

Application of queuing methodology to analyze congestion: a Case study of the Manila International Container Terminal, Philippines

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Abstract

The objective of this paper is to apply queuing methodology in order to analyze congestion at the Manila International Container Terminal (MICT) in the Port of Manila, the Philippines. The vessels calling at the MICT have to wait in a queue before receiving services at berths because of congestion. For vessel operators and cargo owners this situation creates waiting time costs and delays in delivery of goods to final customers. One option to decrease waiting time is to expand capacity by increasing the number of berths. Construction of a new berth is a time consuming and costly procedure, which needs to be considered carefully before being implemented. To

determine whether the data collected is suitable for queuing methodology, the distribution pattern of ship arrivals has been analyzed. The results reveal that the pattern of ship arrivals follows Poisson's law of random distribution, which confirms the validity of the proposed queuing methodology. Applying queuing methodology, with the objective of minimizing total cost, including waiting time cost and berth's construction costs, reveals that the number of berths at MICT is currently adequate. In order to release congestion, port managers must take other actions.

Keywords: port capacity, port economy, congestion, queuing theory, container terminal.

1. Introduction

One of the main factors that affect the export competitiveness of a developing country is the cost of international transport services. This factor is a more significant impediment to participation in international trade than tariffs and other trade barriers. If shipping costs were to double across economies, annual growth would decrease by more than one-half of a percentage point.

Similarly, approximately 70 percent of the variations in countries' gross domestic product (GDP) per capita are due to their ability to access foreign markets, which is affected by transport costs.

Transport costs depend on a number of geographic and economic factors. One of the main reasons for high transport costs is poor transport infrastructure including maritime transport which handles nearly 90 percent of the global freight market¹.

¹ See <http://siteresources.worldbank.org/INTGEP/Resources/335315-1257200370513/04--Ch4--96-127.pdf> Date of access: 27/09/2013.

This study applies queuing theory to analyze capacity expansion decision (developing new berths) in response to the congestion problem facing the Port of Manila in the Philippines. The Philippines Government is also looking for measures to decongest Port of Manila.² The Philippines consists of 7107 islands; it has a long coastline that extends to 235,973 sq. km – longer than the coastline of the United States (UNESCAP 2002). These islands connect to each other and the outside world via maritime transport, which facilitates the movement of goods and people. Because of the country's archipelagic configuration, to have good access to foreign economies it must have an efficient maritime transport infrastructure composed of ports and shipping (Clark et al. 2004).

However, the country's existing maritime transport infrastructure is inefficient and has acted as the primary impediment to domestic and international trade integration. The resulting high cost of transporting people and goods has contributed to higher goods prices and erosion of the competitiveness of exports. The results of research indicate that the quality of onshore infrastructure accounts for approximately 40 percent of the predicted transport costs for coastal countries like the Philippines (Limao and Venables 2001). The following factors contribute to inefficiencies: (a) inadequate port and vessel capacities; (b) ineffective ports management and administration; and (c) constraints resulting from anticompetitive policies and regulation (Llanto et al. 2007). This study focuses on inefficiency due to inadequate port capacity.

This article attempts to determine the optimal number of berths at MICT that maximizes the net benefit. Net benefits, as explained by De Weille and Ray (1974), include benefits to ship owners

² See <http://www.gmanetwork.com/news/story/315429/economy/business/govt-to-look-for-ways-to-decongest-manila-ports> Date of access: 27/09/2013.

(reduction in waiting time cost) and to the port authority (minimizing berths' construction and maintenance costs). If the Port Authority does not invest in order to expand its capacity, it would be able to minimize its costs per ship; however, ship owners will face waiting time costs. On the other hand, constructing berths that will lead to zero waiting time will save waiting time costs for ship owners, but will incur high construction and maintenance costs for the Port Authority. In this context, the optimum number of berths will be the number that would be fully utilized throughout the whole year (lower limit) and would avoid any delay faced by ships (upper limit).

The next section presents a review of the literature on application of queuing theory to port sector. The subsequent sections present the case study, methodology, and numerical solutions, followed by conclusions and discussions.

2. Literature review

Few researchers have applied queuing theory to analyze ports' congestion problem. Sen (1980) addressed the issue of introducing the system of priorities for the analysis of marine congestion problem. In the literature, the service discipline selected for the analysis is most commonly the one that services units in the order of arrival; that is, first-come-first-served (FCFS). However, this system overlooks an important aspect: that the sensitivity of delay for individual units will be different. Therefore, it is important to introduce a system of priorities in order to analyze the possibility of differential sensitivity to delay. The objective of assigning priorities is to minimize the average cost of waiting in a queuing system subject to any constraint that maybe imposed by the delay sensitivity of the units in the system. Sen (1980) solved two constrained optimization problems in order to identify the potential gains that could be achieved by adopting priority

structure. The study applied a single-server system with Poisson arrival and departure, although the analysis could be extended to a general queuing system.

Easa (1987) presented approximate queuing models in order to analyze the effect of tug services on congested harbor terminals. The models are applicable for harbors in which tug shortages are rare. A congested harbor terminal is modeled as a queuing system with m identical tugs (servers) and n identical berths (customers), and with general probability distributions of tug service time and berth cargo-handling time. The models were shown to be reasonably accurate within a certain range, covering situations in which tug shortages are in the order of 10 percent or less of the time.

Berg-Andreassen and Prokopowicz (1992) addressed the issue of conflict of interest related to anchorages and water-development industrial plans. They applied a standard queuing model to the lower Mississippi anchorage system in order to analyze the economic impact of reducing anchorage space in a deep-draft anchorage system. They considered random arrivals and departures and a stochastically formulated cost function. Their model also considers various assumptions related to ships' arrival, stay at berths and other basic cost additions that might occur. Kozan (1994) applied queuing simulation models to determine an optimal balance between the opportunity cost of ship waiting time and the cost incurred in the expansion of the seaport system. To this end, a cost benefit analysis was conducted to evaluate the alternative investment decisions at different time periods that provide the minimum present value of total costs over the planning horizon for a seaport.

Laih et al. (2007 and 2008) discussed the optimal non-queuing toll scheme and the optimal n-step toll scheme for container ships to release congestion at ports. According to that study, the optimal non-queuing tolling scheme would be difficult to implement because it has characteristics of varying amount of fees. On the other hand, the optimal n-step tolling scheme proved to be a suitable alternative. That study conducted a dynamic analysis and compared the difference in the arrival rate and arrival time of container ships before and after implementing the optimal n-step toll scheme. The analysis shows that the arrival time for those ships that had paid the tolls would be backward extended. However, the arrival time would remain constant for those ships that have not paid any tolls. Consequently, the pattern of ships' arrival time would be changed in response to the toll collection, and the tolling administration would be able to relieve the congestion at port.

Dragović et al. (2006) discussed simulation and queuing models in order to determine the performance evaluation of ship-berth link in port. They applied these two models to compute numerical results for the Pusan East Container Terminal (PECT). For the analysis they selected the basic operating parameters such as berth utilization, average number of ships in waiting line, average time that a ship spends in the waiting line, average service time of a ship, average total time that a ship spends in port, average quay crane (QC) productivity, and average number of QCs per ship. Kiani et al. (2006) addressed two factors: berth unproductive time and container ships' turnaround time. The turnaround time of a vessel consists of the waiting and the service time in a port. The port operator can minimize the total turnaround time either by expanding the number and size of their berths or by increasing the service rate of their quayside facilities. Kiani et al. addressed the latter issue in their study and the analysis shows that automation devices

installed on conventional quayside cranes (QSCs) significantly reduce the turnaround time of the container ships calling at the ports. This policy is beneficial in mega ports, where there is always a vessel available to be serviced. For medium and small ports, however, the minimization of the vessels turnaround time results in the costly berths and facilities being unproductive for a certain period of time. To address this issue, Kiani et al. applied queuing theory to the Port of Bandar Abbas Container Terminals (BACT) in Iran to find a break-even point between the container ship waiting times cost and the cost of berth unproductive service time.

Canonaco et al. (2008) studied the productivity maximization of expensive resources such as rail-mounted berth cranes that should minimize waiting times with an adequate rate of service completion. They used a queuing network model to solve this practical problem. Furthermore, an event graph (EG)-based methodology was used in simulator design in order to take into account a systematic representation of real constraints and policies of resource allocation and activity scheduling.

Author/Year	Methodology	Research Objective
Sen (1980)	Priority system/Queuing	To minimize the average cost of waiting in a queuing system
Easa (1987)	Queuing Model	To analyze the effect of tug services on congested terminals
Berg-Andreassen & Prokopowicz (1992)	Queuing Model	To analyze the economic impact of reducing anchorage space
Kozan (1994)	Queuing Model	To determine an optimal balance between waiting time cost and the cost of seaport expansion
Laih et al. (2007)	Queuing Port Model	To design an optimal step toll scheme to decrease queuing
Laih & Chen (2008)	Queuing Port Model	To establish a series of the optimal n-step toll schemes to decrease queuing time
Dragovic et al. (2006)	Simulation & Queuing Model	To determine the performance evaluation of ship-berth link in port
Kiani et al. (2006)	Queuing Model	To find a break-even point between waiting time cost and the cost of berth unproductive service time
Canonaco et al. (2008)	Queuing Network/ Event-Graph Model	To study the productivity maximization of expensive resources that minimize waiting times
Munisamy (2008)	Closed Queuing Network	To evaluate the efficiency of the port
De Weille & Ray (1974)	Queuing theory	To analyze decisions to invest in new berth construction to reduce congestion
Edmond & Maggs (1978)	Queuing theory	To analyze decisions to invest in new berth construction to reduce congestion
El-Naggar (2010)	Queuing theory	To determine the optimal number of berths that minimizes the total cost
Oyatoye et al. (2011)	Queuing theory	To determine the optimal number of berths

Table 1. Literature review. Source: Authors' own compilation.

Munisamy (2008) applied a closed queuing network model to evaluate the efficiency of the Port Klang timber terminal in relation to the cargo handling system and its impact on terminal

throughput capacity. To analyze the reason of congestion, the model considers the interaction among different cargo handling elements for instance forklifts, tractors, trailers, and quay cranes. The results of the model show the performance statistics of the cargo handling equipment, the throughput of quay cranes, and the forecast of the terminal's throughput capacity. Port authorities and port operators could use the methodology and results to design and implement economically efficient operational and investment strategies.

Among these studies, the following researchers have applied queuing theory to analyze decisions to invest in new berth construction to reduce waiting time. With regard to variable ships' arrival over time in the port, De Weille and Ray (1974) investigated the optimum capacity (number of berths) that maximizes the total net benefit. They solved two cases. The first is a simple case in which they assume that the number of ships arrival for each day over a certain period and the service time for each ship is known. With this information it would be easy to compute total waiting time and costs for different number of berths. The second case is a complicated situation in which the timing for ships' arrival and the service time for each individual ship is not known. De Weille and Ray (1974) applied standard queuing theory to compute the waiting time and to determine the optimal number of berths to handle future traffic.

Edmond and Maggs (1978) applied queuing methodology to UK ports: Felixstowe, Grangemouth, Liverpool (Seaforth), Southampton (Solent Containers), and Tilbury. Their study reviewed the operational characteristics of UK container terminals and used queuing models to analyze decisions to invest in berth construction and cargo handling equipment. The results of their analysis show that investment in cranes and berth facilities does not necessarily decrease the queue by the same proportion. This makes it necessary to conduct a cost analysis to compare

different options. El-Naggar (2010) applied queuing methodology to determine the optimal number of berths, which minimizes the total cost, at the Port of Alexandria, Egypt. The analysis shows that the pattern of ship arrivals follows Poisson's law of random distribution, which confirms the validity of the queuing methodology. The applied methodology was based on the assumption that it is feasible to increase the number of berths as long as the marginal cost of berths (construction and maintenance) is less than the waiting cost of ships. The results show that the optimum port capacity, which minimizes the total port cost, is 33 berths for general cargo. The present number of berth is 32.

Oyatoye et al. (2011) applied queuing methodology to analyze the congestion problem at Tin Can Island Port, Nigeria. The analysis shows that the number of berths in that port is adequate to handle the traffic. They conducted interviews with stakeholders at the port to trace out other factors that contribute to port congestion. These factors include complex customs clearance procedures, poor inland transport infrastructure, non-availability of modern and appropriate handling equipment, non-availability of 24-hour operation, use of ports as storage area by importers, and unskilled and untrained staff.

Table 1 shows that only four previous studies (De Weille and Ray, 1974; Edmond and Maggs, 1978; El-Naggar, 2010; Oyatoye et al. 2011) have applied the queuing theory to determine the optimal number of berths that minimizes the total cost. Only three studies (Edmond and Maggs, 1978; El-Naggar, 2010; Oyatoye et al. 2011) have solved the queuing model with the real data, although their case studies are different.

3. Port of Manila

The Port of Manila is situated on the southeastern shores of Manila Bay (see Figure 1). The Port of Manila Bay entrance is 19 kilometers (12 miles) wide, and the bay expands to a width of 48 kilometers (30 miles). The Port of Manila is about 40 kilometers (25 miles) south of Bataan Peninsula and consists of three areas: Manila North, Manila South, and Manila. The Manila International Container Terminal (MICT), operated by International Container Terminal Services, Inc. (ICTSI), is located between the Port of Manila's North and South Harbors. It was established in 1987 and since then has expanded to handle containers throughout the Philippines and worldwide. It handles 65 percent of the Port of Manila's market share.

The main cargo at the Port of Manila's MICT is international containers, but the port also handles non-containerized and general cargo at its basin anchorage. It has the capacity to accommodate five to six vessels simultaneously. The MICT in the Port of Manila is equipped with both container- and bulk-handling tools³.

³ See http://www.worldportsource.com/ports/commerce/PHL_Port_of_Manila_1947.php Date of access: 27/09/2013

Figure 1. Location of the Port of Manila



Source: <http://en.wikipedia.org/wiki/Manila>

Table 2. Performance comparison of MICT with other ports in West Philippines Sea (2012)

	Number of vessels	Waiting time (in hrs) at berth	Service time (in hrs) at berth	Average turnaround time
MICT	1816	15024	36300	28.26
Batangas	8030	0	126770	15.78
Calapan	6707	0	56035	8.35
San Fernando	104	0	1412	13.57

Source: Port Statistics 2012 (January-December)⁴

⁴ available to download at <http://www.ppa.com.ph/ppa%20web/portstat.htm> Date of access 28-04-2014

Table 2 presents the performance of MICT, in terms of waiting and service time, compared to other selected ports in the West Philippines Sea for 2012. Figures presented in Table 1 indicate that the vessels calling at MICT faced higher waiting and service time compared to other terminal ports in the region.

4. Queuing theory

Queuing theory has been regarded as an important analytical tool for solving congestion problems. It can be used to estimate certain important parameters, such as average waiting time of ships, average queuing length, average number of ships in the port, and average berth utilization factor (closer to the actual values).

Jansson and Shneerson (1982) stated that ships arrive to a port mostly at random and hence have varying demands for port resources. Therefore, the short-term demand for port services fluctuates. For example, it is possible that during one week all resources will be occupied and the ships will be in queue; and during the next week there will be no ships at all in the port. As a consequence, the supply of port services or, in other words, the service time of ships is also highly variable. Hence, in order to determine optimal port capacity, it is necessary to analyze the trade-off between the two objectives of a high level of utilization of port facilities and a low chance of delay for port users.

4.1. Queuing time at a single-berth facility

Jansson and Shneerson (1982) used the following assumptions regarding the formation of the queues:

1. Customers (in this case, ships) arrive at random, with the distribution of arrivals described by the Poisson probability distribution.

The probability P_n of the arrival of n ships in the port in a given time period (e.g., a day) can be expressed as:

$$P_n = \frac{(\lambda)^n}{n!} \cdot e^{-\lambda} \quad (1)$$

Where

λ = expected number of ships to arrive during a day,

e = base of the natural logarithm ($e = 2.71828\dots$),

$n!$ = the factorial of the ship number.

The Poisson distribution function of ship arrivals can be calculated only if the average arrival rate during a day is known.

2. Similarly, the service time is a random variable that fits the negative exponential probability distribution. The service time can have many different distributions, but with a Poisson distribution, the distribution of the time interval between ship arrivals will be negative exponential. Service time can also be negative exponential as a special case.
3. There is no upper limit to the queue length.

Under these conditions, the expected (mean) queuing time can be expressed as:

$$q = \frac{\lambda s^2}{1 - \lambda s} = s \frac{\phi}{1 - \phi} \quad (2)$$

Where

q = expected queuing time per ship in days,

λ = expected number of ship arrivals,

s = expected service time per ship in day ($= \frac{1}{u}$, where u is berth capacity),

ϕ = expected occupancy rate ($= \frac{\lambda}{u}$).

The main element of equation (2) is that the mean queuing time of ships is directly proportional to the mean occupancy rate ϕ . The queuing time tends to increase even at low levels of capacity utilization, and will rise more quickly as the level of full capacity is approached.

Marginal queuing time, which is the additional total queuing time that results from the arrival of another ship, is calculated by taking the partial derivative of the total queuing time λq with respect to λ :

$$\frac{\partial(\lambda q)}{\partial \lambda} = \frac{\lambda s^2(2-\lambda s)}{(1-s)^2} = s \frac{\phi(2-\phi)}{(1-\phi)^2} \quad (3)$$

According to the Pollaczek–Khintchine formula (see Jansson and Shneerson 1982), for any arbitrary distribution of the service time s , the mean queuing time q can be expressed as a function of the mean and the variance of the service time and the arrival rate:

$$q = \frac{\lambda[s^2 + var(s)]}{2(1-\lambda s)} \quad (4)$$

By inserting ϕ , which equals λs , and expressing the relative variance $\frac{\text{var}(s)}{s}$ by $V(s)$, equation

4 can be written as:

$$q = \frac{\phi(s+V(s))}{2(1-\phi)} \quad (5)$$

Given the occupancy rate, the mean queuing time is proportional to the sum of the service time and its relative variance.

If s is distributed negative exponentially, its variance equals s^2 , and by substituting this in equation 5, equation 1 is obtained:

$$q = s \frac{\phi}{1-\phi}$$

If the variance of the service time is very small, that leads to the case of constant service time.

Setting $V(s) = 0$ in the general formula gives:

$$q = \frac{s}{2} \cdot \frac{\phi}{1-\phi} \quad (6)$$

Eliminating the variability of service time will apparently reduce the mean queuing time by half.

4.2 Queuing time at a multiberth facility: economies of scale in port operations

Jansson and Shneerson (1982) further extended the queuing model to the multichannel variants by taking into account the situation of several berths. When p is introduced as a symbol for the probability that an arriving ship will find all berths occupied, the average queuing time can be expressed as

$$q = \frac{s}{x(1-\phi)} \cdot p \quad (7)$$

Where x is the number of servers, s is the mean service time (per ship) of each server, and ϕ is the mean occupancy rate. The term $s / x(1 - \phi)$ represents the expected queuing time of those ships, which in fact face a delay, while p is the probability that a delay will occur.

The total effect on queuing time of adding berths comes from both these terms. The first term is negatively related to x . If ϕ is held constant – that is, if the number of berths increases in proportion to demand – the total queuing time will be equal to a constant time p . But p will also be affected and one expects that p will decrease with a proportional increase in demand and the number of berths.

Furthermore, queuing methodology can be used to determine the optimum number of berths required in a seaport to meet the traffic volumes (see De Weille and Ray, 1974).

5. Numerical solution

5.1. Ships' arrival

The data about total number of ships that arrived, waiting time, service time, and total turnaround time for each vessel was provided by the authority at the Port of Manila. The number of ships that arrived at the Port of Manila is 153 in 31 days (for the month of January 2013). The average number of ships per day is 4.9.

Table 3 . Chi-square test to check Poisson distribution for ships' arrival rate

No. of ships (X_i)	Actual frequency f_j	$X_i \cdot f_j$	Poisson distribution (P_n)	Frequency $F = T \cdot P_n$	Chi-square χ^2
0	0	0	0.01	0.25	0.25
1	0	0	0.04	1.21	1.21
2	4	8.00	0.09	2.92	0.40
3	4	12.00	0.15	4.68	0.10
4	4	16.00	0.18	5.63	0.47
5	10	50.00	0.17	5.42	3.87
6	4	24.00	0.14	4.34	0.03
7	3	21.00	0.10	2.99	0
8	0	0	0.06	1.79	1.79
9	2	18.00	0.03	0.96	1.13
10	0	0	0.01	0.46	0.46
11	0	0	0.01	0.20	0.20
	SUM=T = 31	SUM= 149	SUM= 1.00	SUM=30.87	SUM=9.93

Source: own compilation

5.1.1. χ^2 fit test:

To determine whether the data collected is suitable for queuing methodology, the distribution pattern of ship arrivals has been analyzed. The chi-square fit test is applied to check the Poisson distribution for ships' arrival. The null hypothesis is that the actual frequency distribution of the daily number of ships fits the Poisson distribution.

$$\chi^2 = \sum_{j=1}^g \frac{(f_j - F_j)^2}{F_j} \quad (8)$$

Where f_j is the actual frequency, F_j is the frequency for Poisson distribution, $g = 12$. The

result of the chi-square test, presented in Table 3, is $\chi^2 = 9.93$

DF = $g - \gamma - 1 = 12 - 1 - 1 = 10$. Where γ is the number of parameter of the Poisson distribution,

$\alpha = 0.05$. The value of $\chi^2_{\alpha} = 18.31$.

Since $\chi^2 < \chi^2_{\alpha}$ the null hypothesis cannot be rejected, and one may maintain that actual frequency distributions fit Poisson distribution, which confirms the validity of the proposed queuing methodology.

5.2. *Queuing model solution:*

According to the data provided by port authority, the mean service time (at berth) per vessel is 17.62 hours, or 0.734 days.

$\lambda = 4.9$ (expected number of ship arrivals per day),

$x = \text{number of berths} = 5$.

The data shows that, on average, vessels of 23,000 deadweight tonnage (DWT) called at the MICT. As one twenty-foot equivalent unit (TEU) is equal to 14 tons, this means that, on average, vessels carrying approximately 1600 TEU called at the MICT. According to UNCTAD (2013), the charter rate for a container ship carrying 1600–1999 TEUs was 3.7 dollars per 14-ton slot per day for the month of January 2013. This gives a charter price of \$5920 per day. The rental price for a container is \$140 per month, or \$4.67 per day.⁵ For vessels carrying 1600 TEU, this equates to \$7472 per day. The total waiting time cost is \$13,392 per vessel per day. The berth's construction cost is \$15 million per year.⁶

Table 4. Input parameters

Avg. ships' arrival rate	Service rate capacity per service point	Cost of waiting per vessel per day (\$) W_c	Total vessels called at MICT per year V_s	Berth's construction cost (\$Million)
4.90	1/0.734= 1.37	13392	1836	15

Source: Data presented in first two columns was provided by the Manila Port Authority.

Input parameters, presented in Table 4, are used to solve the queuing model. The results presented in Table 4 show that, with the current number of berths (five), the model gives an

⁵ See <http://www.business.com/guides/pricing-and-costs-of-container-leasing-and-rental-services-23137/> Date of access 20/04/2014

⁶ The MICT has constructed berth 6 at the cost of \$200 million including some construction work of berth 7. See <http://www.portcalls.com/berth-6-at-manila-international-container-terminalinaugurated/#> <http://www.portcalls.com/berth-6-at-manila-international-container-terminal-inaugurated/#> Date of access 20/04/2014. On the basis of this information, the total berth's construction cost is taken as \$150 million. We assume \$15 million as annualized berth construction cost that amounts to 10 percent of the total investment.

average waiting time equal to 0.21 days, which is quite close to the actual average waiting time of 0.28 days. This fact confirms the validity of the model used.

The queuing model was solved for different numbers of berths. The results, presented in Table 5, show that increasing the number of berths will decrease the waiting time, which will approach to zero when the total number of berths at MICT is eight. However, in order to determine whether construction of eight berths is a feasible strategy from a national point of view, we need to calculate the total cost.

Table 5. Queuing model output with different number of berths.

Number of berths	Avg. time waiting in line (in days) q_i	Avg. time spent in system (in days)	Avg. entities in queue	Avg. entities in system (n_s)	Server utilization
4	1.34	2.1	6.6	10.1	0.89
5	0.21	0.94	1.01	4.59	0.72
6	0.06	0.79	0.28	3.86	0.60
7	0.02	0.75	0.09	3.66	0.51
8	0.00	0.74	0.02	3.60	0.45

Source: own compilation

The objective is to determine the point at which savings in total waiting time cost per year are less than (in this case) \$15 million when an additional berth is added. The following cost function is used:

$$TC = C_a \cdot S + W_c \cdot V_s \cdot q_i \quad (9)$$

Where, TC = total cost of berth, C_a = annualized capital cost per berth, S = number of berths

W_c = average waiting cost per ship per day, V_s = number of vessels visiting port per year. q_i = average waiting time per vessel per berth.

Equation 9 is solved for different numbers of berths. The results, presented in Table 6, show that total cost including waiting and construction cost is minimum when the number of berths is five, which is the present number of berths serving the vessels. By constructing more than five berths, the waiting cost will decrease, but the berths' construction cost, and consequently the total cost, will increase.

Table 6. Total cost with different number of berths.

No. of berths	$W_c \cdot V_s \cdot q_i$ (\$ Million)	$C_a \cdot S$ (\$ Million)	Total cost (\$ Million)
4	32.94	60	92.94
5	5.16	75	80.16
6	1.48	90	91.48
7	0.49	100	100.49
8	0	120	120.00

Source: own compilation

The MICT has recently completed the construction of berth 6 and has started to construct berth 7.⁷ On the basis of this study, we may not conclude that they are over-investing if we consider the concept of ‘option value’ used in cost-benefit analysis. A modest increase in traffic may make the optimum 6 or even 7 berths. Thus present policy may be quite rational even if it initially involve some excess capacity. However, we may conclude on the basis of this analysis that in order to release congestion, port authorities must take other actions.

This provides a base for future studies to trace out the reasons of congestions and appropriate measures (other than new berth construction) to release congestion. The other possible causes could be inefficient inland connection, operational inefficiency, complex customs clearance, etc. For future studies, it is suggested that questionnaires should be distributed to different stakeholders (for example, port authorities, shipping lines, customs agents, land-side providers) to identify the bottleneck point that creates congestion at ports.

6. Conclusion

Because of its geographical location, the Philippines must have an efficient maritime transport infrastructure to facilitate international trade. But currently, vessels calling at the Port of Manila are facing delays in receiving services due to congestion. This has resulted in waiting time costs, which are borne by shipping lines and owners of cargo. One measure that could relieve congestion is to increase the number of servers, or berths.

⁷ See <http://www.portcalls.com/berth-6-at-manila-international-container-terminal-inaugurated/#http://www.portcalls.com/berth-6-at-manila-international-container-terminal-inaugurated/#>

The decision whether to construct a new berth must be carefully considered, because such construction is very costly. This study can inform that decision. The study applies queuing methodology to determine the optimal number of berths that will minimize the total cost, including waiting and service costs, at the Manila International Container Terminal (MICT). The data for the month of January 2013 was collected and provided by the authority at the Port of Manila. Statistical tests were applied to check the distribution pattern for ships' rate of arrival .

One of the basic assumptions of queuing methodology is that customers (in this case, vessels) arrive randomly at berth and should be served on a first-come first-served basis. The results of the present study reveal that the pattern of ship arrivals follows Poisson's law of random distribution, which confirms the basic assumption and validity of the proposed queuing methodology.

The queuing model was solved for different numbers of berths. The second case is the base case, which depicts the present situation in which five berths are serving the vessels calling at the MICT. The average waiting time obtained after solving the queuing model is quite close to the actual waiting time, which confirms the validity of the model used. In order to conduct a cost-benefit analysis of a capacity-expansion decision, the total cost for different numbers of berths was estimated in order to determine the optimal number of berths. From the port users' perspective, the benefits of capacity expansion are reduction in waiting time and, consequently, reduction in waiting time cost. In this study, the vessels' charter cost and containers' lease cost are considered as waiting time cost because delays in service provision will increase these cost. From the port authority's perspective, it is important to minimize the construction cost of each berth. The study results reveal that the optimal number of berths that minimizes the total cost is

five. The analysis reveals that the number of berths at MICT is already adequate. In order to release congestion, port managers must take other actions. For this purpose, it is recommended that future studies trace out the reasons for congestion at ports and suggest appropriate measures to release congestion.

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