Combining Geographic Information System (GIS) and Simulation for Crew Boat Scheduling

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***Abstract*—This paper aims to describe how Geographic Information System (GIS) can be combined with simulation to develop crew boat scheduling to transport Offshore Oil and Gas employees from Offshore Living Quarter to different working locations (Remote Platforms) to timely meet operational demands while reducing cost and using minimal resources. The approach is to apply GIS to determine the appropriate routing and scheduling with a different number of vessels that will allow employees to reach the remote platforms on time. GIS suggests that, with the new routing and scheduling, the company can reduce the number of vessels. However, due to uncertainty in a number of employees to be transported to each location and the speed of vessels, it is unclear whether the fleet size and the routing recommended by GIS will still be valid. Therefore, a simulation model is needed to simulate the situation with a variable number of employees to be transported. This allows one to evaluate the fleet size and the routing recommended by GIS to ensure that it still provides an optimal solution in a real-world situation. The simulation result confirms that the company can reduce the number of vessels from 6 to 5 vessels and can still be able to meet the transportation required under the time constraints. The average vessel seating utilization increases from 87.0% to 97.8%. With the new routing and scheduling solution, the company can reduce transportation cost by 47 million baht per year.**

***Index Terms*—Computer Modeling; Computer Simulation; Geographic Information System; Routing and Scheduling; Vehicle Routing Problem.**

I. Introduction

Transportation is one of the important activities in the organization since it can affect the organization performance, the ability to satisfy customers, and costs. For Oil and Gas Exploration Company with oil platforms spreading around different location, it is crucial to effectively and efficiently manage and schedule crew boats so that the employees from the living quarter can commute to the appropriate oil platform on time while minimizing the transportation cost. Therefore, crew boat scheduling and routing is a day-to-day operational activity that needs to be focused on. Geographic Information System (GIS), a powerful spatial data processing and analysis support system, became one of the first choices to handle transportation and distribution problem [1]. Nevertheless, the information and factors used in GIS are assumed to be constant such as the number of employees to be transported to each oil platform, and speed and capacity of the boat. Unfortunately, in current operations, the number of employees assigned to each oil platform can vary daily; speed of the boat can be affected by weather condition, and the capacity of the boat can be different since it may need to carry cargo and supplies to the platform along with the passenger. On the other hand, simulation modeling is a widely recognized approach to address the problem with real-world variability. By combining the two approaches, one can ensure that the optimal routing can actually work in the real-world situation. GIS will be used to identify the optimal routing and fleet size, the simulation will be used to ensure that the selected route and fleet size is still valid under uncertain conditions.

Therefore, the objective of this research is to apply Geographic Information System (GIS) in combination with simulation modeling to identify the optimal number of vessels and appropriate routing and scheduling that will allow completed employee transportation within the time constraint. The rest of this paper is organized as follow: Section II describes the methodology of this study. Section III discusses the literature review on GIS and simulation approach for vehicle routing problem. Section IV and V describe the company background, the GIS routing and the simulation model developed. Section VI discusses the results. Finally, the conclusion is provided in Section VII.

II. The Methodology of the Study

In order to achieve the objective of this study, there are several steps to be performed including:

1. Collect information regarding the company background, a number of employees required to be transported, origin and destination locations, fleet size, and current method used for routing and scheduling.
2. Review literature related to approaches for solving vehicle routing problems including GIS and simulation.
3. Use GIS to determine the appropriate number of vessels and the routing and scheduling.
4. Develop simulation model to evaluate routing and schedule recommended by GIS to ensure that it still provides an optimal solution for real-world situation under uncertainty.

III. Literature Review

Vehicle routing problem (VRP) has been widely used to select the path and optimize the routing. In some situation, the routing includes arcs routing problems where there are a sequence of arc rather than points. However, most of the studies simplify the actual distance between two points by a straight-line distance which sometimes may not be true in the real-world route condition [1]. In fact, one can conclude that the VRP is not only a hard-combinatorial problem but also a spatial problem [2]. Unfortunately, the spatial dimension is often neglected. This can impact the validity and the applicability of the solution provided. Therefore, an approach that synthesizes spatial techniques drawn from the field of geographic information system is needed for effective decision support for the VRP [3].

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data [4]. The main advantage of GIS is its ability to access and analyze spatially distributed data with respect to its actual spatial location overlaid on a base map of the area of coverage that allows analysis not possible with the other database management systems [5]. Thus, the use of GIS for transportation applications is widespread and became one of the first choices to handle transportation and distribution problem. Recent studies [2], [6], [7], [8] starts to integrate GIS to handle VRP more efficiently, especially when dealing with road networks or distribution networks. Nevertheless, most of the VRP and GIS works are often characterized by static and deterministic problems [9]. It is possible that the optimal solution provided may not be applicable in complex situations where uncertainty and variability are presented.

With the growing size of problems and the increasing uncertainties in the transportation and distribution environment, simply focusing on algorithm research is difficult to obtain a satisfactory solution of VRP. Simulation can effectively handle the problem of complex systems [10]. One of the major advantages of the simulation model is to handle uncertainties which make the model to better replicate the real-world behavior. However, a simulation model is not an optimization tool. One has to perform experimentation to identify the appropriate routing solution. As a result, by combining optimization with simulation, one can test whether the optimal solution yields satisfactory results in the uncertain condition in real-world situations. Several studies [9], [10], [11], [12], [13], [14] show the application of the combined method of simulation and optimization in transportation and distribution problems. It was found that a simulation optimization is a promising approach in terms of the quality of the solution, especially when the problems are stochastic and dynamics in nature.

Nevertheless, most of the studies in transportation and distribution either combine VRP with GIS or VRP with simulation. There are some studies [15], [16] that combine GIS and simulation and shows that the two techniques complement each other and allows for better results. However, they mostly focus on traffic problem. This shows an opportunity to use a combination of GIS and simulation to address transportation and distribution problems. This study, therefore, proposes to combine GIS and simulation modeling in order to identify optimal routing and fleet size solution that still be applicable in the real-world dynamic condition. The next section provides a background of a case study company that needs to transport a variable number of employees to several locations.

IV. CASE STUDY BACKGROUND

The case study company is an Oil and Gas Exploration company that currently has 1 living quarter and 57 oil platforms located in the Gulf of Thailand. There are approximately 274 employees that need to be transported to oil platforms in the morning starting from 5:30 am to 9 am (210 minutes). The daily number of employees required in each oil platform may differ depending on the production requirements and maintenance schedule. Currently, there are 6 crew boats used to support the transportation. The scheduler receives the transportation requirements at around 5:30 pm the day before. Then, the scheduler uses judgment and own experience to create routing and scheduling for the crew boats. With the current company practice, there are approximately 33 employees (12% of the total) who are unable to get to the working locations (Remote Platforms) on time, which can cause delay and problems in day-to-day operations. Therefore, it is important for the company to find a new approach for better, more efficient crew boat routing and scheduling. The next section describes the GIS and simulation model developed for the case study company.

V. GIS AND SIMULATION MODEL

This section can be divided into 2 parts: Geographic Information System (GIS) and simulation model developed. In order to use GIS and develop a simulation model, data is collected by interviewing scheduler and retrieving secondary data such as a marine database from the company. The geographic coordinates for living quarter and oil platforms are identified. The boat specification and previous schedule are also collected.

A. Geographic Information System (GIS)

The first step is to use Network Analysis in GIS (ArcGIS program) using Dijkstra's Algorithm to analyze and identify routing and the optimal number of crew boats. Dijkstra's Algorithm is one of the well-known, fundamental algorithms in computer science and related fields [17]. Thus, it is a suitable algorithm to be used in this situation. There are 58 locations (1 living quarter and 57 oil platforms). To prepare the input data, the location information is converted from geographic coordinate system to projected coordinated system. Then, an average number of employees needed to be transported to each location is linked. After that, the network analysis in Arc Catalog 10.1 program is performed to analyze possible routing. This process is initially done by [18]. This paper verifies that all the location coordination is correct. The results show a similar outcome that there are 3,306 possible routing.

Next step is to use VRP Solver to verify the optimal routing suggested by [18]. The data on the number of boat and capacity together with the objective and constraint are used as input to the program. There are 6 crew boats with different capacity ranging from 50-55 persons. According to the company policy, the average boat speed is 15 knots, regardless of the boat size. The boat is also allowed to make multiple rounds of transportation if needed in order to save cost. In addition, it will take approximately 30 minutes to load passenger at living quarter. The objective is to transport all 274 employees to their designated location within the time frame of 210 minutes (5:30 am to 9 am). VRP Solver indicates that it is possible to transport all employees to their locations on time by using the recommended routing. Figure 1 on the next page shows the optimal routing for 6 crew boats which is similar to [18]. Note that "1" in the circle refers to living quarter and other numbers in the circle refer to an oil platform in a particular route.

With the use of GIS, the company can easily transport all employees on time comparing to the current manual practice that 12% of the employees are unable to get to their locations on time. Nevertheless, one can see that the input data used in GIS such as a number of employees to be transported to each location is treated as deterministic data. This can impact the validity of the result since the actual number of employees can be differed each day depending on the production requirements and maintenance schedule. This is one of the important limitations of GIS. Therefore, a simulation model is needed to test whether the optimal route is still valid under variation in the number of employees for each location.

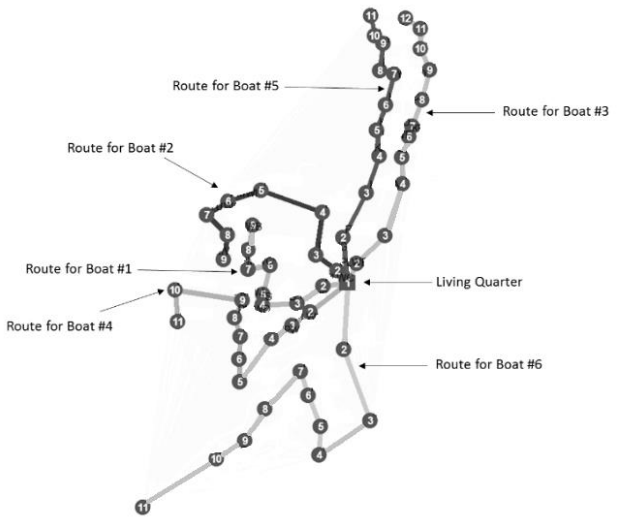

Figure 1: Routing for 6 Crew Boats Suggested by ArcGIS

B. Simulation Model

Once the optimal routing for 6 crew boats is identified, the simulation model is developed to simulate the transportation of employees based on the route suggested by GIS. The simulation model developed in this paper includes uncertainties in staff requirements for each platform, loading/unloading time, and travel time, which enhances the model in [18]. This paper has also collected more data regarding the number of employees for each destination to cover seasonal variation to ensure the validity of the information. The variation in a number of employees is represented by a discrete probability distribution. The simulation model is then further developed using Arena simulation software version 14. The model can be divided into 6 sub-models. Each sub-model represents a crew boat with designated routing. In general, the model starts with boat creation and employment creation for different platform destination. The second part of the model represents employee pickup, travel to a destination, and drop-off. The last section is the recording of drop-off time and the number of employees arrived at each destination. Figure 2 shows the example of a sub-model for crew boat 2 with 8 destinations.

The model is verified by following the animation to ensure that all flows are correct. In addition, the number of employees in/out is also checked. Once the model logic is correct, the model is validated by comparing the model result with the reference result from GIS. It is found that the simulation model result (with 320 replications) is within +/-3% of the reference performance from GIS. The simulation result is not statistically different from the GIS result at 0.05 level of significance. Thus, one can conclude that the model is correct and is able to represent the real-world situation. The next section discusses how GIS and simulation model is used to help the company make a decision regarding the routing and the fleet size.

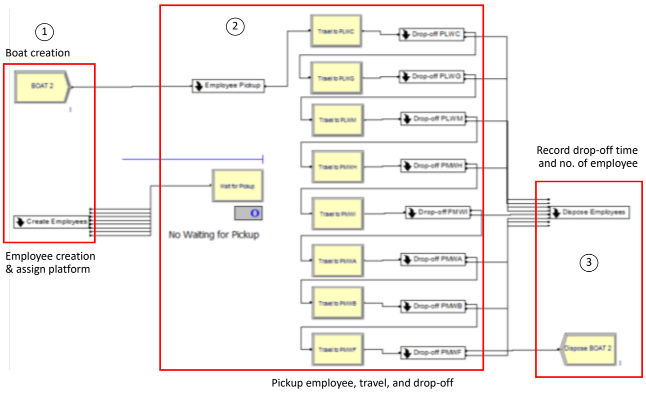

Figure 2: Simulation Model for Crew Boats

VI. DISCUSSION OF RESULTS

This section begins by using GIS to determine the optimal routing and an optimal number of crew boats needed. After the optimal route and number of vessels are identified, the author uses simulation model with variability in the number of staffs required at each platform to evaluate whether the solution suggested by GIS can still transport all employees within the time limit. After that, costs associated with the recommended routing and fleet size will be analyzed.

A. Using GIS to Identify the Optimal Number of Vessels and Appropriate Routing

With the current 6 crew boats, GIS result shows that all employees are able to reach oil platforms on time with average utilization of 87%. This indicates that it may be possible to reduce the number of boats, therefore, GIS is used to find the routing when using 5 boats and 4 boats. The result shows that, with 5 boats, all employees can still reach oil platforms on time. Note that Boat 4 has to transport employees in 2 trips. The average boat utilization increases to 97.8% (not including the 2nd round of Boat 4). On the other hand, when using 4 boats, there are 2 boats that are unable to send employees to the platform on time, although the average utilization is the highest at 99% (not including the 2nd round of Boat 1 and 4). Therefore, one can conclude that using only 5 vessels results in better utilization and lower costs for the company while being able to transport employees on time. Table 1 shows the comparison of utilization and travel time when using different number of boats which is similar to [18].

B. Using Simulation to Analyze Suggested Routing and Fleet Size under Uncertainty

One of the limitations when using GIS network analysis is that the input is deterministic, for example, the staff requirements at each platform and the travel time for each route. Therefore, the number used is the average number. However, in a real-world situation, the required number of an employee can vary day-to-day depending on the need of each platform. The speed of the boat may differ depending on the weather condition. As a result, the author uses a simulation model to evaluate the solution recommended by GIS whether it is still valid when there is variability in a number of staff required in each platform and boat speed. The simulation result shows that, under a variable number of staff requirements and boat speed, 5 crew boats are able to transport all employees on time.

Table 1
Comparison of Boat Utilization and Travel Time

Boat No.	Capacity	Utilization	Last Drop-off	Total Time (Minute)
Current:	**6 crew boats**			
Boat 1	55	69%	6:59am	89
Boat 2	50	92%	7:16am	106
Boat 3	53	87%	7:26am	116
Boat 4	55	93%	7:36am	126
Boat 5	55	100%	7:25am	115
Boat 6	55	80%	8:21am	171
Scenario 1:	**5 crew boats**			
Boat 1	55	98%	7:32am	122
Boat 2	50	100%	7:06am	96
Boat 3	53	100%	8:53am	203
Boat 4				
1st round	55	100%	8:59am	209
2nd round	55	21%		
Boat 5	55	91%	7:35am	125
Scenario 2:	**4 crew boats**			
Boat 1				
1st round	55	100%	9:08am*	218
2nd round	55	78%		
Boat 2	50	96%	8:34am	184
Boat 3	53	98%	7:49am	139
Boat 4				
1st round	55	100%	9:09am*	219
2nd round	55	38%		

* Late drop-off, employees need to reach platform by 9:00 am

In addition, there are also some slack times on each route. The slack time is the allowed delay time that will not impact the ability to transport employees to the destination on time. For example, employees need to be at oil platforms no later than 9 am. The boat departs at 5:30 am so employees need to be at the destination within 210 minutes. The average total travel time for Boat 1 is 127 minutes so the slack time will be 83 minutes (210-127). This implies that if the unexpected delay of no longer than 83 minutes occurs, Boat 1 is still able to transport employees on time.

The highest slack time is 111 minutes for Boat 2 and the lowest is 3 minutes for Boat 4. This indicates that the solution recommended by GIS is still applicable in the real world. However, one needs to pay more attention to Boat 3 and Boat 4 due to low slack time. For example, if Boat 4 is delayed more than 3 minutes, the staff will not be able to reach the platform on time. Table 2 shows the average total travel time and slack time based on 320 replications. Note that the results are different from [18] due to more variation in the model which shows that it is important to include all uncertainty in the model to better reflect real-world situation.

Table 2
Average Total Travel Time and Slack Time

Boat No.	Total Travel Time (Minute)	Slack Time (Minute)
Boat 1	127	83
Boat 2	99	111
Boat 3	204	6
Boat 4	207	3
Boat 5	128	82

The results provided in Table 2 show the average time based on 320 replications. This means that on average all boats are able to transport employees to a destination on time. However, Boat 3 and Boat 4 slack time are relatively low (only 6 and 3 minutes consecutively). Furthermore, since the information provided in Table 2 is the average travel time, it is possible that some trips may have longer travel time. Therefore, it is important to evaluate the risk or the probability that the travel time will be longer than the acceptable time of 210 minutes.

This emphasizes another advantage of simulation that it allows one to evaluate the risk or the probability that the result will meet/not meet the target [19]. In this case study, the target is that the total travel time of each boat should not be longer than 210 minutes (from 5:30 am to 9 am or 3.5 hours). To evaluate the probability of travel time within 210 minutes, a simulation model is run for 320 replications and the data is collected for each replication.

The result shows that the probability of the travel time within 210 minutes is relatively high for Boat 1, Boat 2, and Boat 5 at 97.5%, 99.7%, and 99.4% respectively. However, the probability for Boat 3 and Boat 4 is rather low at 59.4% and 43.4%. The result is in line with the low slack time of Boat 3 and Boat 4. Table 3 shows the probability that travel time is equal to or less than 210 minutes (meet the target).

Table 3
The probability of Travel Time within the Target

	Boat 1	Boat 2	Boat 3	Boat 4	Boat 5
Number within 210 minutes	312	319	190	139	318
Number more than 120 minutes	8	1	130	181	2
Total number of replications	320	320	320	320	320
Probability within target	97.5%	99.7%	59.4%	43.4%	99.4%

With the new routing, the company can reduce the number of vessels from 6 to 5 and increase utilization from 87% to 97.8%. Furthermore, reducing the number of the vessel can also lead to the cost saving which will be discussed in the next section.

C. *Cost Analysis*

Cost analysis is performed in this section to analyze the impact of reducing the number of vessels. The cost of using one vessel can be divided into fixed cost and variable cost. The fixed cost, in this case, is the time charter cost of 105,000 Baht per day. The variable cost is bunker (fuel) cost which is calculated based on the employee transportation activity only. The fuel cost is approximately 24,500 baht per day. Therefore, by reducing one vessel, the company can reduce cost by 129,500 baht per day or 47,267,500 baht per year.

Based on the result shown, one can see that the company can benefit from reducing the number of vessels from 6 to 5 vessels. However, there are risks that Boat 3 and Boat 4 may not be able to transport employees on time. Noted that Boat 4 transports employees in 2 trips. The majority of employees are transported during the first trip and will arrive at the destination on time. Only the employees on the 2nd trip that may not arrive on time on some occasions.

Therefore, the company has to make the trade-off whether to reduce the number of vessels and allows employees to have flexible work hour to match with the later start time. With flexible work hour, the company will be able to save cost significantly. However, if the company is not able to adjust the work hour, it may have to remain using 6 vessels and bear higher costs. Note that the probability within target when using 6 vessels are 100% for all vessels.

VII. CONCLUSION

This research aims to determine the optimal fleet size for crew boats and the appropriate routing that will allow the company to transport staff to different oil platforms. GIS is used to analyze and identify the fleet size and routing under deterministic condition. It is found that 5 crew boats are enough to transport employees within the time limit. This allows the company to reduce the number of vessels and increase utilization. However, the daily staff requirement can be differed depending on the production and maintenance plan. As a result, a simulation model is used to introduce uncertainty to replicate real-world situations. By evaluating the GIS solution in the simulation model, it allows one to ensure that the recommended solution is still applicable in real-world with uncertainty.

This paper shows the advantage of combining two approaches. It will be very difficult to identify optimal routing and fleet size by using simulation alone since one has to rely on trial and error. Using GIS alone can generate optimal solution but it is not guaranteed that the solution will work when there is uncertainty. In addition, simulation also allows one to evaluate the risk or the probability of the expected outcomes. Using GIS alone, one may conclude that 5 vessels will be able to transport employees on time every day. However, with simulation, one can see that there may be some days that the travel time is longer than the target due to a variable number of staff requirements. This information allows the company to better manage employees work hour to match with the expected travel time. In conclusion, by combining two approaches, the advantage of each approach can overcome the disadvantage of others, and thus allows the company to make a better decision.

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