SIMULATION MODEL OF MARITIME INVENTORY ROUTING PROBLEM WITH PARTICULAR APPLICATION TO CEMENT DISTRIBUTION

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ABSTRACT

Simulation is undoubtedly a very useful tool for modelling a system specifically in the presence of stochastic elements and complex interactions between the system entities. In this paper, a simulation model to support decision making in ship scheduling for Maritime Inventory Routing Problem (MIRP) with particular application to cement distribution is presented. The system under study is a combined discrete and continuous system, where a heterogeneous fleet of ships with various sizes and types of contracts transport bulk cement products from production facility (Central Supply, CS) of a cement company to its packing plants (Distribution Centres, DCs). The simulation model in this study has been designed and developed thoroughly to emulate the complexity of the real system of the MIRP. The simulation model has demonstrated the capability to provide support for decision making in ship scheduling of the heterogeneous shipping fleet in the following forms: (a) real time states of inventory levels at CS and DCs and (b) ships' routing. In addition, one of the main strength of this simulation model is its flexibility. It can be easily expanded or adjusted to different size of system entities for example number of CSs, DCs, berths, vessels, and products.

Keywords: Simulation, Routing, Maritime Transportation, Inventory Management, Bulk Cement

1 INTRODUCTION

Cement industry is not only disadvantaged by its plant location constraint, but also by the characteristics of its product. Cement is bulky and heavy product. Transportation costs of this product contribute a high percentage in its cost of goods sold. As cement is also a make to stock product, the immensity of its volume will create high inventory costs. Contrary with these two facts, price of cement is very cheap. Profit margin from this industry is very low. For these reasons distribution plays a very important role in this high volume business.

Mostly, a cement company uses Packing Plants (PPs) for the extension of the market. The input of these PPs, that is bulk cement, is supplied by production facilities as CS. The alternatives of transportation modes used are: truck, train, and vessel. The choice depends on the location of the PPs, support of transportation systems, and economies of scale. However, vessel is the most preferable transportation mode as the volume of shipments is concerned; especially in the condition of poorly developed land transportation system or the PPs are located in different islands.

Distribution problem in a cement industry can be considered as an Inventory Routing Problem (IRP). The products are shipped to its own DCs or manufacturing facilities, on a recurrent basis. Shipments are usually not initiated by orders from the receiving locations, but rather the shipper (central supply) must schedule the shipments to assure that the receiving locations do not run out of stock. According to Ronen [1], this type of problems is known as the Inventory Routing Problems (IRPs). Campbell and Savelsbergh [2] also add that IRP is a variation of the Vehicle-Routing Problems (VRPs) that arises in situations where a vendor has the ability to make decisions about the timing and sizing of deliveries, as well as the routing, with the restriction that customers are not allowed to run out of product. Since the system under study uses vessel as transportation mode, this distribution problem is more precisely called as Maritime Inventory Routing Problem (MIRP).

This paper is organized as follows: Next section introduces an overview of MIRP and simulation. The third section explains the design and development of the MIRP simulation model which includes description of the system, conceptual model, and computerized (Arena® simulation) model. Section four shows initial output of the model. Conclusions and next phase for the study are presented in the last section.

2 OVERVIEW OF MIRP AND SIMULATION

This section presents a brief review about the main topics considered in this study: Maritime Inventory Routing Problems (MIRPs) and simulation in MIRPs.

2.1 Maritime Inventory Routing Problems

Proper scheduling of ocean transportation presents great potential of improving company’s profit and economic performance of shipping. Vessels operating costs may easily amount to thousands of dollars daily or tens of thousands of dollars for the larger vessels and consume fuel while under way, at a similar rate [3-5].

A significant amount of attention has been directed towards IRPs where trucks are used to deliver the products [1, 6]. Even though approximately 90% of the volume and 70% of the value of all goods transported worldwide are carried by sea, until recently, relatively little work has been done on shipment planning in maritime inventory routing [7]. Christiansen et al. [8] also state that the number of research literatures within maritime routing and scheduling problems has been left far behind to those of within land and air transport. Their survey presents almost 60 references on ship routing and scheduling subject published during that last decade, whereas Ronen’s [4] survey includes only about 30 references for the earlier decade.

There are several works that have been carried out in the area of MIRPs. Shih [9] uses a Mixed Integer Programming (MIP) for planning of fuel coal import problem including multiple suppliers and multiple power plants for the Taiwan Power Company to minimize the total inventory costs of the fuel coal. As an extension of Shih’s [9] work, Liu and Sherali [10] study the optimal shipping and blending decisions of coal fuel from each overseas contract to each power plant using a mixed-integer zero-one programming model to minimize the total costs of purchasing, shipping and inland delivery. Vukadinović et al. [11] develop a decision support system that can decrease the work load for the dispatcher and improve the quality of decisions for vessel dispatching problem. They propose a neural network approach as solution methodology. Ronen [1] also uses MIP for determination of the slate of shipments in maritime inventory routing. Some other works in this area also can be found in Ronen [4] and Christiansen et al. [8]. They also call these MIRPs as tactical and operational problems in industrial shipping, where the cargo owner or shipper also controls the vessels. From their surveys, in total, there are less than twenty literatures in this subject for the time span of two decades.

2.2 Simulation in MIRPs

Simulation is one of the most widely used operation research and management sciences techniques [12-13]. Fu [14] also notes that one of the most successful interfaces between operations research and computer science probably has been the development of Discrete-Event Simulation (DES) software. For several decades, simulation has been used as a descriptive tool by the operations research community in the modelling and analysis of a wide variety of complex real systems [15].

A MIRP or marine shipping involves many stochastic variables and complex interactions between the system entities in its practice. The presence of stochastic elements and complex interactions between the system entities often preclude the possibility of obtaining an analytical solution [16]. Ronen [1] models shipment planning in maritime inventory routing using MIP and finds that the smaller size problems are solved to optimality. However, he finds that the modelled MIP problems are very hard to solve and the optimality of the solution for the larger ones is not verified. Vukadinović et al. [11] in their research on vessel dispatching problems find certain disadvantages incorporated in the mathematical programming approach. They assert that mathematical programming models become invalid in the situation where unexpected delays existed.

Paolucci et al. [17] state that defining an optimization model based on a mathematical formulation of the problem to support a decision-making process is neither simple nor suitable. Instead of using mathematical formulation, they use a simulation-based decision support system to the allocation problem of crude oil supply to port and refinery tanks. Cheng and Duran [18] study logistics for world-wide crude oil transportation using discrete-event simulation and optimal control. In general, their model is typified by one supply point with multiple discharging ports, one discharging port per vessel voyage, multiple vessels with similar capacity, one type of product, identical daily costs for each type of tankers, no port entry constraints on vessels, and one-day discrete time slice. This set of system characteristics may work well for a world-wide crude oil logistics system; however some of the system's characteristics tend to make the model being not valid for other MIRPs.

In Ronen's [4] review paper, there is only one published work that uses simulation as the technique to solve the problem. This work is a design of an interactive decision support system to simulate ship voyage alternatives for only one vessel [19]. While in Christiansen et al. [8], there is no simulation model found to be utilised as the method for solving the problems in commercial vessels routing and scheduling in industrial shipping. Nevertheless, there are a small number of works in the area of strategic ship routing and scheduling system design that use simulation approaches with the major decisions on design of transport system and fleet size, and also there is one work on ship routing and scheduling in supply chain problem with major decision on logistic system design.

3 SIMULATION MODEL OF MIRP

3.1 System Description

The MIRP system under study can be classified as combined discrete and continuous system. Mainly, the system's events occur at isolated points in time or in other word according to discrete jumps. The sequence of detailed activities of vessel in MIRP system can be modelled as discrete model. However, the MIRP system also contains inventory system where the state of the system might change continuously over time. In this situation, the inventory part of the MIRP system should be modelled as continuous event model. Fortunately, Arena® can handle both situations.

This MIRP system consists of one CS (also named as PP1) and six DCs (DC A to F and also named as PP2 to PP7). The CS has two berths for loading the cargo into the vessels. DC A to DC E only has one berth each for unloading the cargo, while DC F has two berths. All DCs have land equipment for unloading process except DC B; hence only vessels with self unloading equipment can be assigned to DC B. Following the classification of ship routing and scheduling problems and models from Ronen [20], the problem entities of the MIRP system under study can be described as in Table 1.

Table 1: Problem Entities of MIRP System under Study

Problem Entity	Preference
a. Mode of operation	Industrial
b. Loading and discharge times	Open
c. Number of origins	One
d. Number of discharging ports	Multiple
e. Number of loading ports per vessel voyage	One
f. Number of discharging ports per vessel voyage	One
g. Number of commodities	Multiple
h. Fleet size	Multiple vessel
i. Types of vessel	Multiple
j. Demands (shipment sizes)	Stochastic (full shipload)
k. Cruising speed as a decision variable	No
l. Fleet size and composition	Constant over scheduling period
m. Port entry constraints on vessels	Exist
n. Sea route constraints on vessels	Exist
o. Ports precedence requirements	None
p. Costs	Fixed costs and variable costs
q. Cargo transhipment	Excluded
r. Time between events	Stochastic

3.2 Conceptual Model of the MIRP System

The sequence of activities for a vessel in the MIRP system can be represented as in the Figure 1. Every arriving vessel at CS (Packing Plant 1, PP1) Pilot Station EOSV will be assigned its DC destination and cargo (i.e. its cement type and amount). If all servers (berths) are busy, the vessel will wait at anchorage position with First In First Out (FIFO) queuing discipline, otherwise it will seize one of the available berths. After the vessel successfully berthing, it will then get Initial Draft Survey (IDS), loading the cargo, and

End Draft Survey (EDS). The vessel then releases the berth (unberthing) and routes to CS Pilot Station BOSV. From this station the vessel is sailing to its assigned DC destination. In real system the vessel will send a notice (e.g. 1 hour) before it arrives at DC Pilot Station EOSV. This also applies when vessel arrives at CS. From DC Pilot Station EOSV the vessel sets the route to the available berth. If all berths are busy, the vessel will wait at anchorage position according to FIFO queue. As in CS, the vessel at DC will follow the IDS, unloading the cargo, and EDS processes sequence. Having completed the processes, the vessel then releases the berth and routes to DC Pilot Station BOSV. From this station the vessel is sailing back to CS in empty condition. This sequence of activities will be repeated as a cycle.

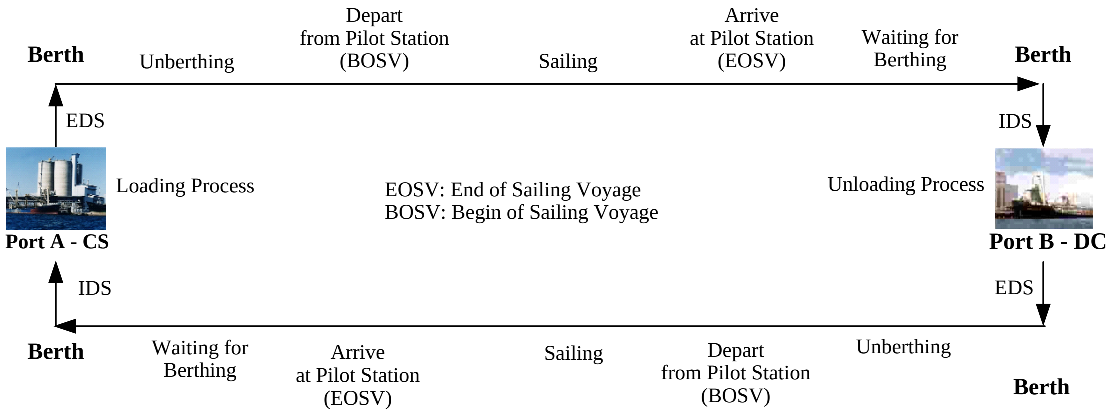

Figure 1: Vessel Round Voyage (VRV) in MIRP

Entities are the dynamic objects in the simulation. While entities usually are created, move around for a while, and then are disposed as they leave, the vessels entities in this MIRP simulation model are created at time 0, move around during the simulation, and never leave the system. It is possible to have entities that never leave but just keep circulating in the system [21]. Vessels entities and other components of simulation model for this MIRP system are explained in Table 2.

Table 2: Components of MIRP Simulation Model

Component	Name	Detail	Description
Entities	Vessel	Quantity Arrival pattern	Number of vessel All vessels are created at time 0
Attributes	Vessel Index		Labelling the vessel: Vessel 01, Vessel 02, ...
Variables			Various variables are used to keep information those reflect some characteristics of the MIRP system. These variables such as current stock and maximum capacity of each cement type stored at CS and DC
Resources	Berths	Quantity Capacity Where required Shifts	2 at CS, 1 each at DC A to E, and 2 at DC F Only 1 vessel can berth at one time The berth is required for IDS, loading or unloading, and EDS activities 24 hours a day and 7 days a week
Queues	Berths Queues Anchorage Positions	Capacity Capacity Dwell time Rule	No queue is allowed at particular berth (0) Instead of queuing at berth, vessel will queue at anchorage position at particular CS or DC with infinite capacity Until at least one berth available FIFO

From the detailed sequence of activities of a vessel in the MIRP system (see Figure 1), the stations are defined, for example: station number 21 (i.e. PP1-Pilot Station EOSV), station number 22 (i.e. PP1-Anchorage Position), and station number 87 (i.e. PP7-Pilot Station BSOV). These stations will be used in the design and development of the MIRP simulation model. The network representation of these stations and their relationship to activities duration in VRV can be seen in Figure 2. As examples, IDSPTaCS means IDS Process Time at CS and STfDCtCS means Sailing Time from DC to CS.

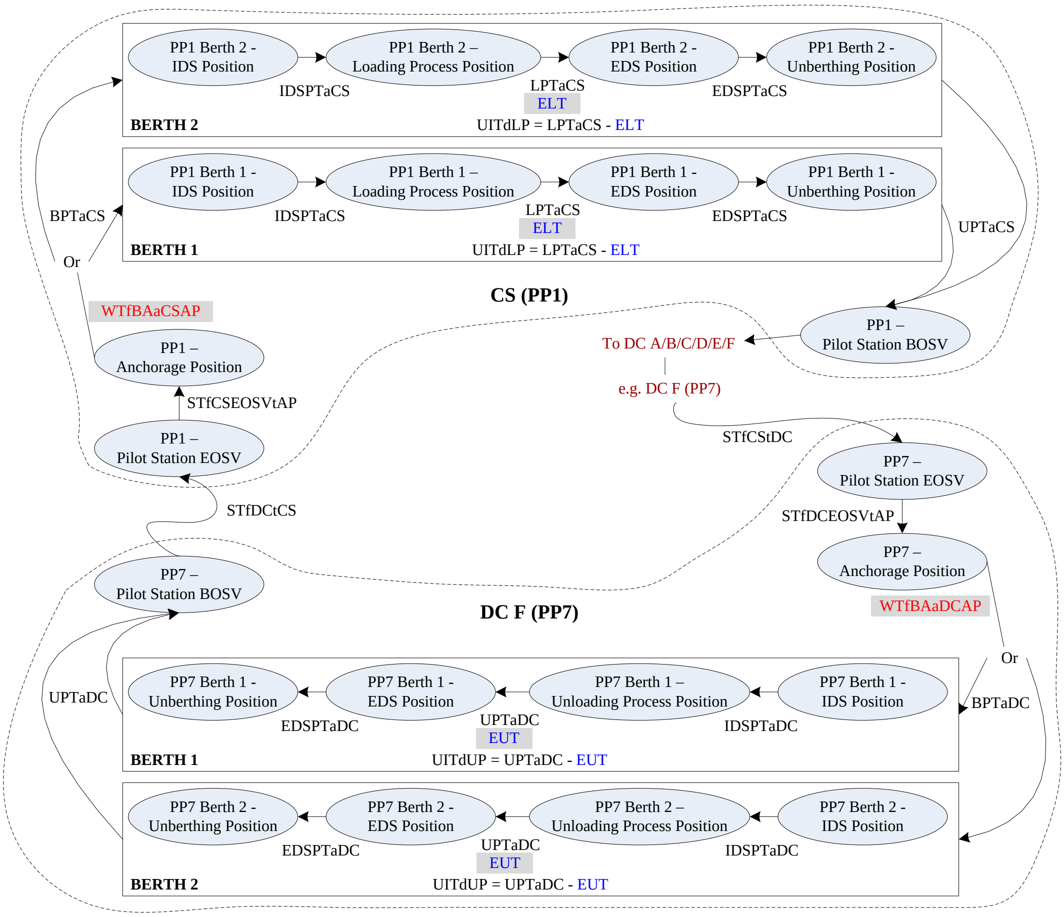

Figure 2: Design of Stations within VRV in MIRP Simulation Model

Several assumptions are made to the MIRP simulation model as the following:

a. Time required for sailing from CS to a DC or from a DC to CS is expressed as a statistical distribution. At the current time of the MIRP system, a vessel may be on its way to a DC or CS (sailing). The remaining time required to complete its journey is assumed to be the proportion of the distance left.
b. If the silos of associated product at particular DC are full during the unloading process, the process will be interrupted for one hour to bring the level of inventory down.
c. Similarly, if the silos of associated product at CS are empty during the loading process, the process will be interrupted for one hour to wait the stock being replenished.
d. If the silos of associated product at CS are full, replenishment process will be interrupted for one hour to wait the level of inventory down.

3.3 Simulation Model of the MIRP System

The structure of computer or simulation model of the MIRP system under study can be seen in Figure 3. The logics begin with reading external data, which were created in a Microsoft® Excel file (i.e. MIRP Initial Values.xls). This file contains parameters and initial conditions of the MIRP system at the current time. Create Vessel Logic then creates unique vessels and assigns initial conditions and attributes values to each vessel. These vessels are then located at their current position in the system, such as sail-go, sail-back, CS, or a DC. Each vessel will then follow the logic at its current position, which is representing the detailed activities in VRV. Sail-Go and Sail-Back Logic is only used once at the beginning time of simulation run if there is any vessel at that position. Each vessel will route inventory from CS to an assigned DC in full load and back in empty. This cycle will continue until the simulation is terminated.

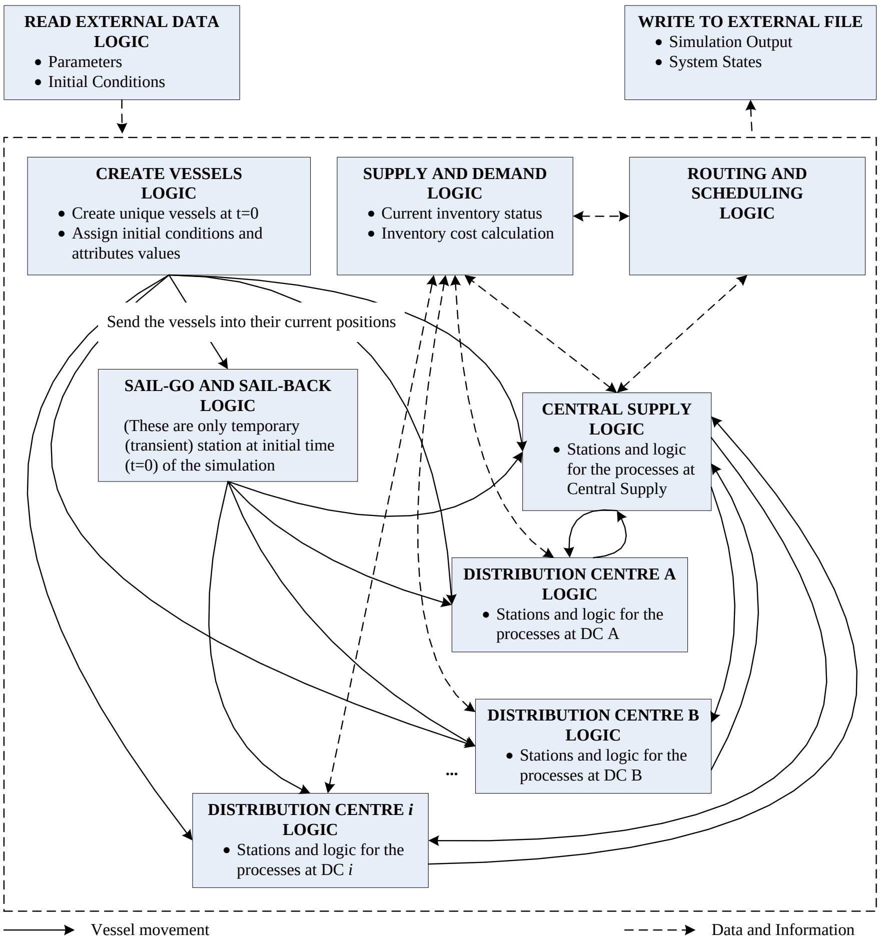

Figure 3: Structure of Module's Logic in the MIRP Simulation Model

As previously defined in the conceptual model, the CS (PP1) area is divided into several sections (stations) according to detailed sequence of vessel activities in this area. This detailed division not only gives flexibility in developing and animating the MIRP simulation model, but it will also promote the validity of the model by eliminating the possibility of miscalculating activities durations of the vessels during the early stage of the simulation run. This miscalculation is due to placing the vessel not at its exact position and consequently not at its exact activity start time, whereas time precision is a very crucial factor in this MIRP simulation model. In term of inventory calculation part of this simulation model, every movement (time advance) of the vessel will affect the inventory status. Time will also be used for calculating other performance measures in the model, such as costs of each stage of a time charter vessel, despatch, and demurrage. Similarly, DCs areas are also divided into several stations according to detailed sequence of vessel activities at DCs. The fundamental reason for this is also similar. Duration for each activity within the VRV is recorded in a global variable every time a vessel has moved from one station to the next station. The detailed logic in Figure 4 reveals the challenge in modelling this MIRP simulation. Due to the size of the model, only the CS part is presented.

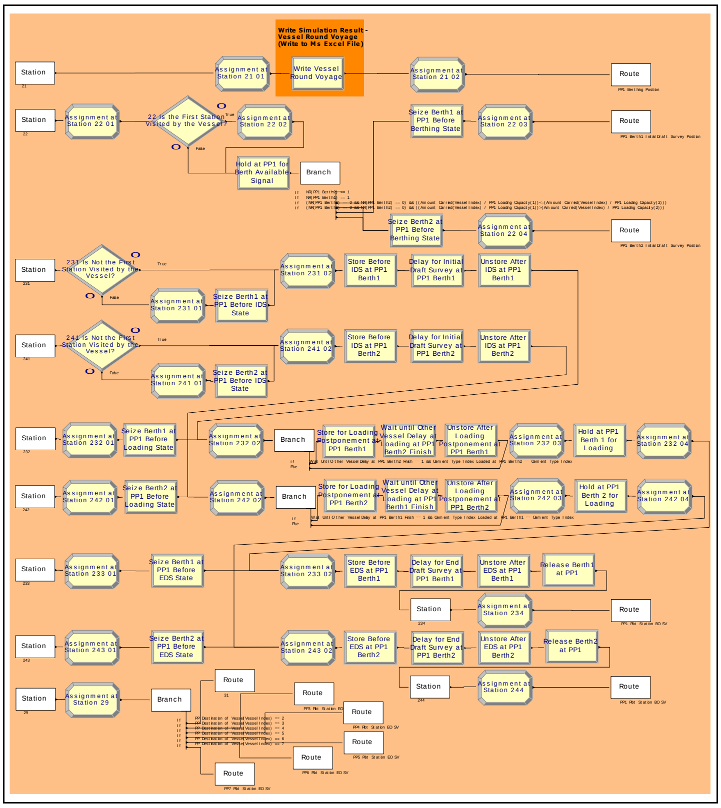

Figure 4: Discrete Part of the MIRP Simulation Model – Logic for CS

Continuously during the simulation run, Supply and Demand Logic will collect data from CS, DCs, and vessels. This data will be used to control the process in the MIRP system and for routing and scheduling purposes. The structure of this logic consists of the following:

a. Defining continuous approach in inventory model and initialisation of PPs inventory levels and cumulative rates for each cement type
b. Observing inventory level to interrupt the unloading process
c. Observing inventory level to interrupt the loading process
d. Observing inventory level to end the unloading process
e. Observing inventory level to end the loading process
f. Observing inventory level to interrupt stock replenishment at CS

The detail logic can be seen in Figure 5 below. Again, due to the size of the model, only some of them are presented. Periodically during the simulation run, the simulation outputs are stored in a Microsoft® Excel file (i.e. MIRP Simulation Results.xls).

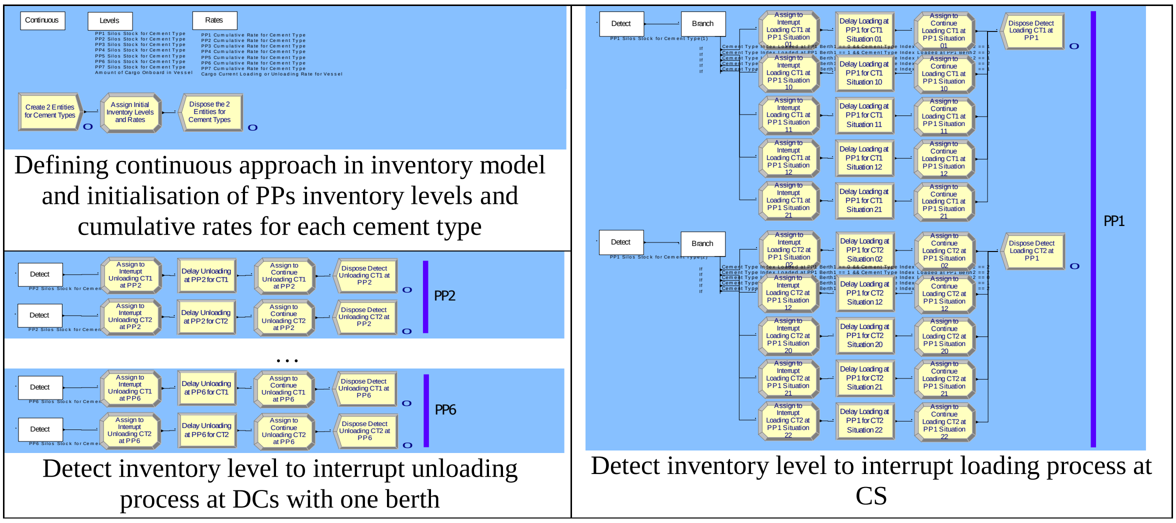

Figure 5: Continuous Part of the MIRP Simulation Model – Supply and Demand Logic

4 SIMULATION OUTPUTS

This section will present the designed performance measures for simulation model of the MIRP system under study and typical results using hypothetical data. The results of the simulation model will be given in three forms: graphical animation, real-time state report and summary report.

Animation provides visualization of the entities flow throughout the system. Current state of a vessel can easily be observed. The movement of inventory levels in silos at CS and DCs and also onboard the vessels are presented in real time. The typical animation of the MIRP simulation model is given in Figure 6.

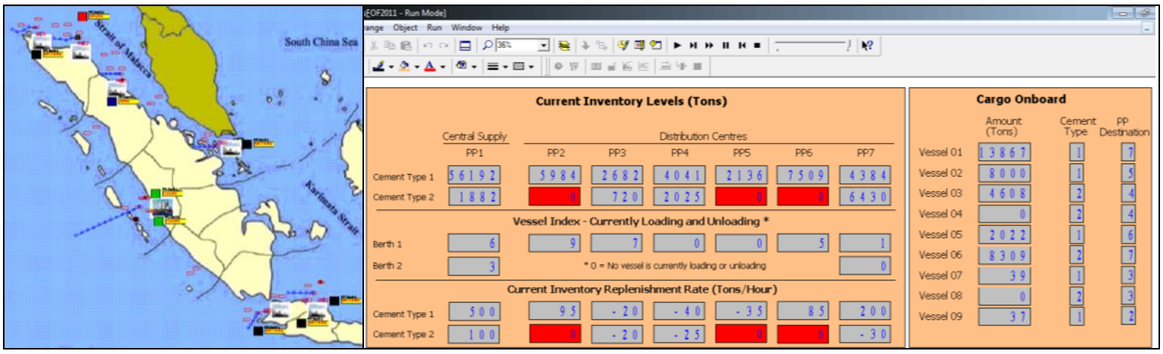

Figure 6: Animation of MIRP Simulation Model

At current stage of this research, the designed performance measures are the real time states of inventory levels at CS and DCs and VRVs which contain DC destination, cargo, berthing position at CS and DC, and duration of each activity. Table 3 shows the element of VRV which will be recorded during the simulation run. A Microsoft® Excel file (i.e. MIRP Simulation Results.xls) has been defined to record the performance measures of the MIRP simulation model as the simulation runs progress. The examples of inventory status and VRVs recorded from the MIRP simulation result can be seen in Figure 7.

Table 3: Vessel Round Voyage Performance Measures

Element	Unit	Element	Unit
Vessel	-	EDS Time at DC	Hours
PP (DC) Assigned	-	Unberthing Position – DC BOSV	Hours
Cement Type	-	Sail Back	Hours
Cargo Delivered	Tons	CS EOSV – Anchorage Position	Hours
Sail Go	Hours	Waiting for Berthing at CS	Hours
DC EOSV – Anchorage Position	Hours	Berth Seized at CS	-
Waiting for Berthing at DC	Hours	Anchorage Position – Berth at CS	Hours
Berth Seized at DC	-	IDS Time at CS	Hours
Anchorage Position – Berth at DC	Hours	Loading Time	Hours
IDS Time at DC	Hours	Expected Loading Time	Hours
Unloading Time	Hours	Unexpected Idle Time during Loading	Hours
Expected Unloading Time	Hours	EDS Time at CS	Hours
Unexpected Idle Time during Unloading	Hours	Unberthing Position – CS BOSV	Hours

InventoryStatusATEVENHOURS *fx* 36700

SIMULATION RESULTS

Inventory Status Record at Even Number Hours

Time Recorded (at Hour)	PP1 (CS) Cement Type 1 (Tons)	PP1 (CS) Cement Type 2 (Tons)	PP2 (DC A) Cement Type 1 (Tons)	PP2 (DC A) Cement Type 2 (Tons)	PP3 (Cement Type 1 (Tons)
0	36,700	7,900	3,200	0	1,000
2	37,700	7,400	3,390	0	1,310
4	38,700	6,201	3,580	0	1,620
6	39,700	5,001	3,770	0	1,930
8	40,700	3,801	3,960	0	2,240
10	41,700	2,601	4,150	0	2,550
12	42,700	1,867	4,340	0	2,685
14	43,700	1,833	4,530	0	2,685

InventoryStatusATODDHOURS *fx* 37200.000000

SIMULATION RESULTS

Inventory Status Record at Odd Number Hours

Time Recorded (at Hour)	PP1 (CS) Cement Type 1 (Tons)	PP1 (CS) Cement Type 2 (Tons)	PP2 (DC A) Cement Type 1 (Tons)	PP2 (DC A) Cement Type 2 (Tons)	PP3 (Cement Type 1 (Tons)
1	37,200	7,650	3,295	0	1,155
3	38,200	6,801	3,485	0	1,465
5	39,200	5,601	3,675	0	1,775
7	40,200	4,401	3,865	0	2,085
9	41,200	3,201	4,055	0	2,395
11	42,200	2,001	4,245	0	2,699
13	43,200	1,850	4,435	0	2,682
15	44,200	1,817	4,625	0	2,687

VesselsRoundVoyages *fx* 8

SIMULATION RESULTS

Vessels Round Voyages

No.	Vessel	PP (DC) Assigned	Cement Type	Cargo Delivered (Tons)	Sail Go (Hours)
1	8	7	0	6800	0.000
2	4	4	0	0	0.000
3	9	2	1	5600	0.000
4	7	3	1	6000	0.000
5	5	6	1	5700	0.000
6	2	5	1	8000	56.728
7	1	7	1	14700	28.645
8	6	7	2	9000	61.016

Figure 7: Microsoft® Excel Sheets for Simulation Results – Real Time States

Arena® has capability to create a summary report of simulation results. This summary report provides useful statistics regarding to the performance measures of the MIRP simulation model. Some of these statistics can be seen in Figure 8. As examples, from this summary report utilization of each resource and its idle time can be identified.

Time

Waiting Time	Average	Half Width	Minimum	Maximum
Hold at PP1 Berth 1 for Loading.Queue	24.5745	(Insufficient)	16.0000	132.43
Hold at PP1 Berth 2 for Loading.Queue	31.9451	(Insufficient)	16.0000	120.86

PP1 Berth1 Statistic	Number Obs	Average Time	Standard Percent	Restricted Percent
Berth in Idle State	47	24.0973	47.19	47.19
Berthing State	45	1.0000	1.88	1.88
EDS State	46	1.0000	1.92	1.92
IDS State	45	1.0222	1.92	1.92
Loading State	46	24.5745	47.10	47.10

Resource Detail Summary

Usage

	Inst Util	Num Busy	Num Sched	Num Seized	Sched Util
PP1 Berth1	0.53	0.53	1.00	46.00	0.53
PP1 Berth2	0.38	0.38	1.00	27.00	0.38
PP2 Berth1	0.16	0.16	1.00	7.00	0.16
PP3 Berth1	0.39	0.39	1.00	14.00	0.39
PP4 Berth1	0.53	0.53	1.00	19.00	0.53
PP5 Berth1	0.26	0.26	1.00	10.00	0.26
PP6 Berth1	0.25	0.25	1.00	9.00	0.25
PP7 Berth1	0.43	0.43	1.00	14.00	0.43
PP7 Berth2	0.07	0.07	1.00	2.00	0.07

Figure 8: Arena® Summary Report of MIRP Simulation Model

Regarding to further development, this MIRP simulation model has already had the capability to provide support for decision making in ship scheduling and to some extent to support integration with the optimization model. This simulation model also has capability to provide information regarding to calculation of inventory and transportation costs and also calculation of unexpected delays due to waiting time for berthing, DCs silos full, and CS silos empty. This information will be useful to determine other performance measures for the MIRP simulation model. Beforehand, this MIRP simulation model is needed to be validated using the data collected from the real system.

5 CONCLUSION

A MIRP or marine shipping is characterized by the present of many stochastic variables and complex interactions between the system entities in its practice, which often preclude the possibility of obtaining an analytical solution. This paper presented a simulation approach as solution methodology for a MIRP with particular application to cement industry. The simulation approach used is a combined discrete and continuous model. The simulation model in this study has been designed and developed thoroughly to emulate the complexity of the real system of MIRP. This MIRP simulation model is taking into account the presence of stochastic elements and complex interactions between the system entities.

The simulation model has shown an encouraging result as it performs as expected. This MIRP simulation model has been designed and developed systematically, so that the model can be easily expanded or adjusted to different size of system entities for example number of CSs, DCs, berths, vessels, and products. The simulation model developed has already had the capability to provide support for decision making in ship scheduling. Even though the effectiveness of the model in term of optimization has not been established yet, current achievement promises further development of the MIRP simulation model to the next stage as has been planned, which is the integration with the optimization model.

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