VESSEL ROUTE OPTIMIZATION FOR OFFSHORE MARINE TRANSPORT

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KEYWORDS

Daily route planning, Excel solver, Offshore marine transportation, Offshore Support Vessel, Sweep algorithm

ABSTRACT

In offshore upstream oil and gas industry, daily logistics and transportation are being served by Offshore Support Vessels (OSV) such as Platform Supply Vessel (PSV), Anchor Handling Tug Supply (AHTS) and Crew Utility Vessel. Marine transportation is then a substantive operating costs. To stay competitive, the cost should be reduced and vessel route optimization can be a tool. The case study company is an exploration and production (E&P) company operating in the Gulf of Thailand. At present, the planning and scheduling tasks of marine vessel in this area are mostly conducted by manual with none use of optimizing tools. Hence, cost and time saving can be expected by the use of enhanced and well-developed vessel route planning. This paper applies the two-phase sweep algorithm to conduct route planning, it is assumed that there are five vessels with varied capacities obtainable to serve offshore daily demands at thirty remote platforms. All demand locations are first to be clustered into groups using polar-angles sweeping method and then refine the routes of vessel for each cluster. All processing phases are implemented using functions and add-in programs of Microsoft Excel. It was noted that the primary stage of clustering plays a very important role to the solution results. However, overall outcomes of process experiments present that the answers are stable and acceptable.

INTRODUCTION

The oil and gas component is generally grouped according to its characteristics and operations being performed. It can be divided into three main parts comprising of upstream, midstream and downstream. The upstream is an initial phase which is normally known as exploration and production or called E&P since its activities relate to exploration and production of petrochemical products such as natural gas, crude oil and condensate.

The upstream business, particularly on working sites that operate offshore, involves with a high investment including risks with possible high rewards. To manage for the optimal return on investment is always a major challenge of this industry.

E&P operating site locations can be both onshore and offshore. The offshore is considered more costly because it faces with bigger challenges comparison to the onshore site. The operating cost, particularly marine transportation cost, at offshore is thus comparatively huge inevitably because of specialty requirements and location disadvantages.

In general, each operating asset comprises of a centralized complex encompassing with several remote platforms scattered over the asset boundary. The complex is normally where the living quarter (LQ) platform is located. Offshore staffs stay at the LQ during off-hours and, on daily basis, going out to work at remote platforms, before coming back to the LQ after missions completed.

The vessels serves daily infield personnel, equipment and material transfer on daily basis. The vessels are generally under long-term time charter contracts. Operating costs such as fuel consumption, wharfage and pilotage fee are accountable and solely managed by the vessel charterer (E&P company). The chartered vessels have individual characteristics and capacities which include numbers of passenger and vessel deck spaces that allow the vessel to carry or accommodate.

At the case study, the vessel routing process is started every morning by a planning officer. The officer receives trip demands every day from production, drilling, well-service, maintenance and safety departments. The routing plan is then arranged manually. However, to establish the vessel routing manually is difficult and cannot give optimal solutions as it can be up to thirty locations needed to visit in a day. Figure 1 shows the vessel route program work flow.

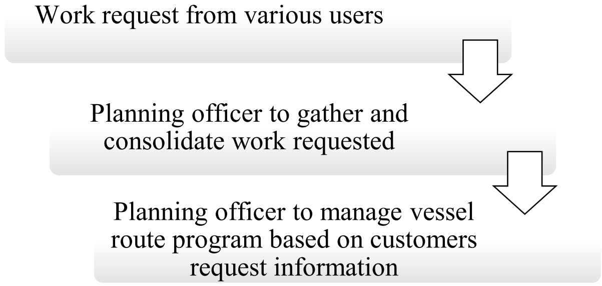

Figure 1: Vessel route program work flow

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The planning officer is accountable for daily route planning and works to serve infield personnel and cargo both outgoing and incoming routes. Since it is currently conducted manually, significant cost and time reduction can be determined by the use of some optimization tools.

The primary objective of this paper is to obtain optimization solutions related to Vehicle Routing Problem (VRP) to conduct vessel route planning. The paper then concentrates on daily offshore infield personnel or deck cargo transfer operations. Supply run between onshore supply base and offshore operating site are therefore not included. Bulk cargo carriage in vessel tanks underneath the deck have also been excluded.

LITERATURE REVIEW

Vehicle Routing Problem (VRP) is similar to Traveling Salesman Problem (TSP) which first written by Dantzig and Ramser in 1959. Liu, et al. (2014) mentioned that the objective of both VRP and TSP are for obtaining the shortest or optimal routes of vehicle and meanwhile capable to serve all required demands. TSP is in regard to one vehicle to serve fleet or group of customers with optimal routes and get backs to original location, whereas the VRP is about two vehicles or more. The offshore logistics is considered more similar to the VRP as generally there are more than one vehicle to serve the demands. The LQ considered as center depot where all paths must start and stop at this location while the remote wellhead platforms regard as demand locations.

VRP can be unraveled by varied optimization approaches such as exact approach, heuristics and meta-heuristics depending on its size and complexity. Heuristic is one of the prevalent approach these days since it requires less processing time but capable to deliver satisfactory outcomes. Two-phase sweep algorithm stands as one of the well-known methods of the heuristic in computational geometry.

Erdoğan (2017) examined that in spite of numerous commercial solution packages utilized to solve the VRP, but these solutions require integration with existing company infrastructures. The software are then needed to be customized for such particular prerequisites.

Microsoft Excel spreadsheet is one of selected solution and considered suitable for the study in view of acquaintance with the interface, ease of utilize, adaptability and accessibility. The built-in capacities in Microsoft Excel are considered standard and adequate for small-to-medium examination.

RESEARCH METHODOLOGY

Background and assumptions

This study uses Universal Transverse Mercator (UTM) coordinate system to identify the platform locations. The UTM is a projection designed to display features on a two dimensional surface.

This paper studies with the following conditions:

Condition 1: Vessel fleet description. Table 1 shows resources (vessels) assumed for this study together with individual capacities.

Table 1: Vessel list and passenger capabilities.

Vessel name	Passenger capabilities
Vessel A	100 passengers
Vessel B	95 passengers
Vessel C	90 passengers
Vessel D	85 passengers
Vessel E	82 passengers

Condition 2: Living Quarter (LQ) platform, location of X = 865817m E and Y = 888640m N (UTM system), referred as the center depot where all offshore staffs stay during off-hours.

Condition 3: Thirty remote platforms with different demands are required to visit as details mentioned in Table 2 below:

Table 2: Offshore installations (remote platforms) coordinates and individual demands.

Platforms	Passenger		X	Y
	In	Out	(Easting)	(Northing)
PF-18	12	0	842858	901599
PF-15	23	0	875100	897851
PF-21	15	0	844448	896479
PF-29	17	1	860950	896950
PF-26	16	0	861721	910145
PF-37	11	1	859297	901594
PF-35	20	0	855369	896130
PF-25	8	0	882519	894349
PF-11	9	1	883550	888634
PF-14	12	0	880688	888692
PF-33	22	0	877407	882663
PF-24	15	0	879898	878799
PF-22	12	0	875046	878799
PF-20	11	1	886299	864351
PF-17	5	0	871808	872728
PF-10	16	1	879098	867198
PF-2	17	0	868734	883966
PF-30	14	1	869123	877838
PF-33A	16	0	890688	893514
PF-19A	9	0	861667	917583
PF-11A	12	0	875536	915085
PF-4A	8	0	883928	913323
PF-6A	15	0	884500	908750
PF-27A	4	0	888927	906915
QP-A	5	1	888725	914540
PF-34A	11	1	899979	889641
PF-24A	13	0	895969	887080

PF-31A	18	0	874069	922763
PF-2A	18	0	875338	919376
QP-S	15	1	899410	829491

Condition 4: Other related conditions are followed:

- No time window limitation.
- No maximum distance limitation.
- Simultaneously visit at the same platform location is not allowed.
- All demands are assumed same priority.
- All constrains must be satisfied and cannot be waived for any reason.

Method Approach

Favinger (2008) explained basic principles of Cartesian coordinates and Polar coordinate system. Cartesian coordinates are used to dot for indicating how far "long" and "up" from the origin point which is x-axis and y-axis consecutively. Figure 2 is an example of the x-axis and y-axis which both equal to 5.

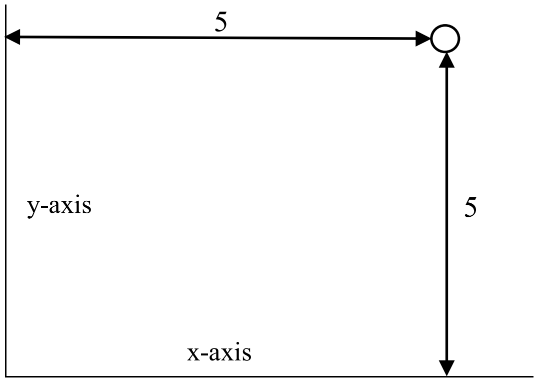

Figure 2: Cartesian coordinates

Polar coordinates are different from Cartesian coordinates as Polar coordinates indicate how "far away" and what is the "angle" of the point. Figure 3 shows that Cartesian coordinates are (5,5) while Polar coordinates provide 7.07 which is the distance away from the original point with the resulted angle of 45 degrees.

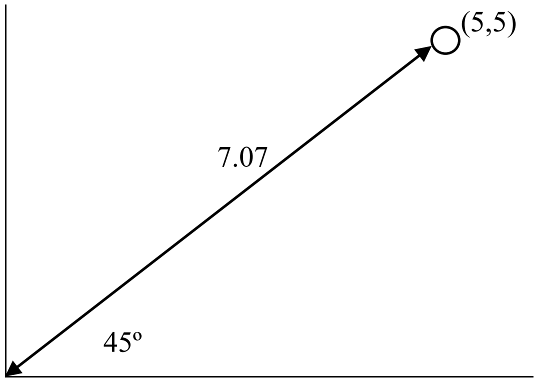

Figure 3: Polar coordinates

Triangle is used to explain how the Cartesian coordinates is turned to Polar coordinates (Figure 4).

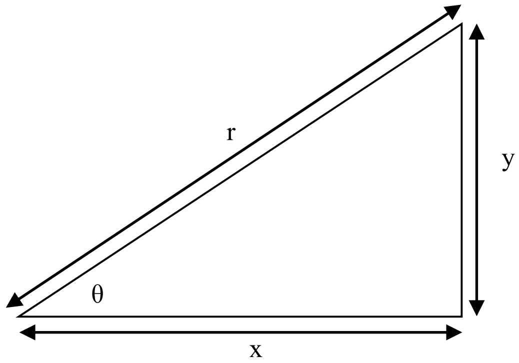

Figure 4: Triangle for conversion between Cartesian coordinates and Polar coordinates

By turning Cartesian system into Polar system, a point of Cartesian coordinates is represented as (x, y) and converting to the Polar coordinates, it will be represented as (r, θ) instead. It can be converted using the formula below:

$$r^2 = \sqrt{(x^2 + y^2)}; \text{ and}$$
$$\theta = \text{Tan-1}(y/x)$$

After getting the polar angle of each demand locations, it first needs to sort the locations according to the increasing order of polar angles in counterclockwise course.

The following approach are generally called sweep algorithm (two-phase heuristic) by cluster-first route-second. Gunadi, et al. (2002) used such algorithm to solve their public transport problem. Wren (1971), Wren and Holliday (1972), and Gillett and Miller (1974) were pioneerly introduced this approach.

Formulate two-phase sweep solution

This step is to sweep the customer locations in radial way or polar radian locations. The polar radian displays the locations in a degree related to the depot location. All processing are completed by existing functions in Microsoft Excel as follows:

- ATAN2 to find arc tangent of the two numbers (x and y).
- DEGREES to convert an angle expressed in radians (ATAN2) to degrees.
- MOD to obtain the remainder after the DEGREES is divided by divisor.
- RANK.AVG to perform ranking against a range of numbers in sequence.

Divide the locations into a set of cluster

In every single sweeping process for demand locations, the sweeping process will be stopped once passenger demands have reached the vessel constrains or maximum capacity. The cluster can then be conducted by grouping the demand locations swept together. The next sweeping process will be continued for the next customer demands until no passenger demands. Figure 5 demonstrates clustered customers after completion of the initial sweep step.

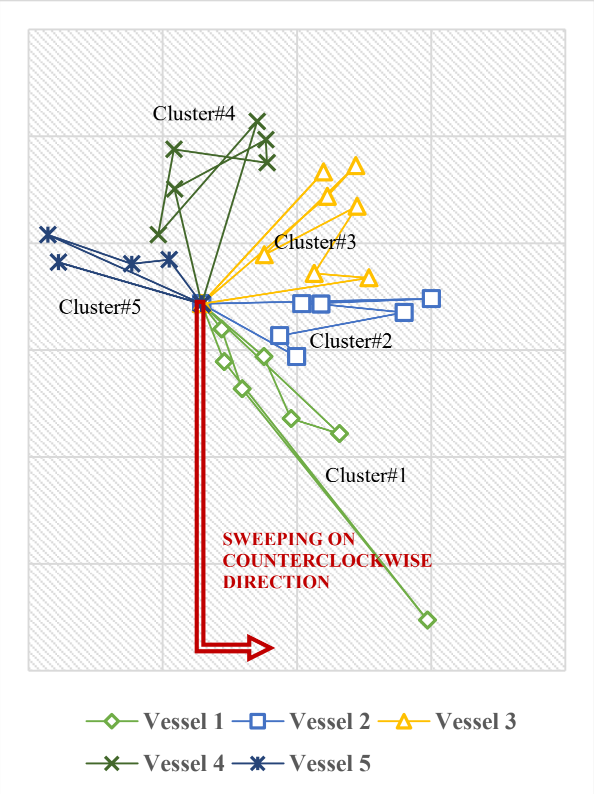

Figure 5: Clustered customers (after initial sweeping)

After the sweeping process, locations are segregated into clusters, the sub-problems are now become smaller and less complex. Thus, solver should be able to manage the sequence of the routes for each cluster to reduce the total distance. This step can be also completed by simple functions available in Microsoft Excel such as VLOOKUP, IF, CONCATENATE, IFERROR and SQRT. Prior to refining process, the model should be first properly divided.

Create distance summary of each cluster

Nodes (remote platform locations) in each cluster will be linked to create routes. Total distance of each cluster is cumulative starting from the depot point to every customer locations and then back to the deport point. To find the distance from one point to one point, it can be explained by the formula below, it is assumed that the Remote Platform A refers to (X_i, Y_i) and Remote Platform B refers to (X_j, Y_j) then;

Distance between A and B = $\sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$

Refine the shortest route each cluster

A typical Travelling Salesman Problem (TSP) approach is used to refine the vessel route with minimum distance. This step will use the distance summary of each cluster as an objective. Every time the shortest path is found, the selected node will be linked to the specified route. Dantzig et al. (1954) introduced a classical mathematical model for TSP as follows:

Let

The nodes (remote platforms) with numbers 1, …, n

C_{ij} is the distance from node i to j

X_{ij} is assigned as a binary variable

= 1 if travelling from node i to j

= 0 if otherwise

Objective:

$$Minimize = \sum_{i=1}^{n} . \sum_{j \neq i, j=1}^{n} C_{ij} X_{ij}$$

Subject to:

$$0 \leq X_{ij} \leq 1 \qquad i, j = 1, \ldots, n; \qquad (1)$$

$$\sum_{i=1, i \neq j}^{n} X_{ij} = 1 \qquad j = 1, \ldots, n; \qquad (2)$$

$$\sum_{j=1, j \neq i}^{n} X_{ij} = 1 \qquad i = 1, \ldots, n; \qquad (3)$$

$$\sum_{i \in Q} . \sum_{j \in Q} X_{ij} \leq |Q| - 1 \qquad \forall Q \subseteq \{2, \ldots, n\} \qquad (4)$$

The objective function is to minimize the total distance of each cluster. Equation 2 and equation 3 are to enforce to visit each node for one time. The equation 4 ensures that there is only one single tour covering all nodes. In each subset Q, sub-tours are not allowed by ensuring that the number of arcs in selected Q must be smaller than the number of nodes in Q. Therefore, the solution gives only one single tour and no partial circuit occurs.

Model Validation

To check validity and effectiveness of the proposed models, it requires to check whether or not the calculated distance are stable and correct, the tackling time must not be too long within acceptable time of response. Also, the demands must be all satisfied.

Manual calculations have been made to compare and validate the computed results. Overall results found palatable. Resulted distances have been reduced using few minutes of solution time. Figure 6 shows computed vessel routes after Microsoft Excel's solving completed. It can be seen that the routes of each vessel are clearly shown in separated clusters. Starting from vessel no.1

(light-green diamond), vessel no.2 (light-blue square), vessel no.3 (yellow triangle), vessel no.4 (dark green cross shape), and vessel no.5 (dark blue cross shape with additional lines) which is the last vessel.

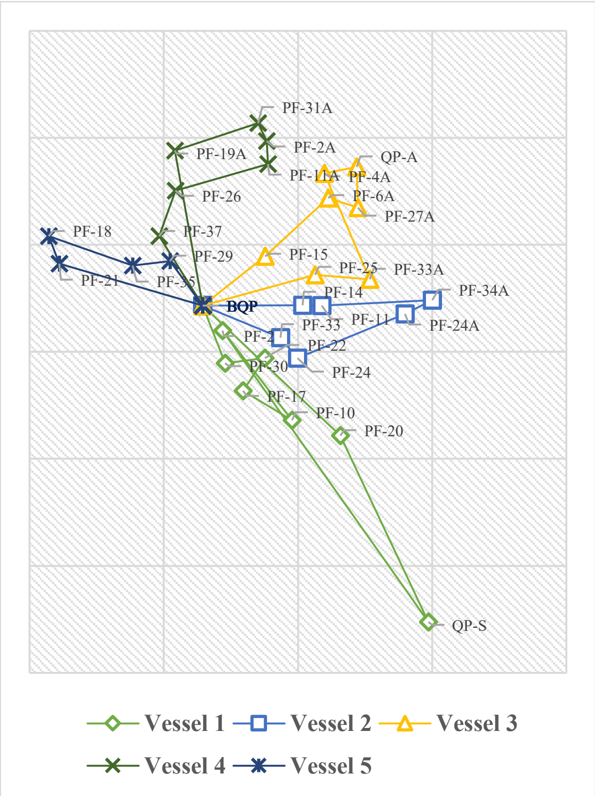

Figure 6: Refined vessel routes after completion of solving process.

Numerous similar-approach simulations have been tested to check, validate and confirm the correctness of the formula and capability of the Microsoft Excel solver. The result shows all satisfactory, while demands and constraints were all satisfied.

RESULTS

Based on the conditions and assumption aforementioned given, it was started at the angle of 000, then add at 10 degrees each until has reached the angle of 360 or 000 again. After testing and approval of execution results, it can be said that all sweeping angles are able to provide the ideal results within a few of minutes of computing time. Table 3 shows the overall performance for each starting angle of sweeping.

Table 3: Overall performance results

Trial No.	Starting Point of Sweeping	No. of Vessel Utilized	Reduced Distance (m)	Processing Time (Sec)
1	000	5	88,475	85.22
2	010	5	42,938	72.69
3	020	5	42,938	38.64
4	030	5	78,552	99.83
5	040	5	99,399	84.98
6	045	5	99,399	113.81
7	050	5	49,268	113.19
8	060	5	82,710	99.41
9	070	5	109,494	128.25
10	080	5	158,460	93.16
11	090	5	158,460	38.92
12	100	5	158,460	38.55
13	110	5	158,460	39.44
14	120	5	158,460	39.33
15	130	5	158,460	38.78
16	135	5	158,460	39.11
17	140	5	158,460	39.64
18	150	5	158,460	39.63
19	160	5	158,460	39.03
20	170	5	158,460	39.30
21	180	5	158,460	38.83
22	190	5	158,460	38.41
23	200	5	158,460	39.50
24	210	5	92,526	127.11
25	220	5	52,297	77.87
26	225	5	52,297	68.59
27	230	5	52,297	38.22
28	240	5	123,822	79.92
29	250	5	117,972	115.11
30	260	5	126,160	103.63
31	270	5	118,486	92.97
32	280	5	133,169	123.00
33	290	5	89,971	81.17
34	300	5	101,375	98.69
35	310	5	117,933	74.09
36	315	5	91,313	92.88
37	320	5	39,355	79.23
38	330	5	45,388	69.03
39	340	5	59,494	96.06
40	350	5	108,122	103.28
		Average	110,840	78.59

Figure 7 illustrates the results of total distance comparison after running the solver. It was found that the appropriate starting angles should be in range from 80 degree to 200 degree as they provide the similar optimal results.

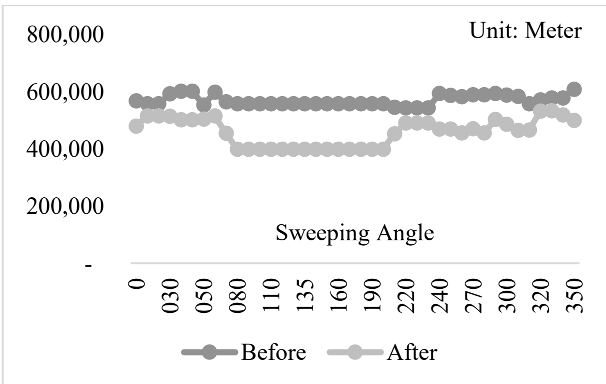

Figure 7: Total distance comparison

As the matter of vessel utilization efficiency, the utilizations results are also satisfied. Vessel utilization rate can be measured by dividing the used capacity of the vessel by the maximum allowable capacity of the vessel. Table 4 offers vessel utilization percentage for main starting angles of sweeping. Since the capacity of vessels in earlier orders are enforced to fully utilized, then the last vessel will always have the least utilization in every angles.

Table 4: Vessel Utilization Result

Starting Angles of Sweeping	Vessel No.				
	1	2	3	4	5
000	98.0	86.3	91.1	97.6	53.7
045	94.0	95.8	77.8	94.1	65.9
090	86.0	84.2	86.7	97.6	75.6
135	86.0	84.2	86.7	97.6	75.6
180	86.0	84.2	86.7	97.6	75.6
225	93.0	92.6	91.1	96.5	53.7
270	96.0	92.6	90.0	89.4	58.5
315	97.0	96.8	94.4	94.1	42.7
Average	92.0	89.6	88.1	95.6	62.7

In terms of the processing time, the average computing time is approximately to one minute. Figure 8 shows results of solution times of each sweeping angle.

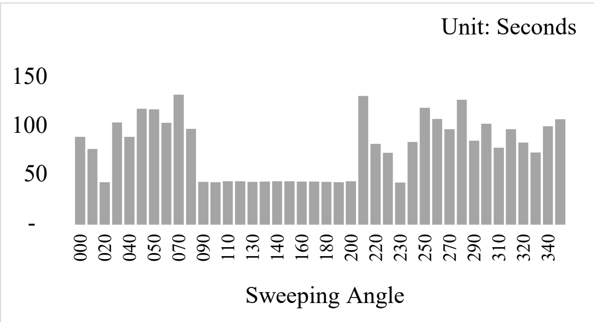

Figure 8 Solution times for starting point of sweeping

CONCLUSION

This paper starts from gathering data required for this study. It includes platforms coordination, existing resources (vessel) capacities as well as current implementation work process that relevant to the vessel route planning and scheduling.

A planning officer is accountable for daily vessel planning and scheduling to pickups and delivery personnel and materials with offshore operating fields with regard to the center complex as the depot. Such planning operation is categorized as the daily routine tasks and conducted by manual. Therefore, significant saving (both time and cost) could be expected by a support of automated optimization program. The experimental computational results provide favorable route planning outcome by the two-phase sweep algorithm approach.

It was notably that the first stage of clustering plays a vital role and directly affects to solution outcomes. A careful selected clustering can result in a better solution. The algorithm approach was tested and found capable as decision supporting tools. The result provides a great reduction of total distance. The demonstration is created in Microsoft Excel as the advantages of its capabilities that are to be accessed, adopt and upgraded when required.

In this paper, the model has been created for a common situation which all the routes must only start and finish at the depot. However, it is conceivable that the vessel routes may start or finish at remote platforms (not depot). However, such a condition has not been built in this study.

Other attractive points are different sorts of demands at a single demand locations, and multiple priority of demands. There are numerous things to explore and improve in the upstream marine logistics offshore.

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