IMPROVEMENT OF SHIPBERTH CAPACITY FOR A CONTAINER PORT

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Graphical Abstract

Abstract

This paper presents a proposal of optimization of ship berth capacity for container port. Many aspects need to be taken into account in the process of optimization, which are waiting time, productivity of port, number of berth in port, and various sizes of container ships. The efficiency of a port depends on the speed of cargo handling. In this study, mathematical model had been derived to determine the required quay or wharf for a new port. The mathematical model can also be used to determine the required number of cranes in an existing port to maintain a good average waiting time. In order to determine the required number of quay, six elements had been considered in the equation of the mathematical model. The elements are arrival rate, overall length of ships, berthing time, number of operating cranes, average waiting time, and crane rates. Every single element is a dependent mode and inter-related to one another. The mathematical model was modelled using MATLAB, with twenty sample data, by simulation method. The findings were then compared to those of other researchers who had attempted to solve the problem using queuing theory and simple mathematical analysis. The results showed that the simulation is 85 percent more effective in determining the efficiency of a port based on the provided parameters. The main objectives were achieved, signifying that the sharing of cranes with adjacent berth is mainly used to maintain cargo handling rates at port.

Keywords

Shipberth Capacity; Mathematical Model; Number of Cranes; Number of Berths; and Average Waiting Time

Introduction

Ports, like most other commercial activities, are constantly changing. Their designs and infrastructures change as the vehicles using them are changing, whose functions are developed and altered as the trade passing through them varies in type and quantity [1]. Ports can be classified into two types; inland port and seaport.

Some ports on a lake, river, or canal have access to a sea or ocean, called as inland port [2]. Most inland ports are directly linked with the sources where the factories are placed in the same area. Railways and roads are built to transfer cargo from ship to shore or shore to ship. As years go by, fishing port has gradually evolved into modern port because of geographical factor [1].

A new era for dry cargo shipping and ports was established in mid-sixties, when ports and shipping entered a new phase of operation. Most general cargos evolved into container ships and bulk cargo to bulk carriers [3]. These types of ships tend to cause many problems to the ports, due to the rapid size growth of the ship, greater than previous. Thus, ports have to make changes in order to match their draft limitation and cargo handling technology to make sure ships turn-around in port. Even in late 80s, the container ships continued to grow and larger gantry cranes were required to reach across them [3].

Container ships may bring about several problems to the port operators such as the high investment to containerize a route, the needs of a comprehensive information system and greater efficiency, high skill requirement of dock workers, faster customs clearance, better documentation procedures and requirement to review more of the country's transportation law [4]. More prominently, the increase in size and complexity of ships will increase the cost of the shipping time.

The development in size of terminals is very similar to the growth of container ships size. Like port, ship berth is an important single construction in a modern port. Berth is the point at which containers are transferred for land carriage and vice versa. The berth utilization depends on the speed of loading and discharging containers, commonly known as the container throughput [5].

Development of a port is also parallel with the development of ships in terms of technology. A ship is an entity and port is a place where collection of activities runs. There are three major factors which influence changes of a port, such as increase in supply of ship tonnage, specialization in ship types, and increase in ship size [6]. These factors create problems tothe port, especially in water depth, and types of cargo handling that requires more productive and specialized terminal facilities to handle and store containers.

Port congestion will cause the ships to keep on waiting until vacant berth is available. There are three options to reduce waiting time or queuing problem, which are to increase the number of berth, increase the working time at the berth, and increase the cargo handling speed at the terminal. The number of berths required at the port depends on the demand, type and size of the ships [7]. When cargo handling process doubles, the effect is similar to when new berths are built.

Model Development

The fundamental of model development also refers to the criteria as discussed in the queuing model for the container terminal from technical papers studied. The criteria are based on the nature of cargos, characteristics of arriving ship like tonnage, container handling capacity, and container terminal characteristic such as closing time and cargo handling time [8]. These are vital guidelines to the research in order to minimize ship queuing time.

The model development has seven parameters from physical capacities and the operational efficiencies. The mathematical model can be used in two different conditions, either to determine the productive average waiting time, or to define the required quay length for a new port. The parameters are arrival rates, ship length, berthing time, average waiting time, number of berths, number of cranes being operated and crane rates.

The optimization strategies cater the berths and cranes required to reduce the queue number of ships and avoid serious congestion in the port [9].The main strategy is either by fixing the number of berth or the number of cranes .Simulation is the most suitable way to analyze the port operation [10]. Handling rates is an important indicator to achieve efficiency, which is the key to maintain good port productivity even if the number of ships increases. Efficient port can produce high turnaround of ships at certain time [11]. High number of berths does not necessarily mean no delay, nevertheless still provides adequate facilities to cater high number of incoming ships [12].

Efficient port services will attract ship owners to dock at the port, and this may lead to the high number of arrival rates. Firstly, high number of ships call requires faster productive speed of handling rates at each berth. Proper arrangement of queue number of ship to the available berth plays important role to avoid traffic congestion at the port [13].

Secondly, optimization strategies need to be applied to maintain excellent cargo handling and the productivity of port. The handling rates productivity is directly related to the transfer function of terminal, the number and the movement rate of quay cranes, the use of yard equipment, and the productivity of workers employed in waterside, landside and gate operations.

Mathematical Model

Based on the seven parameters as discussed, a mathematical model has been formulated.

$$Q_\ell = A_r \times \frac{\sum_{k-1}^{n}(S_\ell \times B_t)}{C_r} \times [C_n] \times [W_t] (1)$$

where Q_ℓ represents quay length of the port. Dependent parameters B_t, C_n, n and W_t represent berthing time, number of cranes operated, number of existing berths and average waiting time. Independent parameters A_r, S_ℓ and C_r represent arrival rates, ship length and crane rates.

Simulation Analysis

The mathematical model had to be simplified in a proper way in order to suit the MATLAB environment and to start the simulation process [14]. The formula was rearranged in order to determine the waiting time of a queue number of ships.

$$W_t = \frac{Q_\ell \times C_r}{A_r \times C_n \times \sum_{k-1}^{n}(S_\ell \times B_t)} (2)$$

$$W_t = \frac{M}{PR} (3)$$

with

$M = Q_\ell \times C_r$, P = $A_r \times C_n$ and R = $\sum_{k-1}^{n}(S_\ell \times B_t)$. M, P and R are constant values.

$$W_t = \frac{L}{R} (4)$$

where L = M / P. The final equation was then used in the MATLAB program, where L refers to the constant value, while R is the variable.

Assumption and Limitation

In this study, there were several assumptions and limitations in achieving the main objective to reduce waiting time for a queued number of ships. The assumption refers to certain element in order to choose the final parameters for the mathematical model. Some assumptions were made to simplify the model, which would be simulated later. Limitation also refers to the result from this simulation.

To achieve efficiency, firstly, there must be good arrangement of the container yard. There should be no traffic congestion among the import and export containers, and yard equipment are used in proper way. Secondly, the gate operation hour must be efficient, and the inspection, weighing and documentation must be properly checked [2].

Thirdly, the labourers need to be well trained, highly skilled, motivated and work in safety manner [3]. This will promote higher productivity of workers employed in waterside, landside and gate operations. Then,the port handling rates need to be raised to about 80 to 90 percent. Lastly, the berthing time shall bevaried and calculated by different percentage of container movement.

RESULTS AND DISCUSSION

This section discusses the simulation results based on the proposed mathematical modelling. The proposed mathematical model consists of the parameters that should give some impacts to the desired average waiting times. Parameter such as ship length reflects the capacity of containers that are going to be loaded and discharged at the port. Sometimes, it also depends on the destination of the consignees and the efficiency of port to serve ships at the minimum time [15].

The results were tabulated in the form of tables and graphs by MATLAB. The results would give more understanding on the relationship between the average waiting time and other parameters.

Simulation Result

The results were presented in tables and graphs from the ships call data from 2005 to 2010, and for the next coming 4 years. The results were based on the waiting time produced by simulation according to the mathematical model. The waiting time was measured in hour unit and the input data were referred to the previous number of berths and cranes.

Figure 1 shows the average waiting time according to the number of cranes being operated at each berth. The average waiting time is inversely proportional to the number of cranes. At this stage, the best average waiting time for year 2005 is about 9.82 hours, with 8 units of quay cranes being operated. The highest average waiting time is 26.18 hours, with 3 units of cranes were being operated.

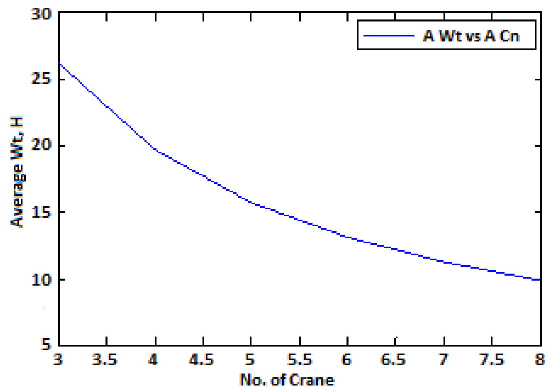

Figure 1. Average waiting time against the number of cranes

The relationship between the berthing time and number of cranes is shown in Figure 2. The graph indicates that the berthing time slightly decreases according to the number of cranes. The efficient berthing time for year 2005 is when 8 units of quay cranes were used per berth. The trend of the graph is quite similar from year 2005 to 2010, and the average waiting time is considered high based on the existing berth and operated number of cranes at that time.

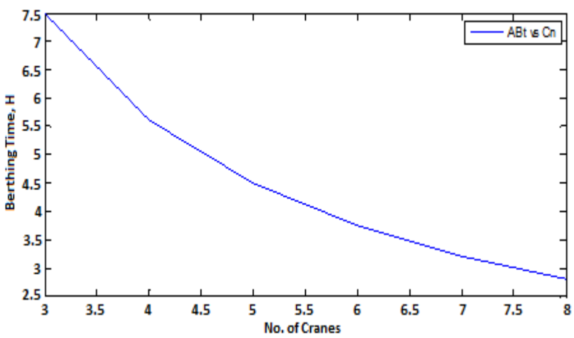

Figure 2 Berthing time versus number of cranes

Table 1 shows predicted average waiting time based on the numbers of crane and berth for the next coming 4 years. All results obtained are within the acceptable range and with evident reduction of average waiting time per year. Additional numbers of crane and berth will indeed contribute to the efficiency of container handling operation and reduction of average waiting time, hence will reduce queuing time of ships at the port.

Table 1. Predicted average waiting times based on number of berths and cranes

Quay Length (m)	Number of Berths	Number of cranes	AverageWaiting Time (H)
4800	6	4	8.66
5600	7	5	7.28
6400	8	6	6.71
7200	9	7	5.99

The optimum average waiting time is 5.99 hours by using 9 berths and 7 units of crane. Increase in number of berth indicates the expansion of the port itself. Expansion can be done gradually to ensure that all berthing operations run smoothly. Sharing of quay cranes with adjacent berth can be done for ships that requires more numbers of cranes. This can reduce the cost incurred by the port. The data from Table 1 are plotted in Figure 3, Figure 4 and Figure 5

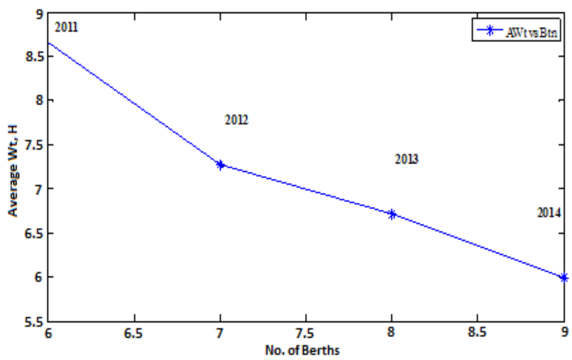

Figure 3. Predicted average waiting times against the number of berths

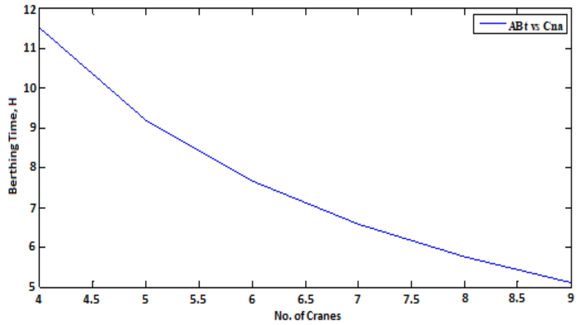

Figure 4. Predicted berthing times against the number of crane

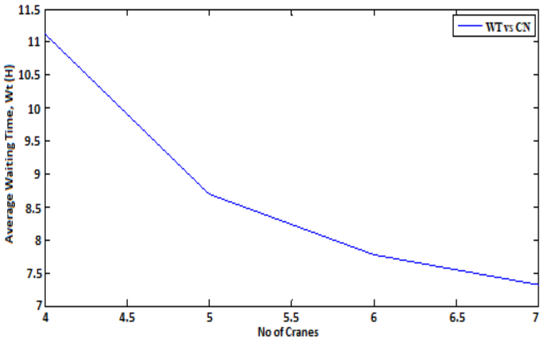

Figure 5. Predicted average waiting times against the number of cranes

Verification of Results

This section discusses the verification of the results in detail, compared to the actual situation. This section also reviews the effectiveness of additional number of berths and cranes at the port understudy. Currently, the port understudy provides 5 berths and minimum of 3 units of cranes per ship call.

Table 2. Comparison of actual versus predicted average waiting time

Year	Awt for Actual Data (H)	Awt for 4 units of Cranes	Awt for 5 units of Cranes	Awt for 6 units of Cranes	Awt for 7 units of Cranes
2005	26.18	19.63	15.71	13.09	11.22
2006	21.75	16.31	13.05	10.88	9.32
2007	20.40	15.30	12.24	10.20	8.74
2008	19.80	14.85	11.88	9.90	8.49
2009	21.21	15.90	12.72	10.60	9.09
2010	20.32	15.24	12.19	10.16	8.71

Table 2 shows the comparison of results in terms of the average waiting time between actual data and the proposed simulation model. The number of cranes and berths was increased in the proposed model. The average waiting time was varied accordingly. The actual data had 5 berths and 3 cranes for cargo handling process, compared to the predicted average waiting time having up to 7 units of cranes and 5 berths. The average waiting time was varied over the years based on the number of ships call at port. The increase of number of cranes up to 7 units seems practical in order to ensure the results within the acceptable ranges.

The best way to cope with high number of cranes with sufficient budget is by sharing the quay cranes from the adjacent berths. This is because the berthing time at port is different from each other and depends on the capacity of containers to be discharged.

Table 3. Comparison between actual data with the increment of berths and cranes

Year	Average Waiting Time (H) from Actual Data (H)	Number of berths	Number of cranes	Average Waiting Time (H)
2005	26.18	5	4	11.13
2006	21.75	6	5	8.70
2007	20.40	7	6	7.77
2008	19.80	8	7	7.32
2009	21.21	9	8	7.30
2010	20.32	9	9	7.28

The comparison between actual data and proposed average waiting time with the increment number of berths and cranes is shown in Table 3. Most of the results produced are better than those of actual data from port. The best average waiting time is about 7.28 hours, by using 9 units of cranes and berths. Basically, 6 berths and 5 units of cranes are sufficient to handle the operational process at port according to the arrival rates for the year 2005 till 2010.

The increase of number of berths is directly proportional to the extension of quay length at port. Additional berth at port can be done by extension of jetty for certain targeted years. Additional cranes for operation can be done immediately without too much impact on cost. These applications (additional berth and crane) can be the best solution to cater high ships call. Referring to Table 3, positive change of waiting time is evidenced from 2005 to 2010.

Table 4. Estimated number of ship calls

Year	Number of Ship calls	Average Ship Calls per month
2011	7000	583
2012	7656	638
2013	8000	667
2014	8656	721

Table 4 shows the estimated number of ship calls. The numbers of ship calls at port under study increases annually. The increment clearly indicates that the port understudy has positive evolution towards upholding her world class ranking. The increment can encourage the port understudy to expand and offer better services. The total ship calls were derived from the average numbers of ships entering the port both for loading and discharging containers.

Table 5. Predicted average waiting time for 2011-2014

Quay Length (m)	Number of berths	Number of cranes	Average Waiting Time (H)
4800	6	4	8.66
5600	7	5	7.28
6400	8	6	6.71
7200	9	7	5.99

Table 5 shows the predicted average waiting time for the next four years with the estimation of number of ship calls. The increase of number of berths will extend the wharf length at port. Most of the results produced are between the acceptable ranges, which are less than 10 hours. The use of 7 units of cranes per vessel produced the optimum and the best average waiting time that is 5.99 hours.

With additional numbers of crane and berth, there will be systematic drop of annual average waiting time [16]. Additional numbers of berth can be done gradually based on the number of ship calls. Normally, high ship calls for a certain period of time will not affect container throughput for that particular port. This is the best approach to avoid port congestion to occur.

The key point to improve the port performance is the cargo handling processes, followed by services rendered to cater the ever increasing ship numbers entering the port [17]. Technological advancement of services can also ease the process of container handling at port. Efficient services offered will become a strong attraction to ship operators to select the port as their hub or service provider.

Conclusion

This paper has presented a method to estimate the optimum number of berths and cranes required at port under study in order to minimize ships queuing time. The optimization strategies are based on the hypothesis that the increment number of berths and cranes can reduce the average waiting time at port. The high demand of number of cranes can be managed by sharing the quay cranes with the adjacent berth and saving the cost for the ports.

The Queuing theory has been made as a main reference to determine the best selection of parameters in the mathematical model. The use of mathematical model is the best fundamental for the simulation analysis. The best selection of variables in the mathematical model will improve waiting time. The developed mathematical model can be used for existing and new port, for through simulation.

In this study, analysis has been simulated for the next 4 years on the port understudy, with high ship calls estimation over the years. Most of the simulation results show the average waiting time of less than 9 hours. The best average waiting time is about 6 hours, by using the 7 units of cranes and 9 berths. The application to West ports has verified the anticipated benefit of using suggested optimization to evaluate the average waiting time, and of the best interest for both ship operators and the port authority. The evaluation is up to the standard when the port reached high performance in terms of cargo handling.

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