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PORT CAPACITY FORECASTING AND THE IMPACT OF THE DREDGING WORKS ON PORT SEA OPERATIONS USING DISCRETE EVENT SIMULATION

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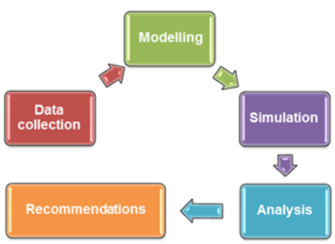
Graphical abstract



Abstract

Continuous capacity expansion is vital for ports to handle future growth due to the increase in volume of maritime transport and size of the vessels. Some improvements and developments are required for the port to enhance its capacity throughput. In order to accommodate huge vessels without any restrictions, there is a need to deepen the channels. Furthermore, there is also need to widen the channel to prevent congestions. However, dredging work for deepening the harbour waters will reduce the utilization of the berths and navigational areas. This will significantly affect the port capacity and hence its income. In this paper a simulation program based on queuing theory and discrete event simulation is developed and used for forecasting port throughput and simulating dredging conditions. Data from a container port and an Automatic Identification System (AIS) were utilised to develop the simulation program in MATLAB-Simulink. Using this tool, port capacity was simulated and the effect of dredging on port capacity was studied. An appropriate period of time needed for dredging is determined by taking into considerations the blocking of some berths and limiting the number of vessels passing the channels during the dredging operations. The results from the simulations could then be used for planning the dredging works.

Keywords: Marine safety, dredging and reclamation works, AIS, queuing theory, discrete-event simulation, port capacity

Abstrak

Pada masa kini, pengembangan kapasiti yang berterusan adalah penting untuk memastikan bahawa pelabuhan kapal boleh mengendalikan pertumbuhan masa depan. Ini disebabkan oleh pertumbuhan perdagangan dunia yang meningkatkan jumlah pengangkutan maritim dan saiz kapal menjadi lebih besar. Beberapa penambahbaikan dan perkembangan diperlukan untuk pelabuhan untuk meningkatkan daya pemprosesan kapasitinya. Dalam usaha untuk menampung saiz kapal besar yang tiada had, terdapat keperluan untuk mendalamkan saluran pelabuhan secara berterusan. Tambahan pula, terdapat keperluan meluaskan saluran untuk mengelakkan kesesakan. Kerja pengorekan untuk mendalamkan saluran akan mengurangkan penggunaan dermaga dan kawasan pelayaran. Ini akan menjejaskan kapasiti pelabuhan dan dengan itu mengurangkan pendapatannya. Dalam kertas kerja ini, program simulasi berdasarkan teori giliran dan simulasi diskret-acara dibangunkan dan digunakan untuk meramal kapasiti pelabuhan dan simulasi semasa pengorekan dijalankan. Data-data dari sebuah pelabuhan kontena dan Sistem Pengenalan Automatik (AIS) telah digunakan untuk membangunkan program simulasi dalam MATLAB-Simulink. Dengan menggunakan program ini, kapasiti pelabuhan telah disimulasi dan kesan pengorekan pada kapasiti pelabuhan dikaji. Tempoh masa yang sesuai bagi kerja pengorekan telah dipilih dan juga menghadkan bilangan kapal yang dapat memasuki dermaga dan melalui saluran semasa operasi pengorekan. Hasil daripada simulasi kemudiannya boleh digunakan untuk merancang kerja-kerja pengorekan.

Kata kunci: Keselamatan marin, pengorekan dan kerja penambakan, AIS, simulasi diskret-acara, kapasiti pelabuhan

1.0 INTRODUCTION

The volume of the world trade has rapidly increased due to the increasing of the demand and supply of the goods throughout the world. The environment of port will become more critical because it will handle the increasing number of ship arrival and the growth of ship size. Increasing the number of those ships will lead to the congestion and risks from squatting at the port restricted waters due to increasing ship drafts. Through the AIS receiver, data on ship movements in the Straits of Malacca, Singapore and Port Tanjung Pelepas (PTP) operational areas could be recorded as a valuable source for ship traffic information. The data obtained from the AIS receiver can be utilized for the purpose of the marine traffic collision risk analysis [1]. The data can also be used as a basis for the planning of dredging and reclamation operations, port capacity and future development. Development of port access, navigation and harbour channels are not increasing at the same pace as a vessels' size to meet the growth of world trade. Safety now becomes a very important issue due to the fastest growing navigational activities in port. Dredging work will reduce the utilization of the berths and navigational areas which will affect the port capacity and hence the port income. There are many papers using different types of codes and simulation programs and models with varied simulation languages for purposes to predict and analyse the port performance, techniques of container handling, equipment and container yard utilization, port capacity and operational efficiency concerning the container yard, yard truck and ship planning and scheduling and access, gate and berthing and other important conditions [2]. The discrete-event simulation models for container terminal operations had been used by Dahal et al. [3], Canonaco et al. [4], Petering and Murty [5], Petering [6], Petering et al. [7], A Cartenì and S De Luca [8] and Ozhan Almaz & Tayfur Altiok [9]. In this paper the discrete-event simulation model is considered for forecasting port capacity and to determine the effect of dredging process on port performance and port capacity.

2.0 RESEARCH METHODOLOGY

The general approach framework and the stages of the research process are shown in Figures 1and 2.

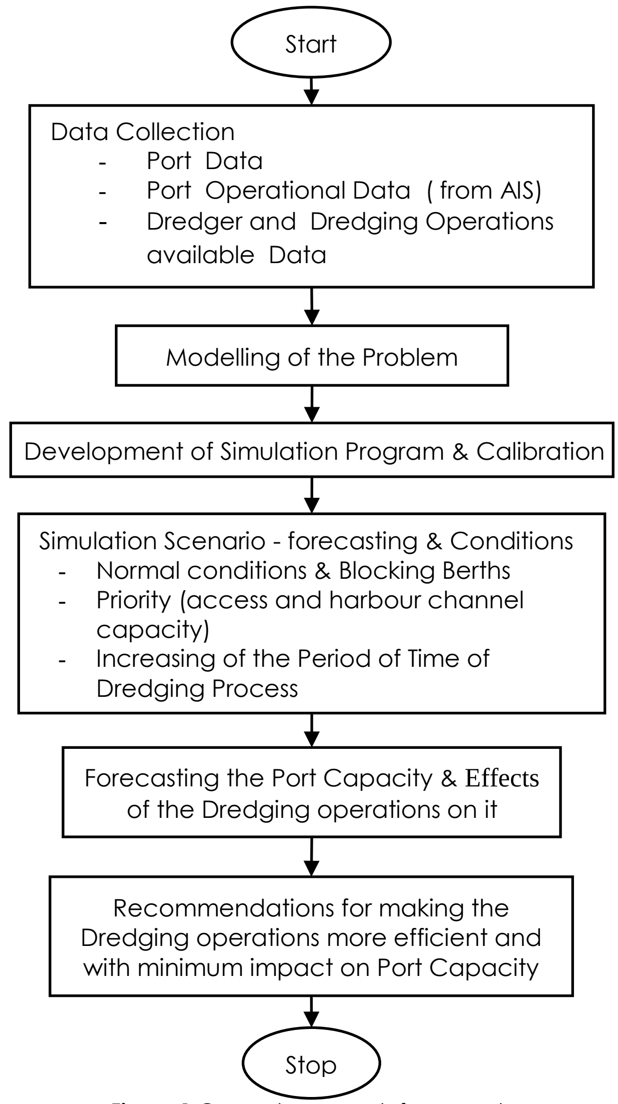


Figure 1 General approach framework

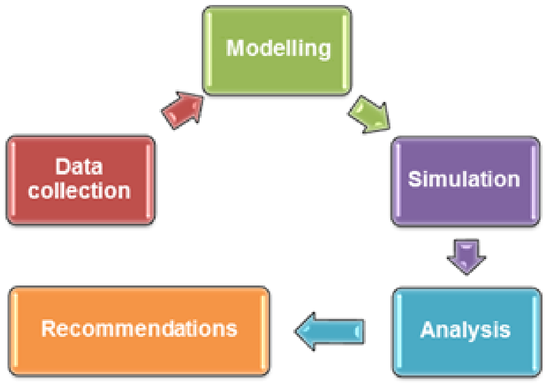


Figure 2 Stages of the research process

2.1 Simulation Model And Simulation Scenario

Simulation Events Library provides a discrete-event simulation engine and component library for Simulink. Using it, is easy to model event-driven communication between components to analyse and optimize end-to-end latencies, throughput, packet loss, and other performance characteristics. Libraries of predefined blocks, such as queues, servers, and switches, enable to accurately represent the system, and customize routing, processing delays, prioritization, and other operations.

The Simulation program was developed and carried out using Math lab Simulink SIM-events and based on queuing theory and discrete event model. The input values of the parameters are based on both; AIS and port data. The average ship arrival rate is used for generating the number of ships or the number of calls by using the basic input parameter which is the inter-arrival distribution. The commonly assumed distribution of this parameter in the literature is the Exponential distribution [10]. The average service time follows the Poisson distribution. The simulation program can determine and predict variables such as average waiting time, traffic intensity, berth utilization, port capacity, number of ships at anchorage, channels, turning basin and at the berths, etc. The output can be visualised using Simulink virtual reality (VR) Library as shown in Figure 3.

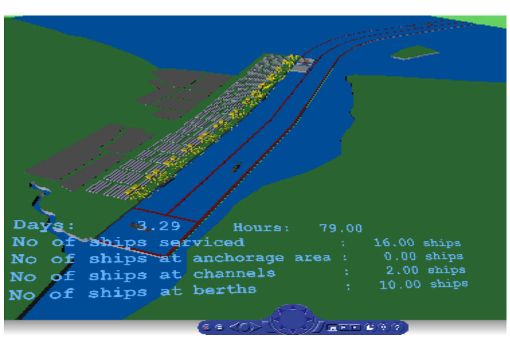


Figure 3 PTP port in 3D animation using VR Simulink

Simulation Scenario is based on 30, 60 and 180 days of dredging time. In addition, the impact of the dredging works is based on the following conditions:

- Blocking of two berths at any one time.
- Time gap between the two ships entering channel is one hour.
- Limiting the capacity of the navigation and access channels by allowing only one ship for inbound or outbound.

Also, in this simulation model the Queuing Approach for a container port is used in the simulation program as illustrated in the following Figure 4:

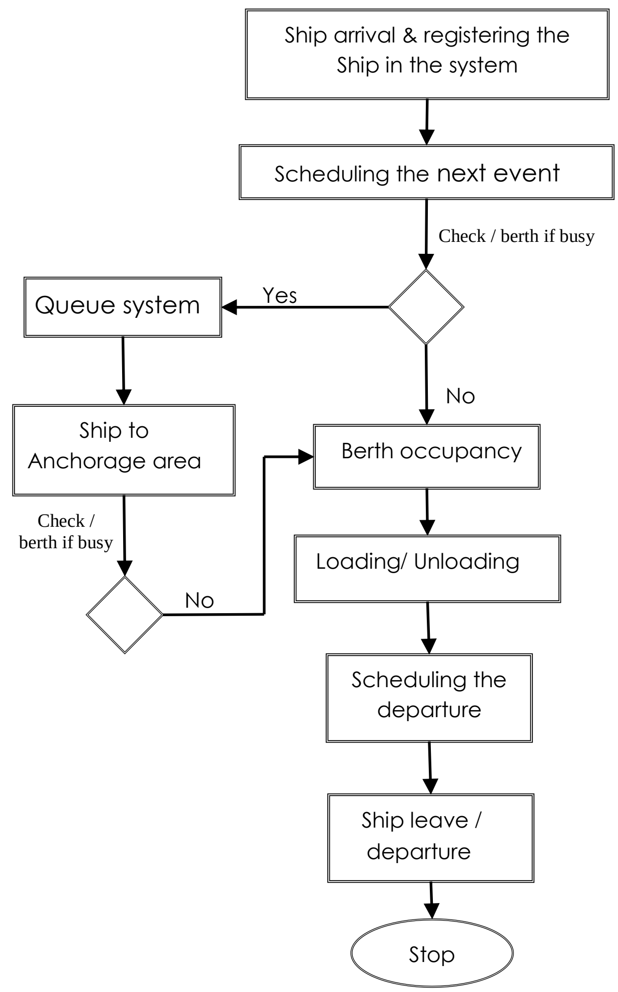


Figure 4 Queuing Approach for a container port used in the simulation program

2.2 Case Study

Port Tanjung Pelepas (PTP) is situated at the Pulai River, which is in the South West of Johor. This port can be accessed through the Straits of Malacca as shown in Figure 5. The Straits of Malacca is one of the busiest shipping lanes in the world. PTP has the potential to become one of the main ports in the region. The main specifications of PTP are as follows;

- 14 berths with a total length of 5.02 km.
- Sheltered bay & no tide restriction.
- 15 -19 meters of terminal draft.
- 12.6 km length of harbour, navigation & access channels for two-way traffic movements.
- 600 m of turning basin diameter.

Figure 5 Locations of Port Tanjung Pelepas

2.3 Dredger

A dredger is used to dig, transport and dump a certain amount of underwater laying soil at a certain time. The grab dredger is the most common used dredger in the world. Grab dredges are easy to understand due to the simplicity and they are especially suitable for dredging close up to existing quay walls or other structures with minimum risk of damage, and the grab equipment is often capable of lifting individual boulders. Grab dredges are usually used for maintenance dredging. However, it has the disadvantage of being a discontinuous, batch-type system. Having an approximate speed of one bite per minute. The capacity of a grab dredger is expressed in the volume of the grab. Grab sizes varies between less than 1 m^3 up to 200 m^3 (See Figure 6). The dredging depth depends on the length of the wire on the winches. However, the accuracy decreases with depth. For mining of minerals dredging depths can reach more than 100 m. Based on that, this technology of "grab dredger" can be used for PTP in dredging and reclamation works.

Figure 6 The world's largest & heaviest grab dredging system

2.4 AIS Data

Through the AIS receiver, data on ship movements in the Straits of Malacca, Singapore and Port Tanjung Pelepas (PTP) areas could be recorded as a valuable source for ship traffic information. A program has been established by UTM to retrieve the data for the purpose of marine traffic collision risk analysis.

AIS data were collected using AIS receiver located at the Marine Technology Centre, UTM. AIS raw data used were from April to September 2010. These data were extracted and filtered from Comma Separated Values file (CSV format) using Math lab m-file codes. From the AIS database the important parameters are given as follows:

- Ship call = MMSI
- Period (T) = Date & time
- Time of arrival = Date & time
  Heading = course
- Location & Position = (latitude, and longitude)

The number of ship calls and the average of ship arrival rate (λ) (ship per hour) are shown in the Table 1 and in Figure 7 respectively:

Table 1 Data Extracted From AIS POS Report

No	Months	Hours per month	Number of Ships
1	April	151	91
2	May	350	298
3	June	720	597
4	July	642	489
5	August	458	374
6	September	279	304
Total	6	2600	2153

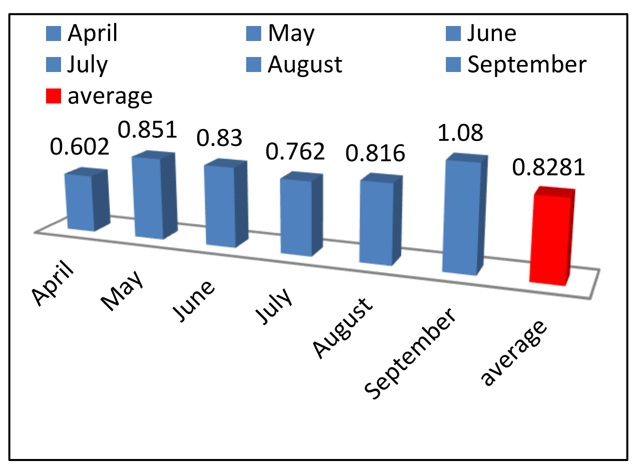


Figure 7 Average ship arrival rate

3.0 RESULTS AND DISCUSSION

3.1 Forecasting the Capacity of the Port

Forecasting of the port performance and port capacity are shown in Figures 8, 9, 10 and 11. Table 2 shows the summary of these simulated results.

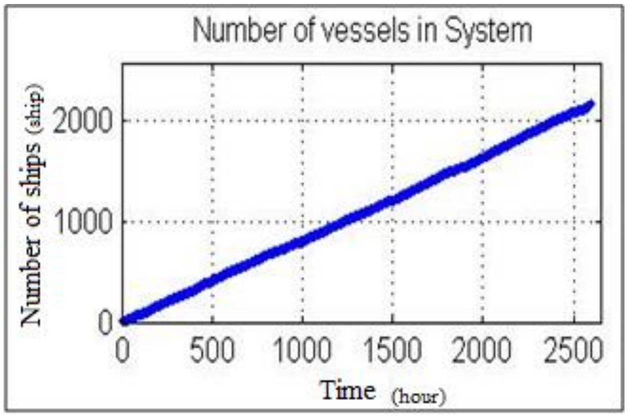


Figure 8 Number of ships in the system

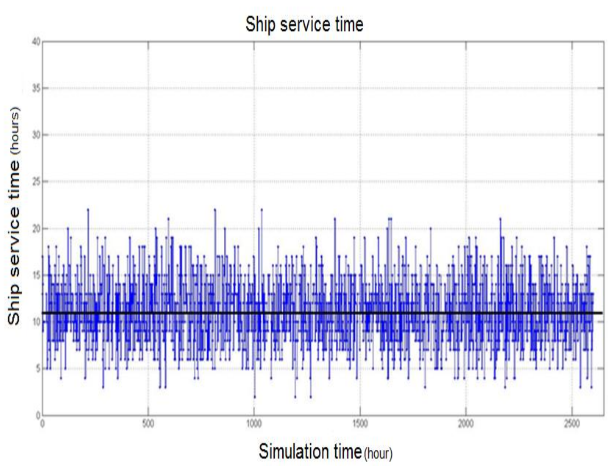


Figure 9 Ship service time

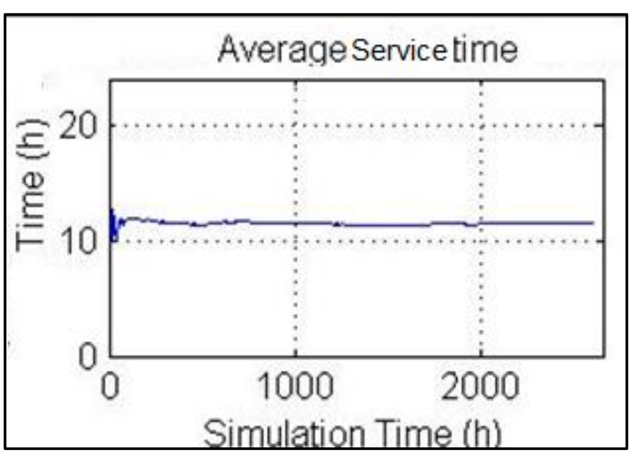


Figure 10 Average service time

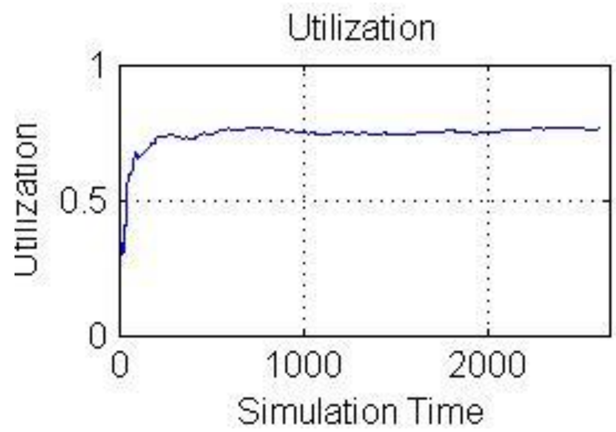


Figure 11 Utilization

Table 2 Summary of important simulation results

Average ship arrival rate (λ)	Number of Ships (N)	Average ship service rate (μ)	Utilization (ρ)	Average service time (t_s)
0.8281	2153	0.07692	0.7629	11.02

The effect of increasing the average ship arrival rate (with fixing the number of berths constant (n_b = 12) and considering that the anchorage area is unlimited capacity) on the operational area of the port is demonstrated in table 3. Figures 12 and 13 show the effect of λ on the number of arriving ships (N) and on utilization as indicator of berths' service.

Table 3 The effect of λ on port operational areas

Average ship arrival rate (λ)	No of ships	Number of ships at		
		Anchorage Area	Channel	Berths
0.8281	2153	0	0	12
1	2561	0	0	11
1.65	2831	1402	6	12

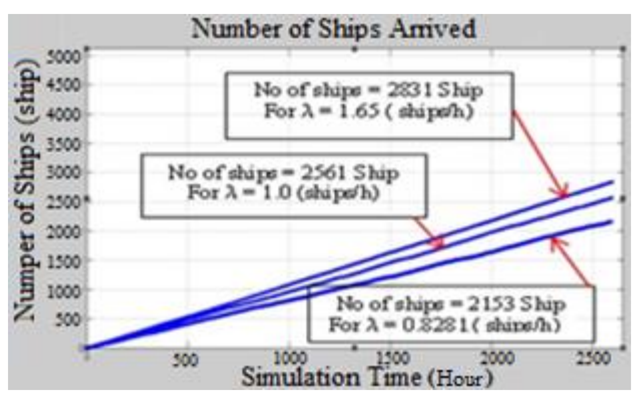


Figure 12 Number of ships arrived for different λ

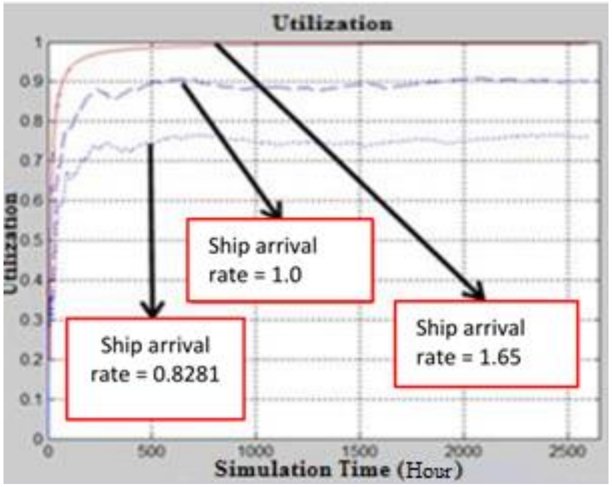


Figure 13 Utilization for different average ship arrival rate

3.2 Calibrating the Simulation Results by utilizing the AIS Data

Automatic Identification System data and port data provide valuable data for the calibration of the developed simulation ship traffic program to identify how accurate the simulated results to ascertain the port capacity and the capability of the channel and port to sustain the foreseen numbers of vessel movements.

Using the analytical method found in the literature [10] the program was calibrated and both AIS and port data utilized for this purpose. Table 4 provides an example of the analytical and simulation results of average ship arrival rate (λ), average ship service rate (μ), utilization (ρ) and average service time (t_s) which were close enough to each other. Figure 14 shows the program interface and other simulation results for both analytical and simulation methods.

Table 4 Simulation and analytical results

Methods	λ	μ	ρ	ts
Analytical	0.82807	0.07676	0.899	13.03
Simulation	0.8281	0.07692	0.7629	11.02

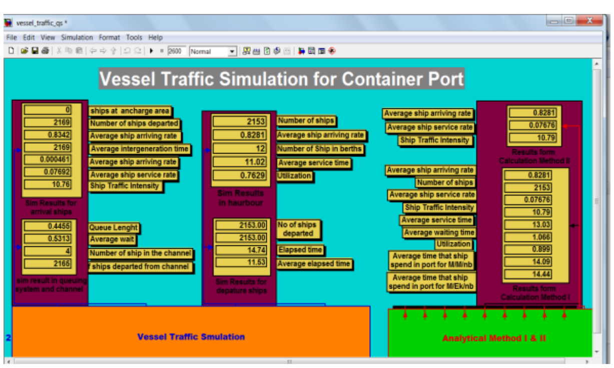


Figure 14 Simulation results of the analytical and simulation using discrete event simulation

3.3 Effects of the Dredging Operations on the Port Capacity

This study utilizes both the AIS and port data (the average ship arrival rate (λ) and Average ship service rate (μ)) for predicting the effect of dredging on port capacity. Figures 15, 16 and 17 show the simulation results for normal condition for a period of one month. This is for the condition; Number of berths, n_b =14, Average ship arrival rate, λ =0.8281 (ship/h), Average ship service rate, μ = 0.0416 (ship/h) and the capacity of channels is for two ships (one inbound and the other ship is outbound).

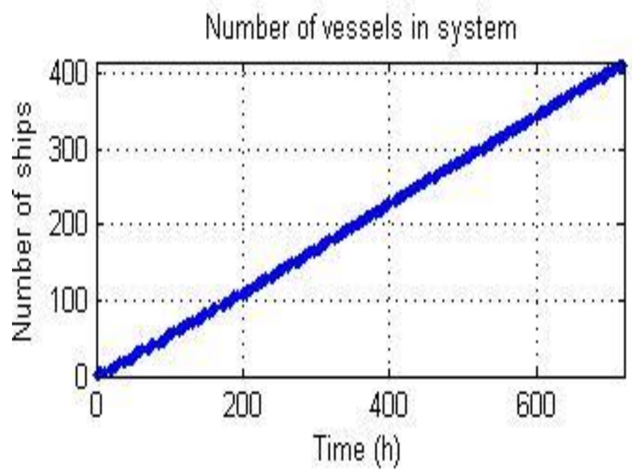


Figure 15 Number of vessels in the system

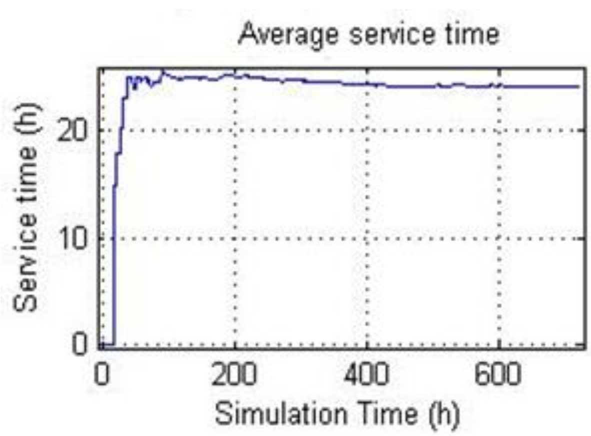


Figure 16 Average service time

Figures 18 and 19 show the simulation results comparing the number of ships serviced between normal and dredging conditions for a period of one month. This is for the Dredging condition; n_b = 12, λ = 0.8281, μ = 0.0416 and the capacity of channel is one ship (inbound or outbound).

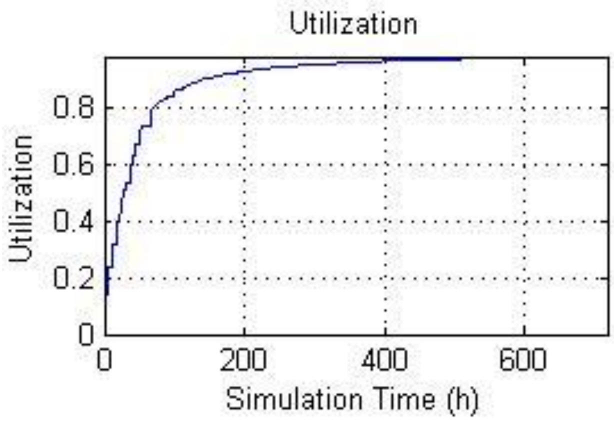


Figure 17 Utilization

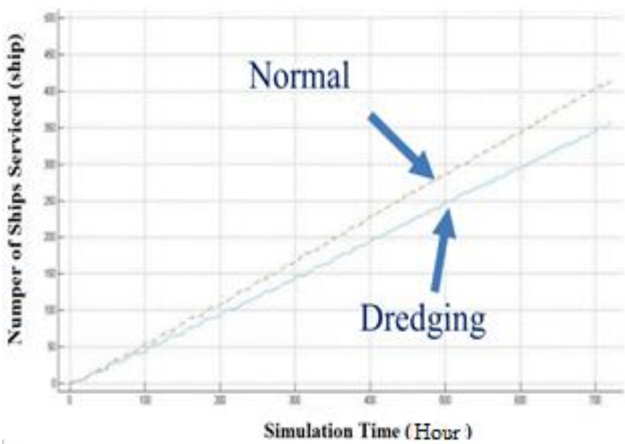


Figure 18 Number of ships serviced

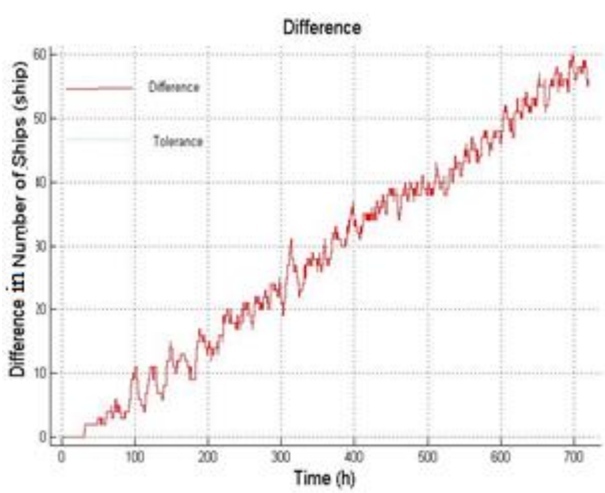


Figure 19 The difference in the number of ships serviced between the normal port operation and during dredging conditions

Figures 20 and 21 show the simulation results for normal condition for a period of two months. This is for the condition; Number of berths (n_b)=14, λ=0.8281, μ = 0.0416 and the capacity of the channel is 2 ships (inbound and outbound).

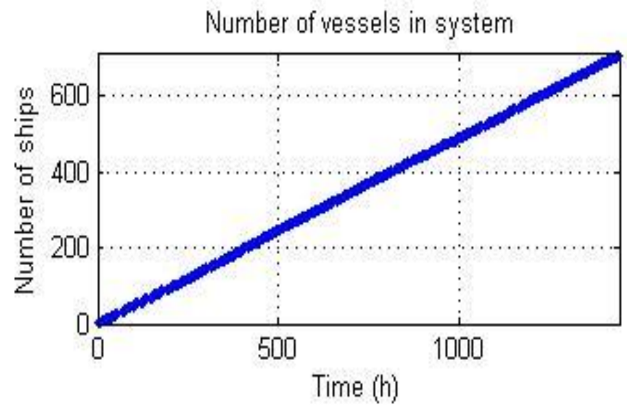


Figure 20 Number of vessels in the system

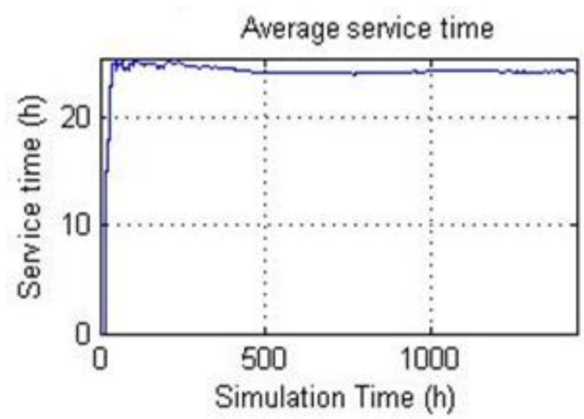


Figure 21 Average service time

Figures 22 and 23 show the simulation results for normal and during the dredging conditions for a period of two months. The Dredging Condition: Number of berths (n_b) =12, λ=0.8281, μ=0.0416 and the capacity of channels is one ship (inbound or outbound).

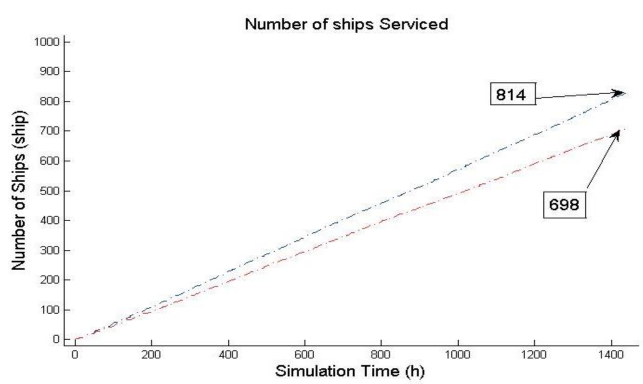


Figure 22 Number of ships serviced

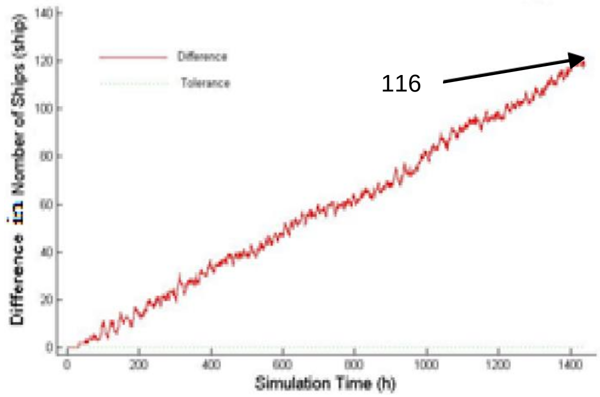


Figure 23 The difference in the number of ships serviced between the normal port operation and during dredging

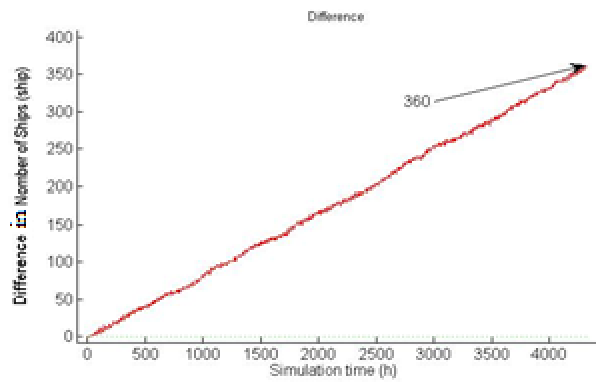


Figure 25 The difference in the number of ships serviced between the normal and during dredging conditions

Figures 24 and 25 show the simulation results for normal and during dredging conditions for a period of six months. The Dredging Condition; Number of berths, n_b = 12, λ = 0.8281, μ = 0.0416 and the capacity of channels is one ship (inbound or outbound).

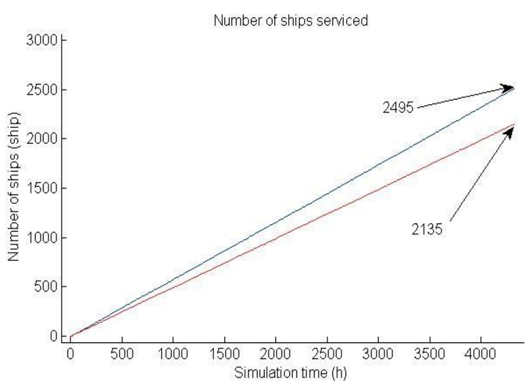


Figure 24 Number of ships serviced

Table 5 and Table 6 give the summary of the results for the number of ships serviced in the normal situation and compared with the condition when dredging is being conducted based on AIS data and Port data respectively.

Table 5 Summary of the simulation results at normal and dredging conditions based on AIS data

Conditions	Total Ships arrived	No. of ships in Anchorage area	Total ships in system	No. of ships in channels	No. of ships at Berths	No. of ships serviced	Difference (ships) [a]
Normal (1 month)	464	49	415	2	14	399	54
Dredging Period (1 month)	406	48	358	1	12	345	
Normal (2 months)	880	50	830	2	14	814	116
Dredging Period (2 months)	759	48	711	1	12	698	
Normal (6 months)	2561	50	2511	2	14	2495	360
Dredging Period (6 months)	2198	49	2149	2	12	2135	

[a] The difference in ships is the subtraction of number of ships serviced in the normal condition from the number of ships serviced during port dredging condition.

Table 6 Summary of the simulation results based on port data in 2013

Conditions	Total Ship arrived			No. of ship in Anchorage area			Total ship in system			Difference (ships) [a]		
	Con[b]	Non[c]	Total	Con[b]	Non[c]	Total	Con[b]	Non[c]	Total	Con[b]	Non[c]	Total
Normal (1 month)	380	407	787	1	10	11	379	397	776	29	54	83
Dredging Process (1 month)	380	391	771	30	48	78	350	343	693			
Normal (2 months)	751	836	1587	0	11	11	751	825	1576	47	118	165
Dredging Process (2 months)	741	756	1497	37	49	86	704	707	1411			
Normal (6 months)	2307	2539	4846	0	36	36	2307	2503	4810	166	359	525
Dredging Process (6 months)	2186	2192	4378	45	48	93	2141	2144	4285			

[a] The difference in ships is the subtraction of the total ships in the system for the normal condition from the dredging the total ships in the system for process condition.
[b] Con: Container Vessel
[c] Non: Non-container vessel

The simulation results show the forecasted throughput capacity of the port and the effect of changing the number of the arriving ships on the total ship serviced and capability of the berths through the utilization factor. The number of ships in the system increases up to 19% by increasing the average ship arriving rate about 20% and up to 31.5% by doubling the average ship arriving rate. But also increases the number of ships stacked at anchorage even when the cargo handling facilities were used to full capacity. This is indicated by the utilization factor ($\rho \approx 1$).

The simulation results show that the dredging works have a significant impact on port capacity due to the reduced number of ship calls which affected by blocking some berths and limiting the navigation in near the access of harbour channels during the dredging. There are other factors such as the length of navigation channel or a reduction in the ship speed and the position of the dredger especially when it is located near to the approach of navigation channel. These factors will be considered in the future.

The simulation results by utilizing AIS data shows that the difference of the number of ships/calls between the normal port operation condition and dredging condition is about 54 ships and it increases to about 47% by increasing the period of dredging two times and 150% by increasing the period of dredging period six times.

The simulation results by utilizing port data show that the difference of the number of ships/calls between the normal port operation condition and dredging condition is about 29 container ships and 54 non-container ships from a total of 83 ships. It increases to more than 50% by increasing the period of dredging period two times. Also the difference of the number of ships/calls for both container and non-container ships increases to more than 158% by increasing the period of dredging period by six times.

4.0 CONCLUSION & RECOMMENDATIONS

From this research work, the following can be concluded:

i. The simulation program developed is a useful tool for detecting and predicting the traffic intensity and congestions at the port operation areas, moreover, it's capable to forecast the port capacity which is useful and reliable for future port development.

ii. The impact of dredging and reclamation works on port capacity was predicted and demonstrated using the data obtained from the vessel traffic simulation. It is the first time that such developed computer simulation program is used for this purpose.

iii. AIS data can be utilized for the vessel traffic discrete event simulation with dredging activities in order to have a more realistic evaluation of port capacity.

iv. In the future, the simulation program will be upgraded to include other factors that may contribute to the port reduced capability during the dredging works, such as the length of navigation channel or a reduction in the ship speed limit and the position of the dredger especially when it located near the approach of the navigation channel. Moreover, the simulation can be upgraded for the purpose of navigational risk analysis during dredging operations and during congestions due to port development and capacity expansion which leads to increase number of ship calls.

The following recommendations for PTP operations can be given as follows:

- To reduce the effect on port capacity, the time taken for dredging and reclamation works should be reduced to a minimum by using modern efficient dredging equipment.

- The number of berths blocked due to dredging should be less than three since more berths blocked causes less ship calls and thus port capacity is significantly affected.

- The dredging and reclamation works should start from the berth No.1 for the reasons:

  a) Berths 7 to 14 can handle larger size vessels which are more economical and give the possibility to save more time in the beginning of the dredging works.
  b) Ensuring a smooth operation without disturbing the navigational access channels that could delay the transhipment operations.
  c) Allowing more time in the beginning of the dredging works to make estimation and solving any problems occurring. Moreover, it gives confidence to the staff of PTP operational room to ensure smooth operations.

Acknowledgement

The authors would like to thank the PTP for their helpful information and support.

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