Modelling Of Water Supply Cost For Offshore Platforms

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Abstract: An offshore platform like other industries requires water resources to support daily operation and activities. Supplying water to offshore platform mainly executed in two conventional ways: transported using offshore supply vessel and self- produced onboard platform using seawater desalination process commonly known as a freshwater generator. An alternative method such as water reuse or water recycling also received growing attention as one of a promising integrated solution for improvement of water resources. However, each water supply options have different characteristics and limitations in term of supply capacity, cost associated and level of water quality. Hence, it's difficult to identify which water supply sources that fulfil the demand and cost-effective. This paper proposes a new mathematical model namely Economic Water Supply Model (EWSM) for the operating cost function that includes the most representative variables in the process. This model enables decision-makers and owners to assess the economic value from the different sources of water supply for the offshore platform. The calculation of these extended cost function also enables a detailed comparison to be made of the various water sources from an economic of view in order to analyze the effects of supply capacity for cost-effective of various suppliers. In this sense, a model of the structure costs associated with each of the available water supply technologies can be useful input for future design, planning and operational stage of offshore water supply process.

Index Terms: Offshore platform, water supply, offshore supply vessel , freshwater generator , water reuse ,economic water supply model

1. INTRODUCTION

WATER resources is one of the most important utility systems is mainly support systems of equipment operation and living quarter area in offshore platform. Fresh water is necessary for offshore applications such as industrial usage and to provide potable water for workers. Supplying a constant and regular of fresh water and potable water required for the essential daily needs. [1] stated that potable water is important for a small community in platform itself to some facilities such as cafeteria, living quarters, management and other support functions. The offshore environment differs from land-based oil production scenarios which is water resources is commonly supplied by Offshore Supply Vessels (OSV). OSV play a major role to supply water and other supplies to support offshore platform operation regardless of deep or shallow water activities. Based on a study by [2] who worked on problems related to current form of water supply, OSV depend directly on weather and navigation compatible with characteristics of the vessel type. Thus, sometimes interrupt the delivery time and can resulting in the delaying of water supply. Freshwater can be self-generated on-board platform using desalination system. Seawater desalination is the process of converting seawater into consumable water using seawater desalination plant. Small desalination plant (SDP) are also known as freshwater generator (FWG), stationary or mobile, dedicated for the supply of drinking and industrial water in remote areas, hotels, hospitals are also available for ships and offshore platforms [3]. Seawater desalination is another option of providing freshwater supply and promising solution to overcome the water scarcity in offshore platforms. The use of seawater desalination plant on offshore platforms is preferable due the several advantages as discussed by [4]. Various studies have been carried out to analyze economic benefits of desalination system compared to water transport particularly in water stress area [5]–[7]. This is mainly supported by advancement in desalination technologies that resulting in the declined trend of desalination cost. Beside conventional water supply using OSV and FWG, an alternative method such water reuse or water recycling also received growing attention as one of promising integrated solution for improvement of water resources [8]–[10]. Potential of water reuse for offshore platform application is recently studied by [2], [11].The authors found that significant energy savings and environment efficiency can be obtained by utilize the water reuse onboard offshore platform. However, each water supply options have difference characteristics and limitations in term of supply capacity, cost associated and level of water quality [12]. As example , the long distance between supply base to offshore platforms represents a major challenge in logistics supply chain, furthermore OSV is exposed to weather and sea condition uncertainty. Thus, selection of best water option is influenced from the capability of water supply operation to fulfill water demand and effective supply with less cost. Based on study conducted by [13], the major changes of water supply on board is not only related to water production but also with better planning of water supply tend to increase operating efficiency, better productivity and profitability. The idea of supply model to offshore platform can be trace back from [14] works on technoeconomic model in 1988. [14] stated that the supply operation is one of the major factors that influencing the cost of offshore operations and affects the cost of other activities. He proposed a technoeconomic model as a method of studying the characteristic of logistic support and of designing a system for securing effective supply to an offshore platform. Various study deduced the important of cost water model for economic and environmental efficiencies. [5], [15]–[18]. The development of various of economic water models have been widely used to study water supply problems however focus on mainland water resources. Intensive literature has found there is no current cost model was developed specifically for offshore water supply. The only approach used is by referring to technical guideline by [19].

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Therefore, this paper constitutes useful models to assist platform owners and managers to identify the most efficient and cost effective of water supply sources and strategy. The aim of this paper to analyze the cost effects of three supply methods using a novel economic water supply model. The application of this model was applied Mobile Offshore Production Unit (MOPU) which is the oil rig platform located at east of Malaysian.

2. METHODOLOGY

2.1 Development of Economic Water Supply Model (EWSM)

An overview of the EWSM for offshore platform developed for this study is presented in Fig. 1. The EWSM consists of two parts, namely freshwater water supplied using OSVs from the onshore supply base, supplied by self- generated desalination unit located in offshore platform and re-use water from the treated on-site wastewater treatment plant (WWTP). EWSM calculates the quantity of water which is needed from the OSV and the amount of extra water needed (more than water demand). Excess water commonly can be supplied by the desalination process or wastewater treatment. The capacity of each specific sources determines the supply limits. The water demand from the user sectors required to feeds into the EWSM to determine the supply limits. For the supplying water by OSV, the capacity limit is determined by the quantity of water that has been transferred by the OSV. In case of the desalted water, the supply limit is the desalination plant's capacity and the supply limit of wastewater treatment plant are also determining by the capacity of its plant.

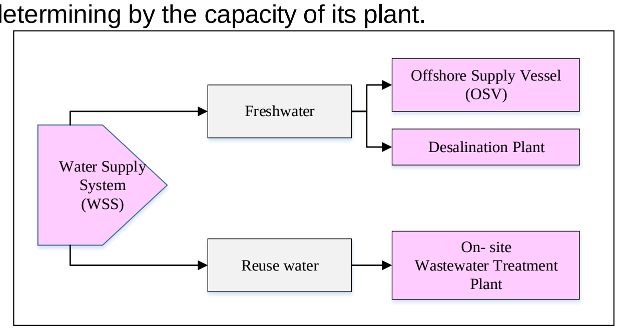

Fig. 1: *Water supply model in offshore platform*

2.2 Model Formulation

The proposed Economic Water Supply Model (EWSM) was established based on three (3) supplies method consisting direct supply from offshore supply vessel, water generation using FWG desalination unit and wastewater treatment plant (WWTP). The EWSM developed is the cost model of supplying water which can assist the planners and decision makers in decision making to calculate the overall cost of water supplied using OSV, FWGs and WWTPs, and to determine which types of water supply source will be employed for cost-efficient in order to satisfy the user's demand and the goal of suppliers. EWSM was divided into three (3) sub-models are OSV economic model, FWG economic model and WWTP economic model.

2.3 EWSM for OSV

EWSM of OSV was applied for the supplying of water to offshore platforms using OSV consider that each supply vessel starts its trip at the supply base with completely empty cargo. Then water is transported by OSV on a regular basis from supply base to offshore platforms. After the first trip, OSV will turning back to the supply base to reload the water and start a new trip in order to fulfil the demand of water from the current platform and deliver to other offshore platforms. This process will be repeated until the water demand is satisfied. At this time, OSV must return to the onshore supply base, known in the model as virtual port, to finish its route. The water needed for the supply purpose has been purchased directly from the onshore supply base. In this model, the various attributes of the total cost for supplying water via OSV are examined includes transportation and water purchased cost. The total cost of water supplied via OSV was calculated using equation 1 as shown below:

$$C_{TotalOSV} = C_{osv} \times V_w \qquad (1)$$

Where,

$C_{TotalOSV}$ = total cost of water supplied

V_w = volume of water supply

C_{OSV} = cost per m^3 (USD/ m^3).

Hence, the cost of water supply via OSV is formulated as follows:

$$C_{OSV} = 2\frac{C_{tr}}{M_{OSV}} + C_{wp} \qquad (2)$$

Where,

C_{osv} = cost per m3 (USD/ m3)

C_{tr} = cost of transportation per m3 (USD/ m3

C_{wp} = cost of water purchased per m3 (USD/ m3)

M_{OSV} = capacity of water per trip (m3/ trip).

The transportation cost considers the cost of transporting freshwater from supply base to offshore platform. The associated transportation cost, C_{tr} is the outcome of two attributes which are the day rate cost, C_{dr} and fuel cost, C_{fuel}. The transportation cost will then be calculated by multiplying the day rate of OSV by duration of vessel chartered and by vessel contingency factor for delays due to weather condition which is set at 0.05-0.8. The duration of vessel chartered is the total time needed for one complete trip. On the other hand, vessel contingency factor for delays due to weather condition such as waves, wind and sea currents [20], [21] represents the factor that significantly impact vessel operation and transportation cost. The equation to calculate the transportation cost was adopted from equation mentioned by [22] as follows:

$$C_{tr} = C_{dr} \times t \times (1 + f_{ves}) + C_{fuel} \qquad (3)$$

Where,

C_{dr} = cost of day rate (USD)

t = duration of vessel chartered per day (day)

f_{ves} = vessel contingency factor for delays due to weather condition (%) is constant

C_{fuel} = cost of fuel consumption per day (USD/day).

In addition to the above, the cost of fuel needed for a single OSV to perform the water supply task to offshore platform is given by the following:

$$C_{fuel} = DFC * D_{sea} * Pr_{fuel} * N_{main} * Oil_{corr} \quad (4)$$

Where,
DFC = daily fuel consumption (tons of fuel)
D_{sea} = days at sea
Pr_{fuel} = price of fuel (USD)
N_{main} = number of main engines (constant)
Oil_{corr} = lube & diesel oil correction factor set as1.15 (constant).

The location of offshore platform is one of the factors that contribute to the transportation cost. The relationship between transportation cost and location of offshore platform will be represented by distance of platform to and from onshore supply base. In order to embed the new factor mentioned above, Equation 3 is modified as:

$$C_{tr} = (C_{dr} \times ({}^{distance}/_{24\ speed}) \times ((1+ f_{ves}) + C_{fuel}) \quad (5)$$

Transporting water from supply base required from the supplier to provide certain amount of water for a trip. Therefore, the cost of water purchase from the supplier also will be one of the important factors will influence the cost of water supplied. The cost of water supply normally has been calculated by accumulating the cost per unit volume of water and the total volume of water. Cost of water per unit volume always depending on the market price and water is charged per cubic meter (m^3). Therefore, the formula is as expressed below:

$$C_{wp} = C_w \times V_{wp} \quad (6)$$

Where,
C_{wp} = cost of water purchased per m^3 (USD/ m^3)
C_w = cost per m^3 of water per m^3 (USD/ m^3)
V_{wp} = volume of water supply per day (m^3/ day)

As discussed above, factors affecting the cost of water supplied via OSV must be considered in cost calculation. This is to ensure the accuracy of the cost for optimization purpose later in the next section. Finally, the total water cost of water supply using OSV then become:

$$C_{OSV} = \frac{C_{tr} + C_{wp}}{V_{wp}} \quad (7)$$

2.4 EWSM for FWG

Cost is become one of major factor in implementing FWG desalination technologies. There are three types of costs associated with FWG system as mentioned in the literature. These include the capital cost (CAPEX) as well as operating cost (OPEX) which then formed the final cost known as total water cost (TWC). CAPEX for a desalination plant typically are associated with the construction of the over-all infrastructure [23], [24] and including all standard equipment and material. The construction cost of plant is 50-80% of the initial investment cost and the remaining 20- 50% are cost of design, licensing and loan of investment [23]. However, some cost has been absorbed as part of platform installation cost. The cost evaluation method that have been developed by [25] can be represented as Equation 8 below:

$$C_{FWG} = \frac{({}^{I_o}/_{n}) + C_{op}}{M_{FWG}} \quad (8)$$

Where,
C_{FWG} = cost of water using desalination per m^3 (USD/m^3)
I_o = capital cost (USD), n is day of service
C_{op} = operation cost (USD)
M_{FWG} = capacity of water produced per day (m^3/day)

Operating costs commonly calculated on annual or annual allotment basis involving two parameters which are the fixed and the variable cost. Fixed cost include insurance and amortization, and variable cost include labour, energy, chemicals and maintenance [23].

$$C_{FWG} = \frac{({}^{I_o}/_{n}) + C_{fix} + C_{var}}{M_{FWG}} \quad (9)$$

The equation assumed that every year the desalination unit produces the same amount of water and have the same operation cost. In offshore case, labour is required to operate and maintain the FWG. Hence, an important cost has been considered into the original equation to cater on location factor which is transportation cost. Transportation cost in FWG desalination cost model is a cost of transporting of maintenance labour, C_{trlab} to the offshore platform. Thus, by considering the mentioned parameter, new desalination cost can be formulated as:

$$C_{FWG} = \frac{({}^{I_o}/_{n}) + C_{fix} + C_{var} + (C_{trlab} \times p)}{M_{FWG}} \quad (10)$$

Where,
C_{fix} = fixed cost includes insurance and amortization per year (USD/ year)
C_{var} = variable cost (cost of labour, energy, chemical and maintenance) per year (USD/ year)
C_{trlab} = cost of transportation of labour for maintenance per year (USD/ year)
p = distance/ speed (Nm)
M_{FWG} = capacity of water produced per year (m^3/year)

C_{fix} and C_{var} can be written in percentage (%), which is percentage from the total capital cost, I_o. Thus, equation is as follow:

$$C_{FWG} = \frac{\left(\frac{I_o}{n}\right) + (g.I_o) + (f.I_o) + (C_{trlab} \times p)}{M_{FWG}} \quad (11)$$

Where,
g = rate of fixed cost (%)
f = rate of variable cost (%)

Hence, the final total cost of seawater desalination can be simplified as given:

$$C_{FWG} = \frac{\left(\frac{I_O}{n}\right) + (g + f)I_O + (C_{trlab} \times p)}{M_{FWG}} \quad (12)$$

2.5 EWSM for WWTP

There is an alternative in obtaining water demand in offshore platform by treating the wastewater or called water reuse. Water reuse using wastewater treatment plant (WWTP) cost model consists of two mains costs as described by [26] encompassing the capital cost, I_o and operation cost, C_{op}. Cost relationship include in this case, the capital cost for WWTP is not considered in this calculation because WWTP is a compulsory equipment in offshore platform whereby offshore platforms are self-contained units with all facilities including grey/ black water disposal system or known as water treatment system [27]. The cost for WWTP has been calculated by considering that every year the WWTP produces the same amount of water and have the same operation and maintenance cost. So that, the cost of watersupply by WWTP, C_{WWTP} are as follows:

$$C_{WWTP} = \frac{C_{op}}{M_{WWTP}} \quad (13)$$

Where,
C_{WWTP} = cost of water supply using WWTP per m^3 (USD/m^3)
C_{op} = operation cost (USD)
M_{WWTP} = capacity of water produced per year (m^3/ year).

3 Data Collection

Data was collected from various sources both from primary and secondary data. Some of important primary data obtained from through field survey and technical manuals meanwhile secondary data are mainly obtained from scientific journal [28] [20], [21], [23], [24], [29], [22], [5] and [30]. Two importants data were aquired are operational data and financial data as shown in Table 1 to Table 3. The operational data is used for determination of physical of supply sources purpose such as specifications of supply vessels, freshwater generator and WTP, capacity for each supply, supply operation time. The financial data is used for determination of commercial viability purpose such as charter cost, investment cost and maintenance cost.

TABLE 1: *OFFSHORE SUPPLY VESSEL DATA*

Parameters	Value	Unit
Charter rate per day	4200	USD
Contingency factor	40	%
Capacity of water per trip	560	m3
Cost of water purchased	4	USD
Cost of fuel consumption	2	USD/litre
Engine nominal power	1732	kwh
Number of engines	2	n
Engine bsfc	0.198	kg/bkW.h
Engine fuel consumption	816.5	litre /hour
Vessel speed	14	knots
Duration in hours per trip	8	hours/trip

TABLE 2: *FRESHWATER GENERATOR DATA*

Parameters	Value	Unit
Volume of water to be supplied by FWG	60	m3
Capital cost	78000	USD
Year of service	5	years
Percentage of Fixed cost	15	%
Percentage of Variable cost	60	%
Cost of transportation	15432	USD
Capacity of water produced per year	21900	m3/year

TABLE 3: *WASTEWATER TREATMENT DATA*

Parameters	Value	Unit
Volume of water to be supplied by WWTP	15	m3
Capital cost	93000	USD
Cost of operation per day	38.75	USD
Amount of water produced per day	15	m3

The model was tested to offshore platform Oil Rig namely MOPU A with capacity of 24 persons located 150km off Bintulu coast in Sarawak, East Malaysia. The platform data is given in Table 4.

TABLE 4: *MOPU DATA*

General Input	Value	Unit
No. of crew onboard	24	person
Location of platform	81	nm
Water storage capacity	141	m3

4 RESULTS AND DISCUSSION

4.1 Model Functional Test

The analysis is carried out based on set of predetermined supply scenarios as previously mentioned. The analysis intended to establish the argument basis on how economic performances can be assess using this model. The water cost for oil rig offshore platform case study was calculated by proposed model. The calculation was done based on various platform location from shore. This is to determine the effect of platform distance from shore as distance play important factor that influence the offshore water cost. The results obtained were presented in form of a graph of platform location versus cost was plotted as illustrated in Figure 2. The water cost per m^3 of water supply by OSV at zero distance is 4 USD/m^3, which is water price bought from supply base. FWG water cost is 1.25 USD/m^3 and WWTP is 2.58 USD/ m^3. The value obtained is in range with calculated in various paper as cited in [12], [31].

TABLE 5: *RESULTS OF FUNCTIONAL TEST*

Platform Location, nm	Cost (USD /m^3)		
	OSV	FWG	WWTP
0	4	1.25	2.58
50	33.55	2.36	2.58
100	63.10	5.69	2.58
150	92.65	11.23	2.58
200	122.20	19.00	2.58
250	151.75	28.99	2.58

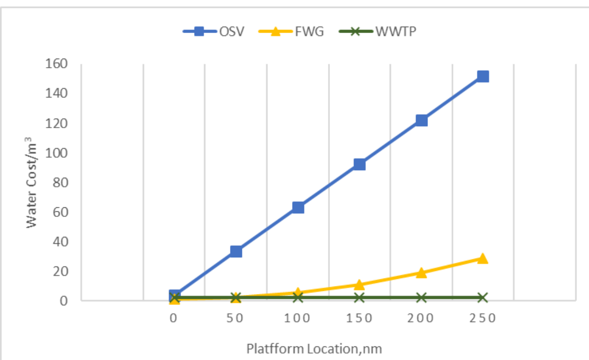

Fig 2: *Graph of water cost at different platform location*

As can be seen from the graph, water cost of OSV has changes proportionally to platform location with 0.591 USD/nm of regression value. Consequently, this is cost of transporting water per nm distance. It suggests a linear trend of the data which depict OSV water cost increasing considerably with distance. This is certainly due to fuel consumption cost effect. Meanwhile, for water cost of FWG it varies slightly with platform location from shore. Even tough location of FWG plant is fixed to platform, there is additional transportation cost for supplying a labor, chemical, replacement component for maintenance works that need to be accounted. As for WWTP, there is no interaction between water cost and platform location as displays in the graph. This is due to the fact WWTP is compulsory equipment which is must have equipment onboard the platform. Therefore, a distance factor can be considerably stated have not affected to its water cost. For the purpose of improving the water supply management and advantage, the conventional water supply approach which considers single supply of each supply method and combination of OSV and production unit as recommended by [2], [19] was studied using this economic model. The water cost simulation is performed to 5 determined scenarios. The proposed utilization of reused water by [11] also taken into the scenario. The calculated water cost presented in Table 6.

TABLE 6: *WATER COST FOR EACH SCENARIO*

Scenario	Volume of supply (m^3)			Cost (USD)
	OSV	FWG	WWTP	
1	100	X	X	3355
2	X	100	X	236
3	50	50	X	1795.5
4	X	X	100	258
5	X	50	50	247
6	50	X	50	1806.5

For the water cost simulation, input water demand is set to 100m^3 for the platform user located 50 nm from port. The results show for scenario 1 with using OSV as single supply, cost of supplying the fresh water is USD 3335. For scenario 2, with using FWG alone, cost of supplying the fresh water is USD 236 which is much lower. However, it should note here that supplying 100m^3 with FWG alone may not be achieved as the general capacity of FWG is around 70m^3/ day [23].Scenario 3 on other hand is conventional water supply planning with 50 % OSV and 50% FWG. The cost constitutes from this supply combination is USD 1795.5. The difference can be seen through 17.4% cost reduction. If consider using 100% supply with WWTP, the saving can be further reduced to USD 258 as in scenario 4. However, WWTP itself unable to meet water demand of 100m^3 at its current capacity which only 15m^3 . For scenario 5, with combination of WWTP and FWG, cost of supplying the fresh water is USD 247. Scenario 6 constitutes about USD 1806.5 for supply combination using WWTP and OSV. The summary of cost simulation is plotted and illustrated in Figure 3.

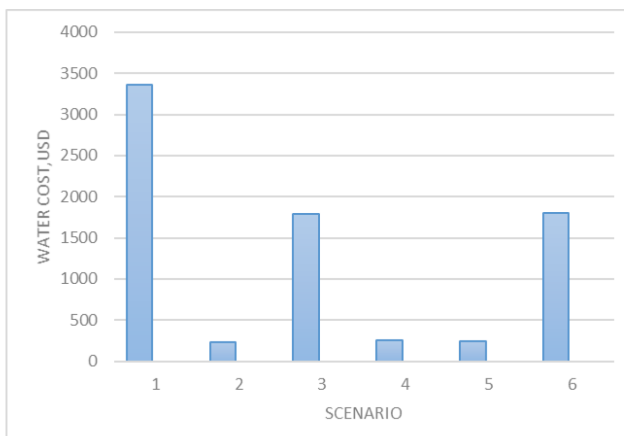

Fig 3: *Water cost according to each scenario*

The graph in Figure 3 noticeably shows that the lowest water cost was obtained from single supply of FWG followed by WWTP. If compared to water supply cost of OSV, its about 93 % saving. However, it should be noted here that the cost saving figure is not significant as FWG and WWTP not be able to fulfil 100% water demand as single supply due to its limited capacity. Therefore, it understood here that supply capacity of each method is another important factor to be considered and observed during the cost analysis. Beside cost and supply capacity, the effect of platform location, equipment weight, and space can have a significant influence over several areas of cost. This cost analysis using proposed economic model can provide a decision maker another important data in the process measuring the economic performance of each method.

4.1 Sensitivity Analysis

For verification purposed, the sensitivity test was performed. The variables assessed in the sensitivity analysis are considered more unpredictable such water demand. Sensitivity analyses were performed to test the variation of output of a model according to variation of sources of input. Sensitivity analyses were conducted by Increasing water demand from minimum to determine maximum water value with 10% interval while other parameters remain the same should increase the water cost. Table 7 reports the computed cost for interval changes of water demand from 0% to 40%.The results in Figure 4 shows that the increasing of interval 10% of water demand respectively to the water cost value which verified the model. Therefore, the algorithm model developed is accurate and reliable for application. The economic model provides the water cost for each water supply method. Furthermore, number of water unit or OSV trip to be employed could be well analyzed using this mathematical model as it provided some degree of capacity changes which are not specified by previous model. This model also provides novel mathematical algorithm to calculate the cost of water supplying using OSV. It is noted that the results of these analyses will influence the decision of future selection of water options. As example, at design stage, this model can be useful to determine which type of water supply to be employed for that platform user. In operation stage which enable user to control economically the amount of water generated from each water supplies

TABLE 7: *WATER COST ACCORDING TO WATER DEMAND*

Interval changes (%)	Volume, m3	Water Cost, USD
0	7.60	31.94
10	8.36	34.77
20	9.12	37.93
30	9.88	41.09
40	10.64	44.25

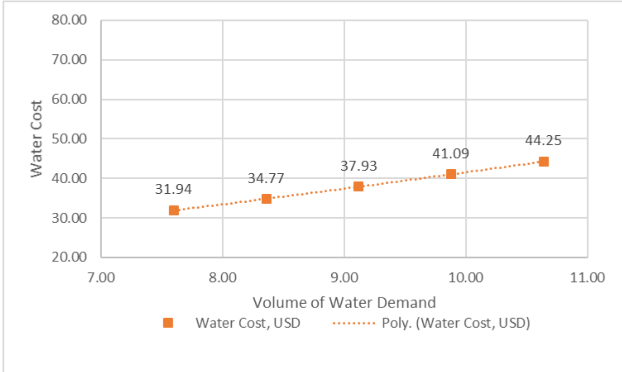

Fig 4: Water *cost sensitivity according to water demand*

5 CONCLUSIONS

In this study, an economic model for offshore water supply based on three supplies method have been successfully developed and verified. It provided a novel platform to assess and compare difference type of water supplies in the form mathematical model. EWSM can serves planners suitable information for determine water cost to offshore platform. The model can produce insights for offshore platform planners at design stage and operational stage to analyses effects of supply capacity for cost effective of various water supply sources. Selection of water supply method must fulfil both cost reduction and capacity of water supply as well. It is noticed that it can be managed and controlled in efficient way, but this will be handled and being part of ongoing another research paper.

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