International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V68I12P206

Volume 68 Issue 12, 31-36, December 2020
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Agreement Matrix Based on Fuzzy Decision-Making to Rank Ship Berthing Criteria

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Abstract - *Ports exist to serve ships, provide access to navigable waterways, and handle and manage cargo. Thus, selecting a suitable port's dock based on a significant number of criteria is critical to avoiding environmental hazards and property damage. This paper discusses the decision-making problem of ranking criteria for ship berthing. The fuzzy technique for order preference by similarity to an ideal solution tool is utilized to provide multi-criteria decision-making. The ranking process includes listing and evaluating potential alternatives for decision-makers (DM), resulting in the arrangement of priorities based on closeness-coefficient values. The proposed model not only copes with the subjective and imprecise opinions of DMs, but it also integrates their subjective judgments as a collective group decision. In this study, three groups of DMs are used for the selection process to evaluate port docks in Peninsular Malaysia, finding that a higher number of experts in a group results in different orders of criteria. Thus, an agreement matrix is proposed to identify correlations between these DM groups.*

Keywords: *Agreement matrix, Fuzzy TOPSIS, Multi-criteria decision-making, Port's dock, Ship berthing*

I. INTRODUCTION

Maritime transportation is essential to the global economy and provides critical goods (e.g., coal and oil) to regions that need them most. Ships used for sea carriage require ports for berthing. Ports exist to serve ships, provide access to navigable waterways, and handle and manage cargo. According to [1], the selection of a suitable Port's dock is crucial to avoid critical adverse situations, such as environmental pollution and property damage. However, different vessel features and destinations make the port selection a delicate task. Moreover, the logistical costs of shipment are essential factors. Therefore, cost efficiency is a major criterion [2]. In [3], Mandal et al. noted that international ports, including those in Malaysia, faced pressures of handling substantial portions of the nation's trade by ensuring optimal efficiency and decreasing turnaround times. Consequently, they found several important criteria to be considered by vessel operators when choosing a dock for maximizing efficiency, minimizing costs, and preventing damages. This problem can generally be formulated as a multi-criteria decision-making (MCDM) problem, which exists to rank the best option from all feasible alternatives based on known criteria.

MCDM under group decision making (GDM), otherwise known as MCGDM, serves a vital role not only in ranking alternatives with respect to conflicting criteria but also in reaching consensus among groups of humans. This, indeed, involves a high level of uncertainties. Decision-makers (DMs) are normally experts and are the most pivotal characters in the GDM processes. In [4], Naim and Hagras applied the MCGDM model to devise a technique to settle conflicts among individuals' preferences with alternatives ranked on criteria and sub-criteria, followed by the synthesis of preferences into a formula for unanimous approval. Examples of MCDM models include the *all-criterion optimization and co-compromise solution* (VIKOR), the analytic hierarchy process (AHP), and the *technique for order preference by similarity to an ideal solution* (TOPSIS) [5-10]. Based on the literature, one of the most widely used MCGDM methods is TOPSIS, which was introduced in [11]. According to [12], TOPSIS requires the chosen optimal alternative to be the one having the farthest distance from the negative ideal solution and the shortest distance from the positive ideal solution. The negative ideal solution refers to the one that minimizes the benefit criteria and maximizes the cost criteria, whereas the positive ideal solution minimizes the cost criteria and maximizes the benefit criteria [13].

Apart from TOPSIS, wherein the weight of criteria and ratings of alternatives are precisely known, many real-life decision problems are confronted with the reality of imprecise, unquantifiable, and incomplete information [8-10], rendering precise judgments impossible. This is where fuzzy TOPSIS comes into play, wherein criterion weights and alternative ratings are given by linguistic terms and expressed by fuzzy values to represent the imprecise or subjective judgments of DMs. In these cases, fuzzy TOPSIS allows all of the important factors or criteria to be ranked, which, in the case of ship berthing, should be carefully evaluated by handlers to increase efficiency.

Recently, studies have investigated the application of fuzzy MCDM in assessing ports.

Owing to global environmental changes and resource shortages, ports play an essential role in economic development and are considered national investments [14-15]. However, the construction and operation of ports cause environmental pollution problems. To handle such problems, Chiu et al. [14] introduced the *green concept* and formulated a fuzzy AHP model for its purposes. The top-five priority alternatives of green-port operation are given as hazardous-waste handling, air pollution prevention, water pollution prevention, port greenery, and habitat quality maintenance [14]. In [15], Chiu and Lai formulated a model for determining the optimum investment in port development from the national investment perspective by considering consumer and investor viewpoints. In [16], Hsu evaluated a safety index using the fuzzy AHP model to assess safety factors from the viewpoint of marine port pilots, by which port managers and ship carriers could develop policies to improve ship berthing safety at docks in Kaohsiung Port, Taiwan. Ying et al. [17] identified primary factors motivating cruise liners to select specific ports-of-call by using fuzzy AHP. Then, they provided information to port operators to improve their management strategies by simultaneously attracting more cruise ships, thus contributing to the incomes of the port employees and regional economies. All studies in this related area have focused on finding an optimum approach to enhancing port subsistence and development. However, they have neglected the importance of port-docking criteria for ship berthing.

With respect to TOPSIS, Wang et al. [18] and Lima–Junior and Carpinetti [19] proposed *fuzzy TOPSIS* to improve supply-chain performance. Awasthi et al. [20] and Yong [21] implemented fuzzy TOPSIS for location planning and selection. Estay–Ossandon et al. [22] utilized two decision-making techniques (i.e., Delphi for capturing expert knowledge and fuzzy TOPSIS for ranking municipal solid-waste treatment). They found that the fuzzy-based model was more consistent than conventional approaches. A case study on smart-glass evaluation was presented in [23] to demonstrate the potential of hesitant fuzzy linguistic term-sets-based TOPSIS, which was a novel and reliable approach for processing qualitative DM judgments. Han and Trimi [24] invited five experts to provide linguistic ratings on selected criteria using a fuzzy TOPSIS technique with FLINTSTONES (a software tool) to generate aggregate scores for assessing and evaluating reverse logistics practices in social-commerce platforms. They utilized TOPSIS fuzzy sets that assumed some DMs were not fully confident in their evaluation, making decisions uncertain. The uncertainty problem in decision-making can be better-evaluated using fuzzy-set representation, even when many DMs contribute [24].

In this study, an analysis of ship-berthing criteria with respect to various alternatives of port-docking is presented. Initially, two DMs assess 13 criteria for analysis. Then, to analyze the effect of the number of DMs (i.e., group size) in relation to the consistency of the evaluation, the number of DMs is increased from two to four and finally to six. All DMs are taken from the marine transportation industry and maritime academics in Peninsular Malaysia. Noticeably, the ranking orders vary with respect to the numbers of DMs. For this reason, a comparison to check the correlation in agreements matrices is presented. The rest of the paper is organized as follows. In Section 2, several definitions are provided, including those of fuzzy sets, fuzzy numbers, and fuzzy TOPSIS methods. In Section 3, a numerical example of ranking criteria for ship berthing is explained. Section 4 concludes the paper.

II. PRELIMINARIES

This section reviews the basic concepts and methods related to this study. These include the definition of fuzzy-set theory, the concept of fuzzy numbers, and the step-by-step procedure for the fuzzy TOPSIS model.

Table 1. Linguistic term of the criteria

inguistic term	Fuzzy triangular number $(\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$
Very Few (VF)	(0.00, 0.00, 0.25)
Few (F)	(0.00, 0.25, 0.50)
Average (A)	(0.25, 0.50, 0.75)
Good (G)	(0.50, 0.75, 1.00)
Very Good (VG)	(0.75, 1.00, 1.00)

A. Fuzzy Sets

The theory of fuzzy sets was proposed by Zadeh in 1965 [25]. Fuzzy set $\tilde{A}$ in X can be defined as two-tuple values, as follows: $\tilde{A} = \{\langle x, \mu_{\tilde{A}}(x) | x \in X\rangle\}$. A fuzzy set, $\tilde{A}$, in a universe of discourse, X, is characterized by a membership function, $\mu_{\tilde{A}}(x)$, that maps each element, x, in X to a real number in the interval [0, 1].

B. Fuzzy Number

A fuzzy number [25] is defined as a fuzzy set having the membership function that satisfies normality conditions. The most commonly used fuzzy number in decision making is the triangular fuzzy number (Figure 1), owing to its intuitive membership function.

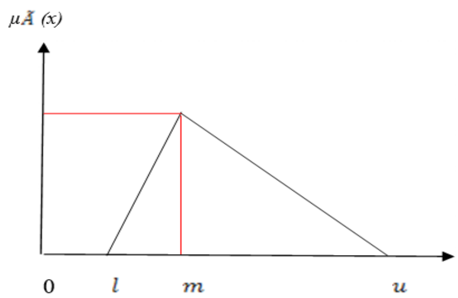

Fig. 1 Triangular fuzzy number $\tilde{A}$

The most probable value of x (the evaluation data) is given by the maximal grade of $\mu_{\tilde{A}}(x)$ (i.e., $\mu_{\tilde{A}}(x) = 1$) with the value of x at m. On the contrary, the least-probable value of the evaluation data is generated with the value of x at l or u, where it gives a minimal grade of $\mu_{\tilde{A}}(x)$ (i.e., $\mu_{\tilde{A}}(x) = 0$). Constants u and l represent the upper and lower bounds of the available area for data evaluation. Both of these constants reflect the fuzziness of the data evaluation.

With respect to the concept of fuzzy numbers, a fuzzy linguistic term [25] was proposed by Zadeh to model linguistic concepts, such as 'low', 'medium,' and 'high.' Each term (e.g., 'low') is called a linguistic term set. Generally, a linguistic term/scale can be interpreted as a term whose values are words from a natural language.

In this paper, a linguistic term/scale of 1–10 for rating the criteria and the alternatives is applied. Table 1 illustrates the linguistic scale on the weight of alternatives, whereas Table 2 lists the linguistic terms and fuzzy ratings for the criteria.

Table 2. Linguistic terms of the alternative weight

Linguistic term	Fuzzy triangular number (l, m, u)
Very few (VF)	(0.00, 0.00, 0.25)
Few (F)	(0.00, 0.25, 0.50)
Average (A)	(0.25, 0.50, 0.75)
Good (G)	(0.50, 0.75, 1.00)
Very good (VG)	(0.75, 1.00, 1.00)

C. Fuzzy Topsis

In this study, the fuzzy TOPSIS method under GDM was utilized for the analysis, which is an established technique that is widely applied to real-life decision-making problems.

Let the MCDM problem have n alternatives ($A = \{A_1, A_2, \ldots, A_n\}$), m criteria ($C = \{C_1, C_2, \ldots, C_n\}$) and p DMs or experts ($E = \{E_1, E_2, \ldots, E_p\}$). The ratings of alternatives versus the criteria provided by each DM can be concisely expressed in a decision matrix format as $X = (x_{ij})_{n\times m}$, where the weighting vector is given as $W = \{w_1, w_2, \ldots, w_m\}$. Specifically, x_{ij} $(i = 1,2,\ldots,n; j = 1,2,\ldots,m)$ and w_j $(j = 1,2,\ldots,m)$ are the fuzzy ratings of alternative A_i with respect to criterion C_j, and the w_j is the weight of criterion C_j. A standard procedure of fuzzy TOPSIS can be summarized as follows [11], [26]:

Step 1: Decision matrix $X = (x_{ij})_{n\times m}$ is normalized using the following equation:

$$r_{ij} = \frac{x_{ij}}{\left(\Sigma_{j=1}^{m} x_{ij}^2\right)^{\frac{1}{2}}}, \quad (1)$$

where x_{ij} with $j = 1,2,\ldots,m$; $i = 1,2,\ldots,n$ are fuzzy numbers based on the fuzzy sets defined in the previous section.

Step 2: Form a weighted normalized decision matrix:

$$v_{ij} = w_j\, r_{ij}\,. \quad (2)$$

Step 3: Determine a positive ideal solution (PIS) and a negative ideal solution (NIS):

$$A^* = max\{v_1^*, v_2^*, \ldots\ldots v_n^*\}, \quad (3)$$

$$A^- = min\{v_1^-, v_2^-, \ldots\ldots v_n^-\}. \quad (4)$$

Step 4: Calculate the distance of each criterion from the PIS and NIS:

$$d_i^* = \sqrt{\textstyle\sum_{j=1}^{m}(v_{ij} - v_j^*)^2},\ i = 1,2,\ldots,n, \quad (5)$$

$$d_i^- = \sqrt{\textstyle\sum_{j=1}^{m}(v_{ij} - v_j^-)^2},\ i = 1,2,\ldots,n. \quad (6)$$

Step 5: Calculate the closeness coefficient of each alternative:

$$CC_i = \frac{d_i^-}{d_i^* - d_i^-}, \qquad i = 1,2,\ldots,n\,. \quad (7)$$

Step 6: Determine the ranking of all alternatives by comparing the CC_i values.

At this stage, it is expected that each individual of each DM provides his/her own judgment or decision matrix $X = (x_{ij})_{n\times m}$. Then, the individual ranking of each DM is derived with respect to steps 1 to 6. In the proposed Method, the direct approach of GDM [27–28] is implemented to aggregate the DMs' judgments as a collective GDM with respect to their individual final rankings of alternatives. In a similar fashion, we can compute the ranking order of criteria $W = \{w_1, w_2, \ldots, w_m\}$ using the decision matrix $(w_{kj})_{p\times m}$, where $k = 1,2,\ldots,p$ and $j = 1,2,\ldots,m$ are the indices of the DMs and criteria, respectively.

III. RANKING CRITERIA OF PORT'S DOCK FOR SHIP BERTHING

In this section, we present the fuzzy TOPSIS method under GDM for the selection of a port dock for ship berthing. The step-by-step procedure of the proposed Method presented here not only provides the ranking process but also considers the uncertain environment that may exist in the decision-making process. There are four stages to be completed in this process. Firstly, the identification of potential alternatives and criteria. Secondly, evaluation ratings are obtained from the alternatives and criteria. Thirdly, the ranking order of the alternatives using the fuzzy TOPSIS method is determined, and finally, the fourth step involves ranking and construction of the agreement matrix. The details of each of these stages will be discussed in the next section.

A. Identification of Potential Alternatives and Criteria

In order to select a port dock in which a ship will berth, six alternatives were considered, as shown in Fig. 2 (we refer the reader to the Appendix for further information). Based on the selected alternatives, 13 criteria were identified based on the DMs' expertise. The alternative port docks consisted of: Hub Port-A_1Container Port-

A_2Transshipment Port-A_3Ferry Terminal-A_4Petrochemical Port-A_5And LNG Terminal-A_6.

The criteria evaluated by the DMs consist of Demand for a commodity-C_1Quality of transport service in international trade-C_2Level of competitiveness of Port-C_3Port tariff structure-C_4Political influence-C_5, Agreement with the port user-C_6, Total Cost of transit-C_7Weather condition/climate-C_8, Source and destination of cargo-C_9, Characteristic and quantity of commodity-C_{10}Method of transport-C_{11}Cost of port service-C_{12}And Port facility-C_{13}. The DMs are allowed to choose among all these criteria during the assessment.

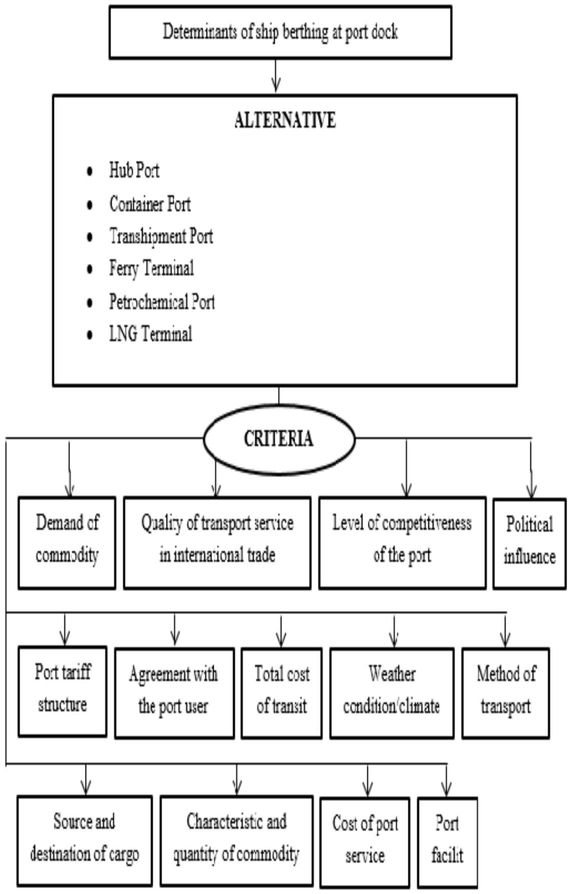

Fig.2 Criteria for ship berthing at the different types of port dock

B. Evaluation Rating of Alternatives and Criteria

Each group provides an assessment with regards to each attribute by applying the linguistic terms shown in Table 1 and Table 2. The aggregation weights of the alternatives are shown in Table 3.

Table 3. The aggregate rating weights of the alternatives.

Alternatives	DM_1	DM_2	Aggregate weights
A_1	(0.75,1.00,1.00)	(0.75,1.00,1.00)	(0.75,1.00,1.00)
A_2	(0.75,1.00,1.00)	(0.75,1.00,1.00)	(0.75,1.00,1.00)
A_3	(0.75,1.00,1.00)	(0.50,0.75,1.00)	(0.62,0.87,1.00)
A_4	(0.75,1.00,1.00)	(0.00,0.00,0.25)	(0,37,0.50,0.62)
A_5	(0.75,1.00,1.00)	(0.75,1.00,1.00)	(0.75,1.00,1.00)
A_6	(0.75,1.00,1.00)	(0.75,1.00,1.00)	(0.75,1.00,1.00)

C. Determining the Ranking Order of the Alternatives using the Fuzzy TOPSIS Method

Next, the distance of each alternative A^+, and A^- can be derived using Eqs. (3–6). The distances obtained were used to calculate the closeness coefficients (CC_i) via Eq. (7), where the final results are listed in Table 4.

Table 4. The closeness coefficient is based on each criterion.

	C_1	C_2	C_3	C_4	C_5	C_6
d-	2.824	2.238	2.501	2.615	1.831	2.517
d+	1.444	1.916	1.872	1.684	2.254	1.642
CC_i	0.662	0.539	0.572	0.608	0.448	0.605

C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
2.395	1.557	2.863	2.631	1.745	2.13	2.35
1.872	2.796	1.358	1.562	2.414	1.931	1.743
0.561	0.358	0.678	0.627	0.419	0.524	0.574

C. The Ranking and Construction of the Agreement Matrix

By comparing the CC_i values (Table 4), it was found that $C_9 > C_1 > C_{10} > C_4 > C_6 > C_{13} > C_3 > C_7 > C_2 > C_{12} > C_5 > C_{11} > C_8$. Therefore, the criterion 'source and destination cargo' (C_9) was selected as the most important criterion for a ship when berthing at a port dock, while the criterion 'weather condition' (C_8) had the lowest ranking.

Table 5. Criterion ranking for different DM group numbers.

	The number of DMs in a group		
Criterion	2 DMs	4 DMs	6 DMs
C_1	2	1	1
C_2	9	3	3
C_3	7	4	2
C_4	4	8	11
C_5	11	13	6
C_6	5	2	5
C_7	8	5	10
C_8	13	12	13
C_9	1	7	4
C_{10}	3	10	7
C_{11}	12	11	8
C_{12}	10	9	9
C_{13}	6	6	12

Likewise, the same calculation was applied to different DM group numbers, i.e., four and six DMs, and the criterion ranking order for these different groups of DMs were ascertained, as shown in Table 5. The first rank agreed by the group of two DMs is 'source and destination of cargo' (C_9), whereas the first rank for the groups of four and six is 'demand for the commodity.' (C_1). The same second rank was found by the DM group sizes of four and six, which is 'level of competitiveness of the port.' (C_3).

Next, the correlation value is obtained using a statistical technique, which allows us to measure how two data sets are correlated to each other. By using the standard correlation calculation, the correlation values for each DM is compared and summarised in Table 6.

Table 6. The agreement matrix for different group numbers of DMs.

Decision Makers (DMs)	2 DMs	4 DMs	6 DMs
2 DMs	-	0.527473	0.401099
4 DMs	0.527473	-	0.560440
6 DMs	0.401099	0.426635	-

In the standard correlation technique, the correlation value ranges between -1 to 1, where each extreme value implies a strong negative, and positive correlation, respectively. Based on Table 6, it can be seen that the correlation values for all pairs are positively correlated. Moreover, from Table 6, it can be seen that the increasing number of DMs, from two to four and four to six, produces rank diversion up to 50%, i.e., they have coefficient values of approximately 0.5. However, when the DM group number increases from two to six, the correlation is reduced to 40%, implying a correlation coefficient of the ranking of only 0.4.

IV. CONCLUSION

In this paper, a well-known MCDM method named Fuzzy TOPSIS was utilized to select a port dock for ship berthing. A systematic numerical example of a real-life application was used to illustrate the decision-making method. This study focused on analyzing opinions from three groups consisting of two, four, and six DMs, where fuzzy TOPSIS was used to determine different criteria ranks for the different group of DMs. The result showed that the attributed weights for a different group of DMs significantly affected the final rankings of the alternatives.

The fuzzy TOPSIS method is able to deal with subjectivity or uncertainty, which arises due to the judgment of a DM. Attributed weights with small changes in values may bring about significant changes in the final ranks. Comparing the results obtained for higher aggregation values, different ranks were obtained due to the number of DMs. The criterion, 'Demand of commodity'(C_1), ranked second out of 13 criteria when it was evaluated by two DMs. However, when the number of DMs increased, the resultant ranking changed to first out of 13 criteria and became the highest importance among all the considered criteria. Additionally, there were significant changes in the ranking of the criterion 'Port tariff structure' (C_4). In the case of two DMs, it was ranked in 4^{th} place, which then decreased to ranks 8^{th} and 11^{th} for the case of four and six DMs, respectively. Furthermore, criterion C_4 was found to be less critical when considered by a large group of DMs.

It was observed that the scores for a large number of DMs gave better rankings than those given by a small group of DMs. Hence, the opinion of a larger group affects the ranking and becomes more synthesized. However, from the agreement matrix, changing the number of DMs from two to four and from four to six would not give a high impact. Both produced correlation coefficients of 0.5 and positively affected by 0.04 in a large group number of experts (four DMs to six DMs). On the other hand, as the number of DMs increased from two to six, the higher number of experts lowered the correlation value, suggesting that the ranks were inconsistent. Thus, it is crucial to consider a large number of DMs when making important decisions. On the other hand, adding one or two additional DMs is unnecessary, as based on the results shown in Table 6, as the trade-off between better decisions versus time-consumption is poor.

Finally, based on the assessment shown here, it can be concluded that the associated data set which contains useful attribute values is correlated to the number of members in a group of DMs. By aggregating the multiple fuzzy linguistic preferences in groups of DMs, appropriate attribute weights can be obtained. It was shown here that the assessment of a larger group of DMs was considered to be more objective and unbiased compared to small groups of DMs. The different number of members in a group of experts has shown the importance of considering the uncertainties among DMs. In the future, we will focus on investigating appropriate methodology to determine the effectiveness of the number of DMs in multi-criteria group decision-making and implementing advanced theories including Type-2 Fuzzy Sets to improve the rankings [29, 30].

ACKNOWLEDGMENTS

This work was supported by Centre for Research Excellence and Incubation Management (CREIM), Universiti Sultan Zainal Abidin (UniSZA) and Talent and Publication Enhancement-Research Grant, Universiti Malaysia Terengganu (UMT).

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APPENDIX

The ships may have few options or alternatives to stop by, whether in a hub port, a container port, a transshipment port, a ferry terminal, a petrochemical terminal or a liquefied natural gas (LNG) terminal. Below are some descriptions of the port docks in Malaysia.

Hub Port

A hub Port facilitates the majority of global trade to regional hubs and distribution networks. A global network of rail, roads and pipelines functions as arterial veins to ports where ships are loaded and unloaded. There are five major global ports, which are Singapore, Hong Kong, Shanghai, Rotterdam and Long Beach.

Container Port

A container Port is a terminal to facilitate and transship cargo containers between transport vehicles for onward transportation, for example trains and trucks. Loaded containers are stored for relatively short periods, whilst waiting for onward transportation, whilst unloaded containers may be stored for longer periods awaiting their next use. Containers are normally stacked for storage, and the resulting stores are known as container stacks. Port Klang, Malaysia is considered as one of the busiest container port in the world.

Transshipment Port

A transshipment Port is a shipment of goods to an intermediate destination, which then travels to another destination. A transshipment may include only seaborne transfer or both seaborne and inland waterway ship transfer. However, in both cases, the transshipment is counted twice in terms of the Port's performance, since it handled twice by the waterside crane and separate unloading from arriving ship A, waiting in the stack, and loading onto departing ship B. Example of Transshipment Port is Port Tanjung Pelepas, Malaysia.

Ferry Terminal

Penang Terminal is the only port operator in Malaysia that operates ferry services that connects the two terminals of Georgetown and Butterworth. The ferry service is the main mode of transportation for residents or tourist between the two terminals.

Petrochemical Port

Petrochemicals are chemical products derived from petroleum. One of the main petrochemical ports in Malaysia is in Kerteh. Kerteh Port has a supply base for oil and gas activities. It also provides services for steel mills, crude oil terminal, gas processing and refining plants.

LNG Terminal

In most cases, LNG terminals are ports used exclusively for the purpose of importing and exporting LNG. LNG is the form used to transport natural gas over long distances, often by sea. The world's largest LNG is at Bintulu Port.