

System simulation for the evaluation of the oil barge operation in Kaohsiung harbor, Taiwan

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Abstract

The oil barge operation in Kaohsiung harbor is a typical system of resources allocation problems in a complex and dynamic environment. Such system is far more difficult to deal with than a static and deterministic system, and often depends on experienced human experts for the oil barge assignment. This research has developed an integrated system for assessing the overall performance of such port operation. Both expert system and system simulation techniques are applied in this analysis. The role of the expert system is to translate the current heuristic of assignment into a rule-based knowledge for the human-like reasoning. To further evaluate the schedule arranged by the expert system, the system simulation model of the oil barge operation has been formulated using the software AweSim®. This model is capable of quantifying the service quality under various assignment scenarios to support the management of the oil barge operation. With the help of such an integrated system, it is expected to facilitate the evaluation of the oil barge operation in terms of efficient resources allocation in Kaohsiung harbor.

1 Introduction

Kaohsiung Harbor, located at the southwest coast of Taiwan, is the largest international port in Taiwan, and the fourth largest container-handling harbor in the world. Excellent geography and port environment contribute to its prosperity. It is located right between the Taiwan Straits and the Bashi Straits, and it has a long and narrow shoal as her natural barrier. The Taiwanese government is planning to make Taiwan a HUB port in the Asian Pacific area. The Port of Kaohsiung will be the best candidate for the trans-shipment center. According to Statistics of 2001, Kaohsiung Harbor Bureau (KHB), the number of inbound vessels has increased 40.1% from 12,888 in 1993 to 18,162 in 2001. In light of this trend, it is necessary to consider the demand for development of the entire port in advance. As part of this, the

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logistic operation of fueling service, provided by the Chinese Petroleum Company (CPC), has a serious impact on the future development of the port. Any delay in the oil barge operation would postpone the schedule of outbound vessels. This would not only cause the carriers to incur extra charges for port service fees, but also create a risk of losing the increase in business potential for KHB and CPC.

The oil barge operation in the Port of Kaohsiung is a typical system with resources allocation problems in a complex and dynamic environment. Such system is far more difficult to deal with than a static and deterministic system, and often depends on experienced human experts for the oil barge assignment. The system manager is confronted by the major dilemma of not knowing the management efficiency under the current dispatching mechanism. Besides, if the dispatching rules need to be modified due to a future resource variation, how would the changes affect the system and how to deal with such development effectively? Currently the system manager lacks a solid tool to assess the system performance, and as such has no appropriate resources improvement plan when the Port of Kaohsiung becomes the trans-shipment center in the future.

This research, supported by the National Science Council of Taiwan, has proposed an integrated system, using both the expert system and the system simulation techniques for evaluating the oil-barge operation in the Port of Kaohsiung. To accommodate the human expert's role in the current oil barge dispatching mechanism, an expert system has been utilized as the replacement of the real expert in the entire modeling process. The heuristic regarding the current schedule arrangement is collected at the beginning through several interviews with the CPC engineers who would set up the oil barges operational plan for the following day, based on the orders from the ship's agents. Such experience is then transformed into a digital form of knowledge base, and stored in the expert system for further reasoning. The results acquired from the expert system will provide the input as the pre-defined schedule for the simulation model, which will represent the complete oil-barge operations, including the transportation and fueling processes. With the embedded statistical process the simulation model is capable of generating significant long-term statistic reports as the system performance indices under the designated resources assignment rules. This will make it clearer and easier to show the decision makers how well the current dispatching mechanism performs. It allows a comparison between various adjustments on assignment rules, and shows the appropriate response plan to meet the future need when the Port of Kaohsiung becomes the trans-shipment center.

2 Methodologies

"Expert systems" are sophisticated computer programs that are equipped with knowledge and inference mechanisms to solve problems efficiently and effectively in a narrow problem domain. These systems evolved from artificial intelligence (AI) systems using symbolic logic and heuristic to find solutions just like real human experts. There are several excellent reasons to justify why people develop an expert system rather than rely on human experts as was done in the past. The advantages of such systems over human experts are that it is permanent, consistent, easy to transfer

and document, and cheaper. A number of different application areas, for instance agriculture, engineering, medicine, and military science, have enjoyed benefits from using such technique [1]. To allocate oil barges for the fueling service is a complex decision-making process affected by several factors that are closely interrelated. Such an arrangement always relies on the expert, and fits in with the "planning" category of expert system applications because they decide on an entire course of action before acting.

One of the major differences that makes expert systems differ from conventional programs is that the expert system manipulates knowledge while conventional programs process data. Knowledge represents information which an expert system needs before it can function intelligently, and this usually takes the form of rules. Rules provide a formal way for recording strategies, or recommendations, developed through years of problem-solving experience. The "IF condition, THEN conclusion" statement is the general expression of rule-based knowledge, indicating the fact that when the condition is satisfied, the conclusion is in effect. By means of direct interaction with domain experts, heuristic could be acquired, and should be organized systematically into a knowledge base. System developers are then required to choose one type of building tool from either the expert system shells (e.g. EXSYS) or programming languages (e.g. LISP). There are pros and cons for both types of tools. Programming languages offer more flexibility but require more effort to design the knowledge base and construct the inference engine that accesses the knowledge. After carefully comparing the functionality of various products, the choice of the expert system tool should primarily depend on the application requirements in the research.

Although the heuristics may provide a feasible approach to solve the current problem, it does not guarantee that it will generate a good solution when something changes in the future. One of the inherent limitations of expert systems is that they are incapable of refining and improving the knowledge base. Unless some experiments can be conducted to show the system performance, the decision makers have no way but to trust the expertise acquired from the so-called expert. Furthermore, as the status of the problem changes in the future, it will be time consuming for the expert to adjust the heuristics. To do an actual real-time test would require a tremendous amount of resources and effort, and is the least cost-effective option. A better alternative would be to resort to formulating some type of mathematical or statistical models that simulate the original problem. Such model building process provides the insights into problems and is widely used to assist in the design, management, or development of policy relative to natural or constructed systems [2].

The oil barge and tugboat services are similar port logistic operations, which require more information than the Queuing theory can provide to support reasonable planning [3]. In order to thoroughly explore inter-related components over a long period of time, and to evaluate various planning strategies based on reliable forecasts, the technique of system simulation is appropriate to deal with the similar problems [4]. In particular, the characteristics of an oil barge operation is the combination of transportation and fueling service with a variable data element, which lends itself to the application of stochastic simulation.

System simulation is a powerful tool for analysis and design. By establishing a set of structural and procedural elements that represent the real system, it would help to conduct the designated experiments, to identify the system behavior, and then to evaluate the overall system performances based on various design or operating strategies [5]. A simulation model itself cannot determine an optimal solution; rather it can produce experimental outcome from which an alternative can be selected. It is therefore applicable for simulation models to answer "What if" questions in the scenario analysis with the specified candidate list. Such analysis is the typical usage of system simulation to support decision-making.

Many dedicated simulation languages have been developed to replace the earlier FORTRAN language as the efficient model-building tool. These languages, such as GPSS, SIMSCRIPT, and SIMAN, use statements specifically designed for representing the state of a system, and moving the system from state to state. However, a complete problem-solving process requires more than just a model by itself. Additional tools and techniques, such as data management, scenario generation, output analysis, documentation and the presentation of results, are necessary to support total simulation projects [6]. In recent years, software engineering has made it possible to develop a multi-functional and user-friendly simulation support system. Among them, AweSim® developed by Symix Systems Inc., provides an integrated problem solving environment for an interactive and graphic modeling process. Meanwhile, this software maintains its flexibility by incorporating independent components, which can be created using other computer languages, with the simulation model. This capability allows the current research to connect the expert system with the simulation model for effective and efficient oil barge management in the port of Kaohsiung.

3 System constructions

In order to build a realistic system, a full awareness of oil barge dispatching mechanics and all aspects of the operational procedures is necessary. At the highest level of the system, the headquarter of CPC in Taipei receives orders from local ship agents, and at the end of a day the CPC will notify the Storage & Transportation Station (STS) in the Port of Kaohsiung regarding the complete orders for the next day. After acquiring such information, the senior engineer in charge of dispatch will arrange the work schedule for each oil barge based on some implicit rules learned from long-term experience. The last stage of the system is to carry out the orders through the oil barge operation, which includes the trip from the STS wharf to the vessel's docking berth and the fueling process. The captain of the barge needs to check the invoice on-site before the fuelling operation begins. The fueling operation requires connecting the oil tube, unloading the oil, closing the valve, and disconnecting the oil tube. For a large order that exceeds a single oil barge's capacity, the first barge will wait for the supply from another barge to finish the required service. Otherwise the barge will either travel to the next vessel, on condition that there is enough oil for the service, or travel back to the STS wharf preparing for the next trip. Figure 1 shows the flow chart of the oil barge operational system.

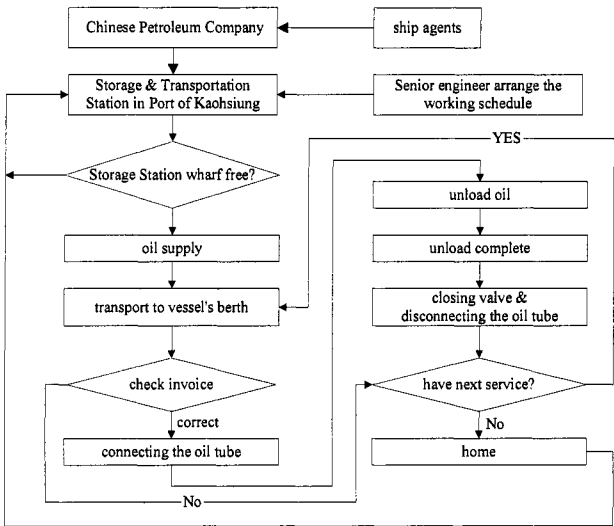


Figure 1: Flow chart of oil-barge operational system

In light of the discussion above, the schematic diagram of the model is illustrated as Figure 2. There are three model components based on the partition of the system flow in sequence. The first module will randomly generate the preliminary information regarding the inbound vessels that need the fueling service. Such vessels are treated as the entries in the system simulation model, which associates the attributes of the oil type, the amount of the order, the berth, and the schedule of arrival and departure. The second module will collect the information generated in the previous process and allocates the oil barge for each entity, using the pre-built expert system. Each vessel entity is assigned the resources of the oil barge as specified by the oil-barge's name, assigned a priority for using the assigned resource, and the content of delivery by the oil barge. The last component is to run the system simulation model for the evaluation of the oil-barge operation under the current dispatching mechanism as represented by the expert system. Information regarding the attributes of entities (vessels) and the allocation of resources (oil barges) forms the foundation for this stochastic analysis that will calculate the service time of each oil barge and the related statistics to generate the performance indices.

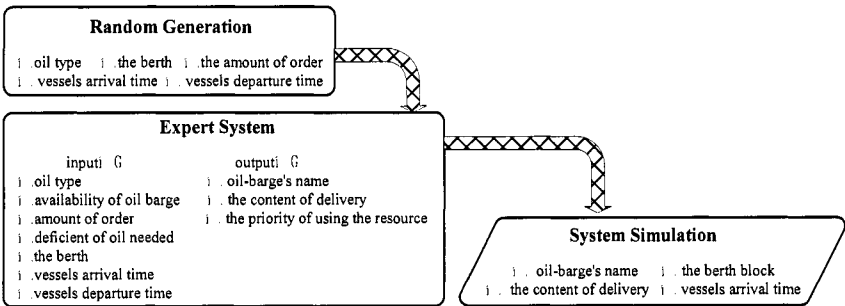


Figure 2: Schematic diagram of the model

3.1 The knowledge base of the expert system

Modeling the oil barge allocation is the most crucial element, and is driven by the expert system, the knowledge base of which is derived from the heuristic. Through face-to-face communication, this research has taken the required information from the CPC engineer in two stages. In the first phase, applying a non-structural interview guides the researchers to the broad view of the domain knowledge. To further extend these initial results, the researchers take part in a constructive dialogue with the human expert in order to elaborate on the dispatching mechanism. The result of this knowledge-acquisition process discloses several factors affecting the oil barge assignment. They are: the vessel's arrival and sailing schedule, the geographic location of the berth, and the amount and type of oil that has been ordered. A detailed discussion on the impact of each factor is listed in the following:

1. Vessel's arrival and sailing schedule: The oil barge operations can only be conducted during the time interval between the vessel's arrival and sailing, and the fueling has to be completed no later than the sailing schedule. These two factors pose immediate constraints for the oil-barge assignment in terms of the resource utilization priority.
2. Geographic location of the berth: The natural formation of the Kaohsiung harbor is like a long strip spanning from North to South with deep-water berths located at the southern side. An inbound vessel will dock at a specific berth based on its tonnage, length, and draught. Logically, an oil barge should be allocated to serve the vessels in the neighboring berths for efficient transportation. In addition, the oil barges with large capacity tend to serve the heavyweight vessels docked at the southern side, where higher fuel demand is common. However, there is an exception when the smaller oil barges cannot handle the service on the northern side, the large ones will then take over the deficiency. To effectively address this issue in the model, the neighboring berths have been aggregated into five clusters each in the northern and southern sides as shown in Figure 3. The vessels within the same cluster will have the same priority for the resource allocation.

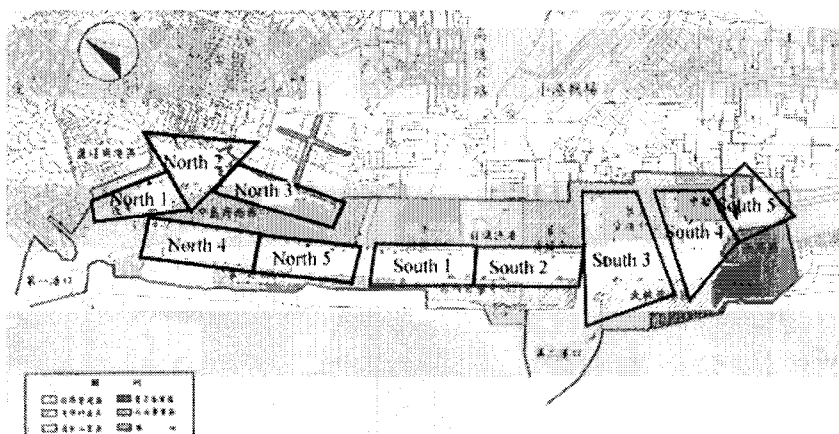


Figure 3: Aggregation of neighboring berths into clusters

3. Amount and type of oil ordered: The variety of oil barges in the STS has made these two factors the essential parts of the dispatching mechanism. The capacity of the barges ranges from 220 to 1500 tones, and the storage tank of a barge carries either diesel oil or fuel oil. The general principles of dispatch are that the oil barge with the larger capacity will be assigned to serve the vessel with the higher demand, and the order of either diesel or fuel will be fulfilled by the corresponding barges as shown in Figure 4.

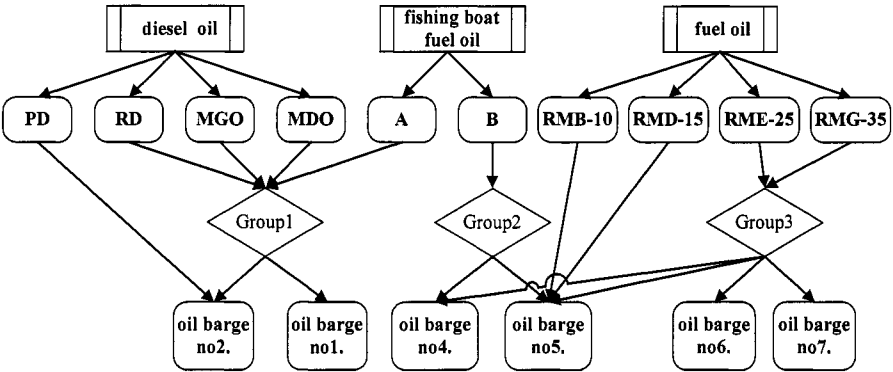


Figure 4: General dispatching principles based on oil types

After thorough interviews, the heuristics of the human expert are carefully translated into the rule-based knowledge using the “IF-THEN” form. The impact factors listed above are associated with the “IF” statement as the prerequisite for the oil barge assignment. To define further complex situations, the “IF” statement may accommodate several conditions joined by some logical operators such as “AND” and “OR”. Once the conditions are validated, the “THEN” statement will be fired to describe the consequence, which is the assignment of the oil barge. One specific example of such rule-based knowledge is illustrated as follows, and is equivalent to the experience that: given a type of oil, insufficient amount of oil after the first fuelling process, and oil barge number 2 is available, the CPC engineer will assign the oil barge #2 to serve this vessel.

IF *Type of oil= MGO, MDO*
OR *Type of oil=A*
AND *Insufficient amount of oil= 0-220*
AND *Working situation of oil barge number 2= 0*
THEN *Barge name= number 2*

3.2 System simulation

Through the experiments on simulated oil barge operation, the long-term statistics (including average service time of barges, mean waiting time of vessels, utility rates of barges, and the efficiency of wharves utilization in the STS) can be derived effectively. Consequently such information can support assessments on the current heuristics of dispatch embedded in the expert system, and helps to identify

bottlenecks in the entire oil-barge operation. If the evaluation shows a deficiency in the system performance, any revised strategy, such as a modification of the dispatching rules, or the addition of new barges to the fleet, can be investigated through the same modeling procedure. Without actually implementing anything, the system manager is able to foresee the outcomes of the proposed strategies and is able to select the most appropriate strategy under all constraints. The same approach can also be applied to deal with strategic planning to meet the future challenge from a highly increased number of inbound vessels.

Three conceptual elements, including workstation, queue, and entity, constitute a simulation model, which can be represented as entities flowing through a network of nodes (queues) and activities (workstations). The first step in the construction of such a model is to define the entity, which is any object with variables representing the system state. In this study, the vessels treated as entities in the model use the system variable to indicate the status of service to their vessels (completed or incomplete). The next and most creative step is to develop a network model whose sequential process is similar to the oil-barge operation as mentioned earlier. The software “AweSim” has been used for the model development through the synthesis of network elements using the graphic form. Using the graphic symbols as a logical and visual medium facilitates the process of conceptualization and communication. Once the graphic representation of the network model is complete, AweSim will transcribe the simulation model into the proprietary script for the model execution.

The framework of the network model in the current study is demonstrated in Figure 5 using the graphic symbols. At the beginning of the model is the "create node" in order to randomly generate the entities, which are the inbound vessels, based on a probability distribution function (PDF). During the creation of the entities, the attributes, such as the amount and type of oil ordered (associated with each vessel) will also be produced following certain patterns. The information from the create node is exported to the external expert system component for the allocation of oil barges. The results are then sent back to the network model by inserting the ASCII file into the second node. Once all required information is available, the next section of the model simulates the oil-barge operation. At first the vessels have to wait for the service from the assigned oil barge in the "await node". When the oil barge is available to serve the vessel, it will fetch the information regarding the upcoming service by means of the "assign node" and will also try to allocate a STS wharf for oil supply in the "await node" if the remaining oil is not enough for the next service. As soon as the action of oil supply is completed, the oil barge will free the resource of the STS wharf by the "free node", and the status of oil

barge usage will be changed by the “alter node”. The following activities, including transportation from the STS wharf to the berth of the vessel and fueling process, require variable time periods that will be calculated in the “assign node”. After the service is completed, the model will release the resource of the oil barge by the “free node” and the entity of the vessel will be dismissed from the system by the “terminate node”.

There are several activity durations in the simulation model that have to be estimated correctly in order to justify the integrity of the model. First, the oil supply on the STS wharves has to pump the designated type and amount of oil to the oil barges. Such activity duration is primarily based on the size of the tube, amount of supply, and the pumping rate that is relevant to the viscosity of the oil being pumped. Secondly, the transportation to and from the STS wharves and the berths of the vessels requires a different time span for each oil barge. Logically, the activity duration for the transportation depends mainly on the speed of the barge and the distance of the trip. The speed of the various oil barges is variable owing to the difference in the horsepower of each oil barge, the weather condition, the degree of crowdedness in the harbor, and the amount of oil loaded. Nevertheless it is too complicated to consider all these circumstances, and therefore the average speed of an empty oil barge is used for calculating the time to travel back to the STS wharves, and 70% of this speed is used for calculating the transport time to the berths for a loaded barge. The service distance is fixed at each pre-classified cluster of a vessel's berth. Thirdly, the activity of the fueling process involves both an oil barge and a vessel. Three influential factors can be identified, which are: the diameter of the oil intake into the vessel, the amount and type of oil required, and the pumping rate, which is decided through negotiation between the captain of the oil barge and the chief engineer of the vessel. According to interviews with senior captains, the model would take 80% of the full pumping capability as the average pumping rate for the simulation. While making the calculation, additional attention has to be paid to the unit conversion from metric ton (MT) to kiloliter (KL). This study applies the standard conversion, that is to say: one(1) MT of fuel oil is equal to 1.06KL, and one(1) MT of diesel oil is equal to 1.2KL.

4 Results and discussion

After the development of such integrated system, model verification is necessary to justify the results from simulation. The expert system has been examined by comparing the simulated reasoning with the real oil-barge schedules using the whole year records. The analysis of discrepancy in both schedules shows 90% of similarity, which is to demonstrate the knowledge base extracted from the human expert can function well to replace the role of the human in the whole modeling process. As for the simulation model, the time for the last oil barge to finish the fueling operation in a working day has been collected and analyzed under the control of using the same schedule. The time deviation between the simulation and the real data is found less than 10%, indicating good quality of the simulation model.

With the solid proof, various experiments can be conducted to evaluate the performance of the oil-barge management system. Under the current dispatching mechanism, it is obvious to identify from the simulation report that the oil barge

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number 1, 2, and 4 have longer working time than the others, while the oil barge number 6 and 7 take up lower ratio of the service activities. Presumably, according to the current low growth rate of inbound vessels in the Port of Kaohsiung the fleet of the oil barges in STS should be enough to handle the fueling service until the year of 2004. Based on the researcher's heuristic, several revised programs for the current dispatching rules have been proposed including "multi-barges assignment", "the most economical resources allocation", and "additional new resources allocation". The knowledge base of the expert system has been modified to accommodate these revised programs. The results from the simulation model show the "the most economical resources allocation" program would further reduce the utility of the oil barges number 6 and 7, but the time for the last oil barge to finish the work is even later. The rests of the proposed revision are not as good as the current one.

5 Conclusions

The integration of expert system and system simulation provide a valuable approach in terms of mapping out the complex system operations in a whole. Yet, the degree of sophistication in such modeling process depends on how complete the knowledge base and the operational procedures had been set up. The current study accumulates the daily working schedules and reports of the oil barges in the entire year. With more than sixty thousand records available for the analysis, the intensive information has laid the strong foundation for building the trustworthy system as shown by the model verification. In consequence, this integrated model is capable of quantifying system performances not only for the current environment but also for the future developments when the Port of Kaohsiung becomes the transshipping center. The embedded decision-support function of the system allows the system manager to easily test the revised programs or strategic plans and to adopt the most appropriate scheme to enhance the overall managerial efficient for the oil barge operation.

References

- [1] Waterman, D.A., *A Guide to Expert Systems*, Addison Wesley, pp. 32-39, 1986.
- [2] Revelle, C.S., Whitlatch E.E. & Wright J.R., *Civil and Environmental Systems Engineering*, Prentice Hall: New Jersey, pp. 1-6, 1997.
- [3] Wang David, *Simulation study on the application of pilots and tugboats - case of Kaohsiung Harbor*, Master Thesis, Dept. of Transportation and Communication Management Science, National Cheng-Kung University, Tainan, Taiwan, 1999.
- [4] Julian A.S., Simulation of an inland waterway barge fleet distribution network, *Proc. of the 1998 Winter Simulation Conf.*, eds. D.J. Medeiros, E.F. Watson, J.S. Carson & M.S. Manivannan, pp. 1219-1221, 1998.
- [5] O'Reilly, J.J. & Lilegdon W.R., Introduction to Awesim. *Proc. of the 1999 Winter Simulation Conf.*, eds. P.A. Farrington, H.B. Nembhard, D.T. Sturrock & G.W. Evans, pp.7-13, 1999.
- [6] Pritsker, A.B. & O'Reilly J.J., *Simulation with Visual SLAM and AweSim*, John Wiley and Sons, NY, pp. 81-84, 1999.