Analysis of coastal state regulation impact on the capacity optimization of floating storage and offloading using multi criteria decision making

H Susilowati¹, R O S Gurning¹, K B Artana¹, A A B Dinariyana¹ and H A Setyono²

¹Marine Engineering Department, Sepuluh Nopember Institute of Technology, Surabaya
²Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), Jakarta

Abstract. Floating Storage and Offloading (FSO) that is opted by most of offshore company to directly resettle crude oil and/or gas from the well during exploitation period has been commonly known as the results of the tanker conversion due to technical similarity as well as time and cost consideration. Some of the users are not aware that the compliance with the Coastal State and/or State’s institutional body where FSO will be permanently operated can be triggered to a great impact within the building and operation stages. Hence, the optimization process to satisfy all aspects such as technical, economical, and regulatory need to be conducted properly. This paper is aimed to analyse the impact of the regulations issued by a Coastal State of where FSO will be permanently operated toward the vessel capacity in the optimization process. The method used to analyse impact of regulation in optimization process is multi criteria decision making (MCDM). The mandatory provisions to convert the ship domestically is put into the influence factor of the ship optimization. Analysis result shows that cost is the most determining criteria, while coastal state’s regulation among top three aspects that influence on FSO capacity optimization

1. Introduction

Floating Storage and Offloading (FSO) is a floating shelter facility in the oil field production facility before crude oil is sold or transferred. In market, FSO is generally built through conversion and modification of oil tanker rather than building from the scratch due to time constrain to meet the on-stream-field development target. The use of oil tanker has a strong advantage for large populations and sizes in the shipping market providing flexibility in choosing the required capacity, herein determine FSO capacity shall be calculated at the earliest stage within the plan of oil field development due to its significant contribution to time and cost overall of oil field development project. The choice of the size of oil tanker to be converted involves many quantitative and qualitative criteria.

Most optimization of FSO capacity only takes into account on technical and economic aspects while the regulatory aspects of the coastal country are not widely considered. This paper aims to find out if a regulation issued by a coastal country where FSO to be operated affects the optimization of FSO capacity. Government can be benefited too by further developing regulation that stimulates business environment in maritime sector.

Many parameters are analysed when determining the design of FSO. These parameters include capacity, type of hull (double hull or single hull), loading and unloading systems, mooring systems, and others. This paper limits the problem only to select which size of converted oil tanker that fitting the
best scenario for required FSO capacity. The regulations included in the criteria are the regulations that are directly related to the size of the ship.

A number of studies have examined several aspects of the use and selection of FSO had been done in the past. These studies include combining evaluations for FSO and FPSO (Floating Production, Storage, and Offloading) as in some cases, both FSO and FPSO share similar characteristics on calculation of oil storage capacity. Kurniawati calculated the economic aspect in the form of a charter rate using economics calculation, such as IRR (Internal Rate of Return) [1]. Biasotto examined the selection of oil tankers that will be converted into FPSOs by evaluating aspects of the ship's hull configuration [2]. Jose and Phillipe analysed the structure of the conversion FPSO to ensure the safety of the operation [3]. Neto stated that the critical aspects that need to be explored in the conversion of oil tanker to FSO or FPSO is the selection of oil tankers to be converted and the project start up structural and installation design in conjunction with large production facilities [4].

All FSOs in Indonesia are currently the result of conversion from tankers. Paik and Thayamballi [5] explained the advantages of converting oil tanker into floating installations are:

1) Capital costs will be lower,
2) Time is faster,
3) Availability of facilities for conversion,
4) In general, the requirements for project supervision are lower.

The capacity size of selected oil tanker determines conversion costs. Paik and Thayamballi mentioned the factors that affect storage capacity are:

1) Rate of Production,
2) Size of parcel export cargo,
3) Difference in grade of fluid that entering storage,
4) Character and efficiency of the offloading system,
5) Buffer capacity requirements.

The simplest way to determine FSO capacity is to determine the large parcels of the off-take tankers that most often come to the FSO, then adding the reserve capacity in anticipation of tanker delays. Optimization of storage capacity can be done with a cost-benefit analysis that calculate the hull size, export system capacity, production cycle and related costs [5]. Ogwo offered a new model for measuring FPSO capacity [6]. The results of the modelling show that the FPSO storage capacity calculated only based on gross production and offtake tanker traffic will be less when compared to the capacity calculated by involving other parameters such as basic sediment and water, drying facilities, number and size of compartments, and others.

Multi Criteria Decision Making (“MCDM”) is a method to select alternatives. This method could accommodate wide information, incomplete, uncertainty, and even contradictory between one criterion to another [7]. Triantaphyllou and Mann argued that MCDM is not a tool that determines the final decision, but rather as a decision support tools [8]. P. Sen et al explained that MCDM needed at the situation where [9]:

1) There are spaces for possible action that can be taken,
2) Each action has consequences,
3) The decision maker should conduct weight calculation.

Studies concerning the selection process of converted oil tanker to FSO or FPSO and selecting ship for investment in general have been also conducted. Sener and Ozturk selected the ship by using Quality Function Development (QFD) method [10]. This method combines user preference with ship attribute. Xie et al conducted ship selection by using Dhempser – Shafer theory [11]. It combines qualitative and quantitative attributes. Yang et al combined Fuzzi and Evidential Reasoning to select the ship under certainty [12]. Evidential Reasoning implemented to minimize the uncertainty. Bulut and Duru used Analytical Hierarchy Process (AHP) and Fuzzy Set to select the ship based on investment criterion [13]. Chang [14] proposed the development of Fuzzy – AHP method which is better than AHP in time complexity.
This paper utilises AHP technique to assess optimization of FSO capacity as AHP has slight advantage over FAHP, TOPSYS, and ANP on its simple procedures for respondent to weighing research criteria and sub criteria given in the research questionnaire. The end result is also considered accurate to support decision making through normalizing process to determine priority values of the pairwise comparison matrix.

2. Methodology

The FSO design will follow and be unique for each oil and gas field. The oil and gas field used in this paper is one of the fields in the Java Sea, Indonesia. Oil and gas field production data is 30,000 barrels oil per day (bopd), while the largest lifting parcels are 315,000 barrels (bbls) and an average of 200,000 bbls. The mechanism and size of the parcel are determined in coordination meetings which are conducted once a month. At this meeting the seller will convey the amount of cargo available on the storage tank. The data above is based on parcel records for the past year in the said oil and gas field.

The depth of the sea where the FSO will be tethered is 45 meters, while the highest significant wave (Hs) in the Java Sea reaches 2 meters and occurs in December, January and February. The frequency of occurrence of Hs above 2 meters is less than 40%, and Hmax is less than 4 m [15]. The assumptions used for the duration of bad weather result in the off-take tanker being unable to lifting are 7 days.

Crude oil which is accommodated on the FSO meets the requirements of API Gravity 35.2 and does not require heating from the heating system. Water is assumed to have been separated on the processing facility so that the water participating into the FSO is minimal and does not require settling time.

The method used to conduct an assessment is the Analytical Hierarchy Process (AHP). AHP was first introduced by Thomas L Saaty in 1980. Belton and Gear proposed the AHP variant to reduce deficiencies in AHP, namely the possibility of reversing the ranking if there is an addition of one alternative that is the same as one of the existing alternatives [16]. Belton and Gear propose normalization in the process of determining priority values.

AHP steps with the normalization process are as follows [17]:

1) Develop a hierarchy of criteria and alternatives,
2) Make a pairwise comparison of the decision making matrix. The pairwise comparison matrix is described as follows:

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**Figure 1.** Flowchart of Analytical Hierarchy Process (AHP)
3) Normalize the decision matrix and calculate the priority on the matrix to determine the weights of the criteria \( w_1, w_2, \ldots \) and \( w_n \). In calculating the weight of each criterion, the pairwise comparison matrix must be normalized. The relative weight of the criterion \( k \)th obtained by calculating the average value of each row in the matrix column. The equation used is as follows:

\[
W_k = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}}, \quad k = (1,2,3 \ldots n)
\]

Symbol \( a_{ij} \) is \( i \) rows and \( j \) column at order matrix \( n \) and \( w_k \) is weight from \( k \) criteria at matrix.

4) Check the consistency of the assessment to verify the results

The equation used is:

\[
CR = \frac{CI}{RI}
\]

CI is calculated by the equation as follows:

\[
CI = \frac{\lambda_{max} - n}{n - 1}
\]

Symbol \( \lambda_{max} \) is maximum eigen value which is calculated by the equation below:

\[
\lambda_{max} = \frac{\sum_{k=1}^{n} w_k a_{jk}}{w_j}, \quad j = (1,2,\ldots n), \quad k = (1,2,\ldots n)
\]

CR should be less than or equal to 10% to be accepted. The high CR will require further assessment of the assessment previously given.

This paper is limited only to the optimization of the size of the FSO originating from the conversion of tankers. The size of the trading tankers to be chosen is in the form of Panamax, Aframax and Suezmax. Table 1 shows the tankers population data as of February 1, 2018 according to Scorpio Tanker Report [18], Fearnleys’s time charter rate as of November 2018 [19], and used tanker prices according to Intermodal as of November 2018 [20]:

| Vessel Type | DWT       | Number of Vessel | % of Fleet | Time Charter 1 year (USD/day) | Secondhand Price (5 yrs) |
|-------------|-----------|------------------|------------|-------------------------------|-------------------------|
| Suezmax     | 120,000 - 199,999 | 554              | 22.1       | 22,000                        | 44,500,000              |
| Aframax     | 80,000 - 119,999  | 626              | 18         | 17,000                        | 31,000,000              |
| Panamax     | 55,000 - 79,999   | 85               | 1.5        | 13,500                        | 29,000,000              |
Loading capacity is 98% of the maximum capacity of the FSO because it complies with the provisions of the classification bureau that alarm overflow will turn on at 98%. The goal to be achieved through this MCDM is to obtain optimal capacity. The assumptions that used are oil and gas fields in the Java Sea, Indonesia. The criteria that will be compared through pairwise comparison include technical, economical, and regulation. The explanation of these criteria is as follows:

1) Lifting Frequency
All tanker sizes that are assumed can be used, but the lifting frequency will determine which tanker will be chosen because of the flexibility factor in the operation especially in relation to the top tank. Calculation of lifting frequency for a month is influenced by the amount of lifting, production and weather assumptions. Based on the above assumptions, the minimum lifting frequency obtained for Panamax size is 4 times a month, Aframax 2 times a month, and Suezmax at least once a month. The lifting frequency is determined at a monthly meeting involving oil sellers, buyers, and carriers. At the meeting the seller stated how much crude oil was available in the holding facility the following month. The buyer will transport the crude oil amount stated by the seller and appoint a transporter to retrieve it. Delays in retrieval generally occur due to weather factors.

2) Execution Costs and Ship conversion
Costs for the execution of tankers depend on the size, supply and demand in the market, and age. In this study the age of the tanker to be executed is assumed to be 5 years old with a double hull structure. Scope of Work conversion and FSO lifetime are assumed to be the same. The costs to be used in the evaluation of MCDM are the assumptions of the cost of tanker execution because the conversion costs will be linear according to the size of the tanker.

3) Production Flexibility (top tank, curtailment)
Top tanks occur when crude oil can no longer be accommodated by FSO. When crude oil reaches 98% of FSO capacity, the alarm overflow is automatically activated to stop crude oil filling the storage tanks. Termination of filling this crude oil will result in a reduction in production and even stop production. Such condition shall be highly avoided because it will cause huge losses. Loss on receipt of crude oil is the most important. There is a potential that the amount of oil production will not be able to reach as it did before the filling stops. This is due to reservoir pressure factors. This flexibility factor is very important so it needs to be included in the evaluation criteria.

4) Non–tax State Revenue
The government establishes fees as state revenues rather than taxes on port services and leases of waters where FSO is installed. Charged fees refer to the size of the ship, so the longer the ship is used as a terminal, the greater the cost to be incurred.

5) Oil Spill Equipment
Oil spill equipment is used in anticipation of the occurrence of oil spill when offshore oil and gas activities take place. The size of the oil boom will depend on the size of the ship used as a storage. The longer the ship, the longer the size of the oil boom needed is also longer.

6) Pump Rate
The ability of the pump to drain oil from the FSO to the offloading tanker determines the time needed for the lifting process. The longer the pump offloads, the higher the potential for top tanks if at the same time the volume of oil entering the FSO is large.

7) Population
Research on the market situation that reflects the tankers population need to be done because it will determine the price and duration of procurement. The more tanker available in the market, the more competitive the price will be and the project owner has flexibility when determining the type and size of tanker to be used.

8) Availability of shipyards
Government regulations require conversion to be carried out domestically. This regulation was issued to further enhance the capabilities and competitiveness of the local maritime industry. The project owner needs to analyse the availability of shipyard size before executing the project. The limitations of shipyards that are capable of converting tankers will pose a risk of increasing
conversion costs. This is because the time needed to convert will be longer when the appropriate shipyard is working on another project. Indonesia has 4 (four) shipyards whose size can accommodate the conversion of Panamax size tankers and there is only 1 shipyard sufficient for the conversion of Aframax and Suezmax.

9) Living Quarter Capacity
Living Quarter will accommodate ship crew and other crew. The FSOs Living Quarter can also be modified so that operators from other facilities are placed in FSOs. The living quarter capacity generally follows the tanker size.

10) Fuel Oil Consumption
The use of fuel will follow the engine capacity on the ship. The ship's machinery generally follows the size of the ship. Besides that, fuel consumption is also influenced by the lifting frequency, because the more frequent the lifting frequency, the greater fuel consumption. This is one example of a contradictory problem that deserves to be resolved through MCDM. According to the design, fuel consumption for Panamax is smaller than Aframax, but because the lifting frequency on Panamax vessels is more frequent, fuel consumption can be greater than Aframax.

The following figure is used to decompose the criteria that is already concluded above into a hierarchy and scale the criteria based on the fundamental scale of intensity of importance on an absolute scale.

![Figure 2. Decomposition of evaluation criteria into hierarchy](image)

The selection process will involve an expert who has more than 15 years’ experience in the conversion of tankers. The expert will be asked for an assessment of the above criteria. The tool that will be used for analytical hierarchy process analysis is Expert Choice software.
3. Result
In the previous section, the objectives, selection criteria and alternatives that will be processed through AHP have been explained. A pairwise comparison matrix is made for each criterion and alternative. Pairwise comparison criteria are made to determine the relative weights of each criterion. Assessment of each criterion is made on a matrix pairwise comparison. Table below is a pairwise comparison result between criteria:

| Table 2. Pairwise Comparison of Criterion |
|----------------------------------------|
| CRITERION | Lifting Frequency (LF) | Execution and Conversion Cost (EC) | Production Flexibility (PF) | Non-Tax State Revenue (NTSR) | Oil Spill Equipment (SE) | Pump Rate (PR) | Population (PL) | Shipyard Availability (SA) | Living Quarter Capacity (LQ) | Fuel Consumption (FC) |
|-----------|------------------------|------------------------------------|-----------------------------|-----------------------------|------------------------|----------------|-------------------|--------------------------|------------------------|---------------------|
| 1         | Lifting Frequency (LF) | 1                                 | 1/7                         | 1/7                         | 7                     | 7              | 1/7               | 1/7                      | 1/7                    | 1/7                 |
| 2         | Execution and Conversion Cost (EC) | 7 | 1                         | 1/7                         | 9                     | 9              | 7                 | 5                       | 5                     | 9                 |
| 3         | Production Flexibility (PF) | 1/7 | 1/7                        | 1                         | 9                     | 9              | 7                 | 5                       | 5                     | 9                 |
| 4         | Non-Tax State Revenue (NTSR) | 1/7 | 1/7                        | 1/7                         | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |
| 5         | Oil Spill Equipment (SE) | 1/7 | 1/7                        | 1/7                         | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |
| 6         | Pump Rate (PR) | 1/7 | 1/7                        | 1/7                         | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |
| 7         | Population (PL) | 0 | 0                         | 0                           | 0                     | 0              | 0                 | 0                       | 0                     | 0                |
| 8         | Shipyard Availability (SA) | 6 | 16                      | 6                           | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |
| 9         | Living Quarter Capacity (LQ) | 1/7 | 1/7                        | 1/7                         | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |
| 10        | Fuel Consumption (FC) | 1/7 | 1/7                        | 1/7                         | 1                     | 17             | 5                 | 5                       | 5                     | 1/7                |

Table 2 shows that the result of pairwise comparison between lifting frequency criterion and execution cost is 1/7. It is mean that execution and conversion cost criterion is more very strong important than lifting frequency based on Saaty’s like-chart. Meanwhile, lifting frequency is more moderate important than production flexibility criterion.

The next step is to make alternative pairwise comparisons on each of the criteria. Reviewers were asked for their opinions on the alternatives for each of the criteria. The pairwise results of alternatives to each criterion are as follows:

| Table 3. Pairwise comparison of alternatives |
|---------------------------------------------|
| CRITERION | Alternative | Panamax | Aframax | Suezmax |
| Lifting Frequency (LF) | Panamax | 1 | 1/7 | 1/7 |
| | Aframax | 7 | 1 | 1/3 |
| | Suezmax | 7 | 3 | 1 |
| Execution and Conversion Cost (EC) | Panamax | 1 | 1/7 | 1/7 |
| | Aframax | 5 | 1 | 1 |
| | Suezmax | 5 | 1 | 1 |
| Production Flexibility (PF) | Panamax | 1 | 1/5 | 1/5 |
| | Aframax | 5 | 1 | 1 |
| | Suezmax | 5 | 1 | 1 |
| Non-Tax State Revenue (NTSR) | Panamax | 1 | 1 | 1 |
| | Aframax | 1 | 1 | 1 |
| | Suezmax | 1 | 1 | 1 |
| Oil Spill Equipment (SE) | Panamax | 1 | 1 | 1 |
| | Aframax | 1 | 1 | 1 |
| | Suezmax | 1 | 1 | 1 |
| Pump Rate (PR) | Panamax | 1 | 1 | 1 |
| | Aframax | 7 | 7 | 1 |
| | Suezmax | 7 | 7 | 1 |
| Population (PL) | Panamax | 1 | 1 | 1 |
| | Aframax | 1/5 | 1 | 5 |
| | Suezmax | 1/7 | 1/5 | 1 |
| Shipyard Availability (SA) | Panamax | 1 | 1 | 1 |
| | Aframax | 1/3 | 1 | 7 |
| | Suezmax | 1/7 | 1/7 | 1 |
| Living Quarter Capacity (LQ) | Panamax | 1 | 1/5 | 1/5 |
| | Aframax | 5 | 1 | 1 |
| | Suezmax | 5 | 1 | 1 |
| Fuel Consumption (FC) | Panamax | 1 | 1 | 1 |
| | Aframax | 1 | 1 | 1 |
| | Suezmax | 1 | 1 | 1 |
Table 3 shows that Aframax tanker is more very strong important than Panamax type in lifting frequency criterion since the value of pairwise comparison is 1/7. Meanwhile, Suezmax type is same important as Panamax in fuel consumption criterion.

After obtaining a rating preference assessment from the reviewer, the calculation is done to determine the priority criterion. This Criterion priority shows the relative weights of each criterion. By using Expert Choice software, criterion priority is obtained as follows:

| Table 4. Criterion Priority |
|-----------------------------|
| Execution and conversion cost | 0.371 |
| Shipyard availability         | 0.218 |
| Population                    | 0.131 |
| Lifting frequency             | 0.077 |
| Pump rate                     | 0.068 |
| Fuel consumption              | 0.043 |
| Production flexibility        | 0.035 |
| Living quarter capacity       | 0.024 |
| Non-tax state rev.            | 0.017 |
| Oil spill equipment           | 0.017 |

The pairwise comparison criteria results shown in table 4 show that the execution and conversion cost criteria have the highest relative weight. This explains that this criterion has the highest preference degree and is the most important consideration in determining the capacity or type of vessel.

The second criterion after execution costs is the criteria for shipyard availability. This criterion includes the regulatory aspect because the obligation to convert inside the country is a mandatory provision from the Government. The capacity of the ship to be converted will refer to the size of the existing shipyard.

The third consideration is the ship population. Population is important because it is based on the principle that the more vessels available, the more competitive the price will be. The ship population is still correlated with the criteria for ship execution costs.

The assumption thus far is that the aspects of production and lifting are the most important considerations not shown in table 4. Lifting frequency has a relative weight of the fourth order while production flexibility is seventh. This shows that operations in the field are considered to be still manageable with the choice of existing vessel types. Other regulatory criteria, namely the provision of non-tax state revenue and the obligation to install oil spill equipment, are considered to have no significant effect on the ship type selection process.

The final step in AHP is synthesizing alternatives priorities across all criteria to determine the final goal. The results of synthesis using the Expert Choice are as follows:

| Table 5. Final Decision |
|-------------------------|
| Combined instance -- Synthesis with respect to: |
| Goal: TANKER SELECTION |
| Overall Inconsistency = 0.10 |

The synthesis results in table 5 show that the type of ship with the highest relative weight is Panamax based on the assumptions given above. This is consistent with the results of the criteria matrix which places the costs of execution and conversion as the most important criteria. Panamax type ships are the cheapest ships when compared to the Aframax and Suezmax types. This type of ship is the most can be
accommodated by domestic shipyards. The criteria for production flexibility and lifting frequency can still be accommodated by Panamax type vessels with adjustments to operations in the field.

The analysis results show that inconsistency is 10% and according to Saaty, then the AHP process can be continued. Sensitivity analysis is carried out to determine ranking changes if there are changes in inputs. The sensitivity analysis results graph are as follows:

![Figure 3. Sensitivity Analysis Graphics](image)

A few modifications made to the input criteria still showed no change in ranking. Thus it can be stated that the AHP analysis carried out is already robust.

4. Conclusion

This paper aims to find out if a regulation issued by a coastal country where FSO is installed will affect the optimization of vessel capacity. The analysis result in Table 4 shows that shipyard availability has second highest relative weight with value 0.218, second order after execution and conversion cost as the highest rank. It means that coastal state regulation to convert tanker domestically has significant role at optimization process. The most optimal vessel size selected is Panamax type, which is the cheapest vessel and could be converted in more shipyards than Aframax and Suezmax type tanker.

Technical, economical, and regulatory criteria make it possible to integrate with this method so that an optimal decision is made. The use of MCDM is not the final method of determining capacity, but can be used as a means of supporting decision-making at managerial level. Detailed engineering calculations and costs need to be done for follow-up decisions at managerial level. Determination of vessel capacity still requires many more criteria as the basis for its evaluation. Further research is needed on the optimization of vessel capacity by involving more criteria such as cabotage law provisions and applicable auction regulations in the country.

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