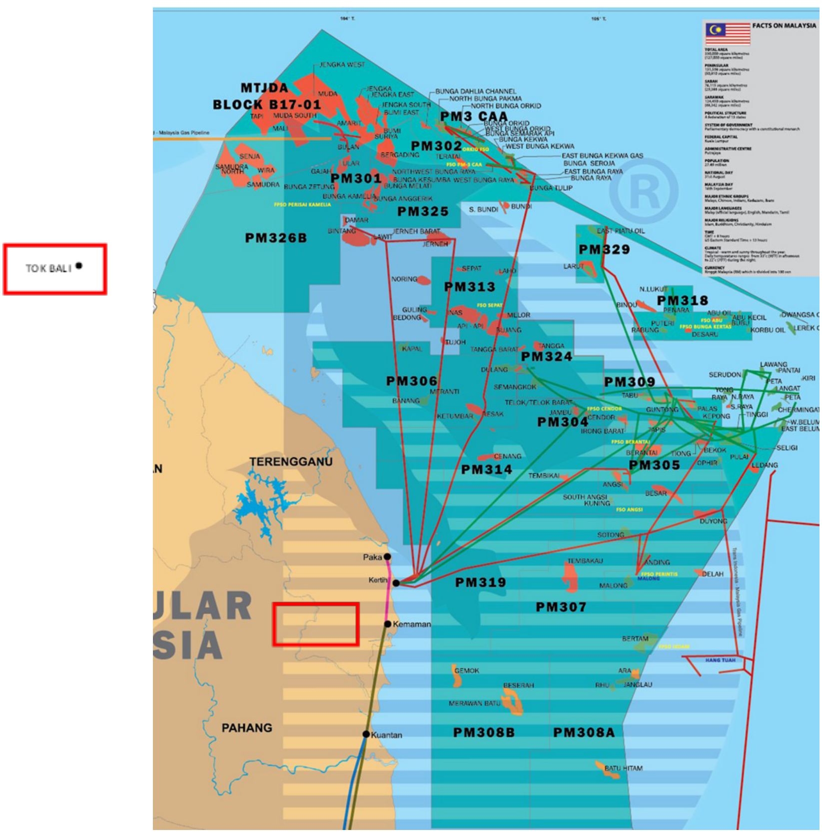

Figure 1: Overview of Oil and Gas Location in East Coast Peninsular Malaysia

Sources: MSGOC

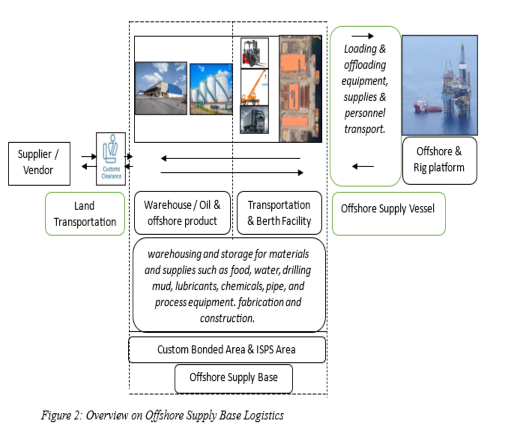

Figure 2: Overview of Offshore Supply Base Logistics

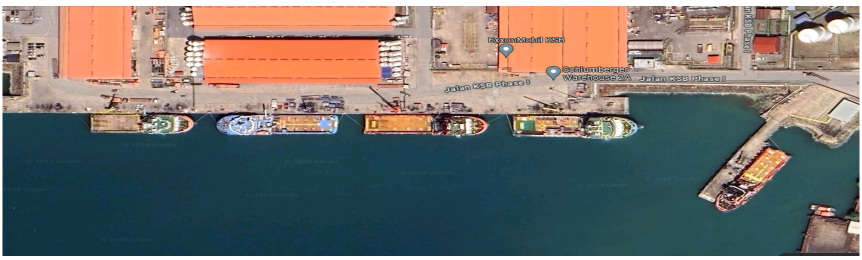

Figure 3: Overview of KSB Jetty Facility

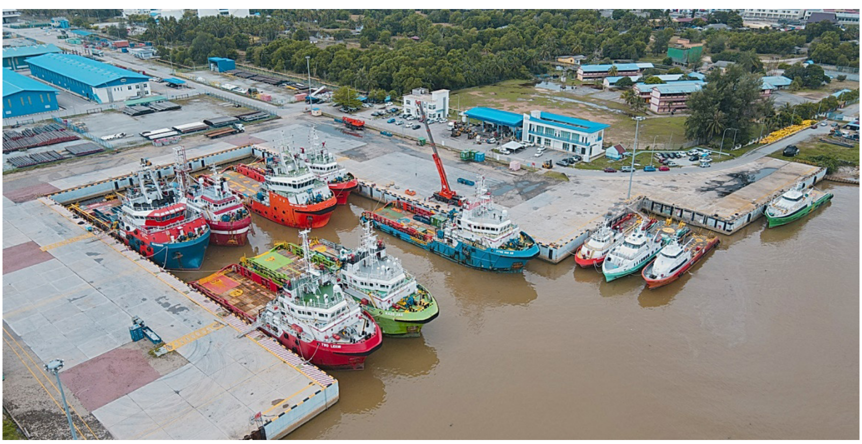

Figure 4: Overview of TBSB Jetty Facility

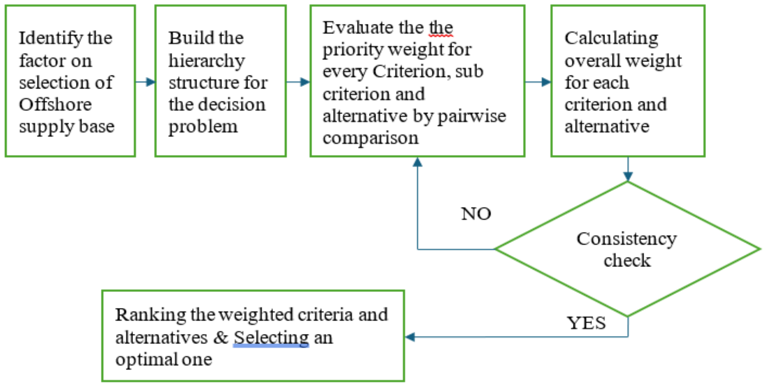

Figure 5: AHP method procedure

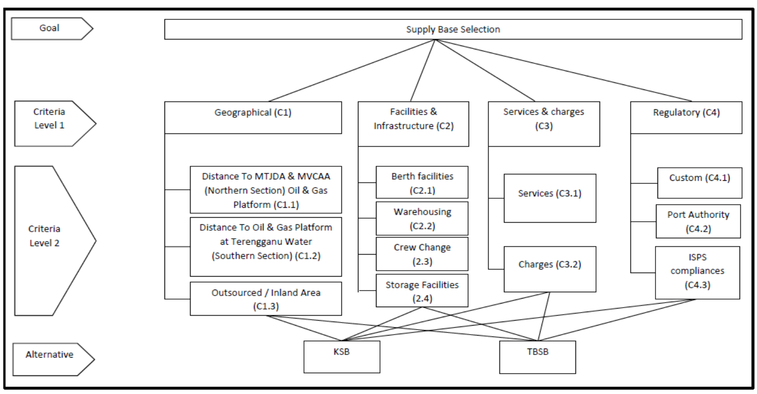

Figure 6: The Hierarchical Structure of Supply Base Selection