Determination of the Optimum Number of Berths for the Cebu International Port by Application of Queuing Theory

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Abstract: Determining the optimum number of berthing spaces in a port is vital in port infrastructure planning and operations. The effectiveness of a port is contingent upon the unloading and loading of the container ships. The optimum number of berths in the port can be determined by applying the queuing theory with the total cost—that includes the construction cost of a berth and the waiting time cost of the ship—minimized as the objective function. This paper studies the application of the queuing methodology in analyzing the state of congestion for the Cebu International Port. The results revealed that the pattern of the arrival of ships follows the Poisson law of random distribution, which validates the assumptions regarding the queuing methodology. The study also found out that the current number of berths in Cebu International Port is adequate and in order to release congestion, port authorities must take other actions.

Keywords: Transport, Queuing Theory, Port Management, Port Development, Maritime Transportation

1. INTRODUCTION

Maritime transportation plays a crucial role in the inter-island and international connectivity. For centuries, the Philippine maritime waters have served as a medium to transport goods for both international and domestic trade. The total cargo throughput for the Philippines increased by 2.92% from 2017 to 2018, reaching 260.95 million metric tons. Domestic cargo moved up 3.84% and foreign trade showed an improvement of 2.30% (Philippine Ports Authority, 2018). In order to support the growing demand for trade, port authorities have been under pressure to improve port efficiency and make services more competitive to accommodate future demand. Ports form a vital link in the overall trading chain and, consequently, port efficiency is an important contributor to the competitiveness of a nation in the global market (Tongzon, 1995).

The transportation system in ports includes different physical elements like handling equipment, storage facilities, and berths. Berths or berthing spaces are among the most important facilities of a port. It provides a suitable and serviceable place for ships to handle goods. For port designers and engineers, the number of berths is an important factor influencing

the total investment cost and the overall design procedure needed in constructing a seaport. The ideal number of berths are expected to serve the handling operations for the arriving ships without delays, and strongly reflects the service capacity of the port and its capacity to accommodate traffic.

The objective of this paper is to identify the optimal number of berths that will provide the maximum net benefit. According to de Weille & Ray(1974), net benefit pertains to the reduction in waiting time cost for ship owners, and the minimization of berth construction and maintenance costs for the port authorities. If a port management authority does not invest in creating new berths to expand the port capacity, it would be able to minimize its operational and maintenance cost; but the shipowners will handle the burden of facing increased waiting time costs. On the other hand, the construction of an additional berth will lead to a great reduction of waiting time that will be profitable for ship owners, but it will incur a high construction and maintenance cost for the port authority. Furthermore, the construction of a new berth is time-consuming and costly, thus it needs to be considered carefully before being implemented.

In order to respond to this challenge, the queuing theory was applied to the arrival and service time patterns in a Philippine port. The Cebu International Port was chosen to be the study area since this port is deemed to be a vital port in the Visayas region and most recently upgraded its port capacity by adding a finger pier. The study would also like to determine whether the arrival patterns of ships in the Cebu port is appropriate for the application of the queuing methodology.

This study is organized as follows. Section 2 reviews the different related literature and studies that have used queuing theory and methodology in addressing maritime transportation problems. Section 3 gives an idea of the situation in the Cebu International Port. Section 4 presents the queuing theory and the related models that will be used. Section 5 provides the experimental setup and the data used the case study. Section 6 presents the results and discussion. Lastly, Sections 7 and 8 summarizes and concludes the results of this study.

2. LITERATURE REVIEW

2.1 Port Congestion

Port congestion is defined as a massive uncleared cargo in the port, that results in the delay of ships at a seaport (Maduka, 2004). This occurs when ships spend a significant time at berth rather than the usual before proceeding or worked on before berth. Furthermore, Onwumere (2008), referred to port congestion as a situation wherein a ship on arrival spends more time waiting to berth in a port. In this context, ships will queue at the channels before getting a space at the terminal.

With respect to the issue of port congestion, shipping and logistic companies would always opt for ports with sufficient available capacity and efficient turnover times. This avoids the risk that the huge amount of capital, which is embedded in their vessels, get used in an inefficient and sub-optimal way. Available capacity implies not only berths but also efficient terminal operations (Meersman, Van de Voorde, & Vanelslander, 2012). It is thus up to the actors (i.e. port managers, port operators, etc.) to provide provisions and policies to create or

maintain sufficient capacity.

2.2 Port Development

Competition among countries has been the norm in the age of globalization. In the game of becoming better than each other and attaining competitive advantage, access to resources and new markets; governments around the world are making intensive investments into different developmental and infrastructure projects. Such projects also include the development of new ports or expansion of existing ones (Hall, 2018).

According to Munim & Schramm, (2018), improvement in quality of port infrastructure and logistics performance would bring significant benefits to the economy of a country. The study made use of structural equation model (SEM) to provide empirical evidence of the economic impacts of port infrastructure and logistics performance. It revealed that the quality of infrastructure has a significant positive effect on national economy. They also discovered that logistics performance affects the seaborne trade of a country.

Port development also plays a crucial role in regionalization and hinterland activities. According to Hall (2018), hinterland connectivity and landside productivity are increasingly important for port performance. Conflicts over congestion, pollution and other negative impacts of container traffic are increasing source of tensions. Managing these tensions requires a clear understanding of the issues and identification of the stakeholders involved in the transport system.

2.3 Berth Optimization

As an essential optimization problem in transportation, the problem of improving port operations to alleviate or avoid congestion has received much consideration over the past few decades. One of the earliest studies was done in the 1960s. Fratar *et al.* (1960) dwelled on the maximum berth occupancy for a seaport. They were able to find out that ship arrival traffic and ship service time in US ports could be represented with the exponential and Poisson's distribution. In 1966, C. H. Plumlee, determined the optimal number of berths in Central America and Ecuador by describing a method that involves total ship waiting costs and berth unoccupancy costs. Furthermore, Nicolaou (1967), was one of the earliest researchers to use the queuing theory and graphical methods to determine the optimum number of berths in a general cargo port.

This field of berth optimization and queuing models was further improved by Easa (1987), wherein the study presented approximate queuing models to analyze the effect of tug services on congested harbor terminals. The congested harbor terminal was modeled as a queuing system and made use of the service time and berth cargo-handling time with general probability distributions. Moreover, Berg-Andreassen & Prokopowicz (1992) employed a standard queuing model to the lower Mississippi anchorage system to analyze the impact of reducing anchorage space in a deep-draft anchorage system. The study made use of random departure and arrivals supported by a stochastically formulated cost function. In 1994, Kozan applied various queuing simulation models in determining the optimal balance between the cost incurred in the expansion of a port and the cost incurred of a ship waiting. In order to evaluate the alternative business decisions at different time periods, a cost-benefit analysis was done that provides the minimum present value of the total costs over the planning period.

The majority of recent studies have applied the queuing theory along with relatively new optimization methods to analyze investment decisions in berth construction. Gokkus & Yildirim (2015), made use of deterministic and probabilistic methods based on artificial neural networks in determining the optimum number of berths in the Izmir seaport. The queuing theory was implemented for the determination of optimum berths and the ship traffic was predicted by using Linear Regression Analysis and Artificial Neural Networks. On the other hand, Munisamy (2010), utilized a closed queuing network model to evaluate the port efficiency of the Klang timber terminal. The research considered the cargo handling system and its impact on terminal throughput capacity by analyzing the interaction between the cargo handling facilities and the reason for congestion. El-Naggar (2010), applied the queuing theory in determining the optimum number of berths in Alexandria port in Egypt using real data of the arrival and service times of each ship. The methodology of this study was based on the assumption that the number of berths can be increased as long as the construction and maintenance cost of berths is less than the delay costs of the waiting ships. This type of methodology was also used by Oyatoye *et al.*(2011) for the Tin Can Island Port. In their study, the researchers were able to identify that the current number of berths is adequate for the traffic intensity of vessels and that other factors such as the current quality of port facilities are the leading causes of port congestion. Lastly, Saeed & Larsen (2016) implemented the queuing theory in optimizing the number of berths in the Manila International Container Terminal (MICT) in the Philippines. In this study, the ship arrival patterns were also examined and were deemed to be statistically appropriate for queuing methodology. It was found out that the current number of berths at the MICT is adequate and to alleviate congestion, the port managers must take other actions.

The central location of Cebu has positioned the island as a natural entry point and trading center for the southern Philippines. As the principal shipping hub of the Visayas region, the Cebu International Port has reached high utilization rates over the past years. Due to the increase of flow of goods and the development that is happening in the region, there is a need to determine the current capability and capacity of Cebu International Port. In addition, only little is known about the situation of the ports in the Philippines. There is a lack of available researches and studies tackling port queuing and berth optimization in the country, most especially in the Visayas region. This study hopes to contribute to the literature in the field of berth optimization for ports in the Philippines.

3. CEBU INTERNATIONAL PORT

The Cebu port network is comprised of the base port and subports. Located in Cebu City, Philippines, the Cebu Base port is divided into the Cebu International Port (CIP) and Cebu Domestic Zone. The Cebu International Port is located in the North Reclamation Area of Cebu City. The entrance to this port is the Mactan Channel, which is a narrow strait between Cebu and Mactan Island. The CIP is just 3km away from the city center. (See Figure 1: Location of Cebu International port)

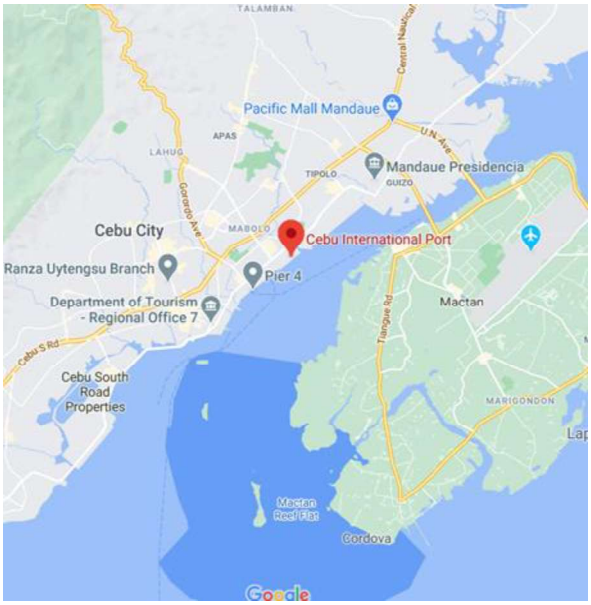

Figure 1 Location of Cebu International Port. (Google Maps, 2021)

The CIP container terminal has an area of 16 hectares. It is owned and operated by Cebu Port Authority, which is an administrative authority established by the Philippine Government. Currently, the cargo handling and service provider of the port is done by the Oriental Port and Allied Services Corporation (OPASCOR). The nature of operations in this port is commercial. The port features a 14-hectare container terminal with dry bulk terminal, standby generators, and is ISPS Security Code Compliant.

Last 2019, the Cebu Port Authority inaugurated a new finger pier constructed by the OPASCOR. This project was done to address the need for more berth and yard space in CIP and increase its operational capacity. The finger pier is a shorter, narrower pier projecting from the main dock of CIP. It is a 1.25-hectare facility that was designed to accommodate general cargo vessel carrying rice, steel, cement, salt and other bulk cargoes bound for Cebu. It has a berthing area of 250m and a yard space of 7,500 square meters that will increase the total storage capacity of CIP to more than 10,000 containers at any given time. This finger pier increased the total number berthing space at CIP to four (OPASCOR, 2019). The construction of this pier was deemed as the solution in preventing further congestion instances similar to the previous cargo stack congestion in 2014 and 2015, when yard utilization reached a high of 90% to 106% resulting to extreme difficulties in vessel and yard operations at the port (OPASCOR, 2018).

The main cargo handled at the Cebu International Port is international containers, but the port also has the capacity to handle non-containerized and general cargo. It has a maximum capacity of 4 vessels simultaneously and the CIP is equipped with both bulk and container-handling tools. The annual capacity of this port is 900,000 TEUs with a total storage capacity of more than 10,000 TEUs at any given time. As of December 2018, the volume of cargoes handled at CIP increased by 45% for domestic containers, 10% for foreign containers, and 10% for general cargoes (Port Calls Asia, 2019). It is also expected by the port authorities that the cargo needs will still increase over time.

4. QUEUING THEORY

Queuing theory has been regarded as an essential analytical tool for solving problems related to congestion. It has the ability to estimate certain important parameters, such as average queue length, average waiting time of ships, average number of ships in the port and also the average berth utilization factor.

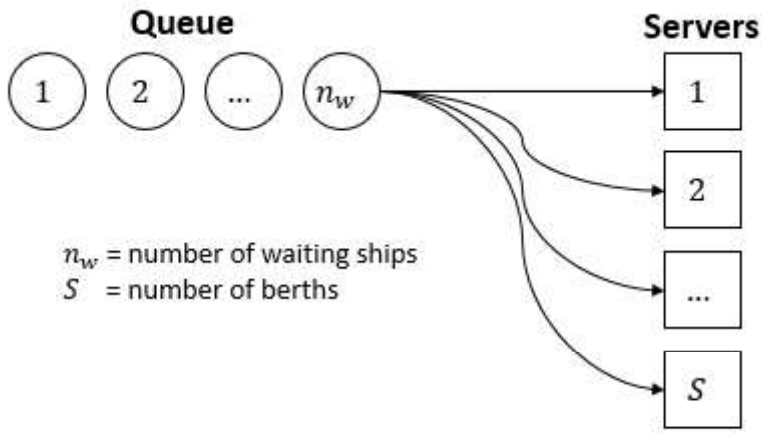

Figure 2 Ship Queue at Port

The input for this problem is normally characterized by some form of arrival pattern usually given by its arrival distribution. The output, on the other hand, depends on the queue discipline and the service mechanism of the server. The most common type of queue discipline is FIFO or first-in-first-out (i.e. first ship that arrives at the port gets served first and therefore the first to leave the system as well.). Kendall's notation is popularly used to describe a queuing system. It takes the form: A/B/C (n). Where A is the input or arrival pattern, B is the service mechanism, C is the number of servers, and n is the limit of the queue or users (Sigua, 2008).

The input or arrival pattern and departures may either follow a random or deterministic pattern. Markov (M) is used to refer to a random process while Deterministic (D) is used to describe a queuing process characterized by regular or constant arrivals or departures (Sigua, 2008).

For this study, since the CIP has multiple berths and ships have random arrival times, the problem can be characterized as an M/M/N (∞) queuing system where the first M implies random arrival, the second M implies random service rate, the N signifying multiple servers, and that there is an infinite queue limit. To analyze the movement of ships in the Cebu International Port using the queuing theory, the following assumptions are used (Jansson & Shneerson, 1982):

- Ships arrive at random and that the probability distribution of arrivals can be described by the Poisson probability distribution.

$$P_x = \left(\frac{\lambda^x}{x!}\right) e^{-\lambda} \tag{1}$$

where P_x is the probability of the arrival of x ships given a certain time period, λ is the expected number of ship arrival during the time period, e is the base of the natural logarithm

(e = 2.71828…) and $x!$ is the factorial of the ship number. It is important to note that the Poisson probability distribution function can only be calculated if the average arrival rate of ships during the time period is known.

- The service time is a random variable that fits the negative exponential probability distribution. With the Poisson probability distribution, the distribution of the time interval between ship arrivals will be negative exponential. As a special case, the service time can also be a negative exponential.
- There is no upper limit to the queue length.

The basic formulas for M/M/N are heavily comprised of variables related to expected arrival rate, expected service rate, number of servers, and queuing intensity. (Sigua, 2008):

Server Utilization

$$U = \frac{\frac{\lambda}{s}}{N} = \frac{\emptyset}{N} \tag{2}$$

where,

λ	: expected arrival rate
s	: expected service rate,
$\emptyset$	: queuing intensity (λ/s)
N	: number of berths

For M/M/N, the value of the queuing intensity, $\emptyset$ may be greater than 1 but the utilization factor, $\emptyset/N$ must be less than 1 for stable condition. Table 1 displays the following queuing formulas that will be used in the study:

Table 1 Queuing Formulas

Average length of queue, $\overline{m}$	$\overline{m} = \left[\frac{P_0 \emptyset^{N+1}}{N!\,N}\right] \frac{1}{(1-\frac{\emptyset}{N})^2}$
Probability that there will be zero ships in the system, P_0	$P_0 = \frac{1}{\sum_{n=0}^{N-1} \frac{\emptyset^n}{n!} + \frac{\emptyset^N}{N!\,(1-\frac{\emptyset}{N})}}$
Average number of ships in the system, $\overline{n}$	$\overline{n} = \left[\frac{P_0 \emptyset^{N+1}}{N!\,N}\right] \frac{1}{(1-\frac{\emptyset}{N})^2} + \emptyset$
Average waiting time, $\overline{w}$	$\overline{w} = \frac{\emptyset + \overline{m}}{\lambda} - \frac{1}{s}$
Average time spent in the system, $\overline{t}$	$\overline{t} = \frac{\emptyset + \overline{m}}{\lambda}$

5. EXPERIMENTAL SETUP

5.1 Data

The data used for this study was collected both from primary and secondary sources. Personal interviews and queries with the Port Manager and Harbor Master of the terminal were

considered as primary sources. Formal and informal interviews at the individual level of discussion were held to obtain further clarification with regards to the facilities and operations of the port. On the other hand, the secondary sources include the records and statistics from the Cebu Port Authority. Ship logs of the Cebu International Port (CIP) for January 2020 were used for this study.

The number of ships that arrived at the Cebu International port is 60 in 31 days (for the month of January 2020). The average number of ships per day is 1.94. The mean service time (at berth) per ship is 1.13 days or 27.12 hours. The inverse of this is the service rate capacity, which means each berth can service 0.88 vessels per day. The average ship length of the vessels that arrived at CIP is 154m. The ship logs data also shows that, on average, vessels of 17,500 deadweight tonnage (DWT) are called at the CIP.

Table 2 presents the input parameters extracted from the data provided by the primary and secondary resources.

Table 2 Input parameters

Expected number of ship arrivals (λ)	1.94 ships/day
Mean service time at berth per vessel (s)	1.13 days
Current number of berths (N)	4 berths
Service rate capacity of berth per day (u)	0.88 vessels
Berth construction cost	USD 20,600,000
Number of ships calls in a year	670

6. RESULTS AND DISCUSSIONS

6.1 Determination of Ship Arrival Pattern Distribution

To determine whether the data collected at the CIP is suitable for queuing methodology, the distribution of the ship arrival pattern has been analyzed. The use of the chi-square fit test is applied to check if the ship's arrival observes the Poisson distribution. Note that the null hypothesis for this test is that the actual frequency distribution of the daily number of ships fits the Poisson distribution. The equation for the chi-squared test can be seen below:

$$\chi^2 = \sum_{i=1}^{x} \frac{(O_i - E_i)^2}{E_i} \tag{3}$$

where O_i is the observed or actual frequency, E_i is the expected or the computed frequency for Poisson distribution, x = 9. Refer to table 3 for the results of the chi-square test.

Table 3 Chi-square test to check Poisson distribution

No. of ships (S_x)	Observed frequency (O_i)	$S_x * O_i$	Poisson distribution (P_x)	Expected frequency $E = T*P_x$	Chi-square χ^2
0	2	0	0.144	4.475	1.369
1	11	11	0.279	8.661	0.632

No. of ships (S_x)	Observed frequency (O_i)	$S_x * O_i$	Poisson distribution (P_x)	Expected frequency $E = T*P_x$	Chi-square χ^2
2	8	16	0.270	8.382	0.017
3	7	21	0.174	5.408	0.469
4	3	12	0.084	2.617	0.056
5	0	0	0.033	1.013	1.013
6	0	0	0.011	0.327	0.327
7	0	0	0.003	0.090	0.090
8	0	0	0.001	0.022	0.022
SUM	T = 31	60	1.000	30.994	3.995

Computing for the degrees of freedom, DF = x - γ - 1 where x is the number of ships and γ is the number of parameters of the Poisson distribution (α = 0.05) gives us DF = 9 – 1 – 1 = 7. Hence, the value of $\chi_\alpha^2 = 14.07$.

Since $\chi^2 < \chi_\alpha^2$ $(3.995 < 14.07)$ the null hypothesis cannot be rejected, and thus, one can maintain that the actual ship arrival frequency distribution at CIP fit the Poisson distribution and confirms the validity of the proposed queuing methodology.

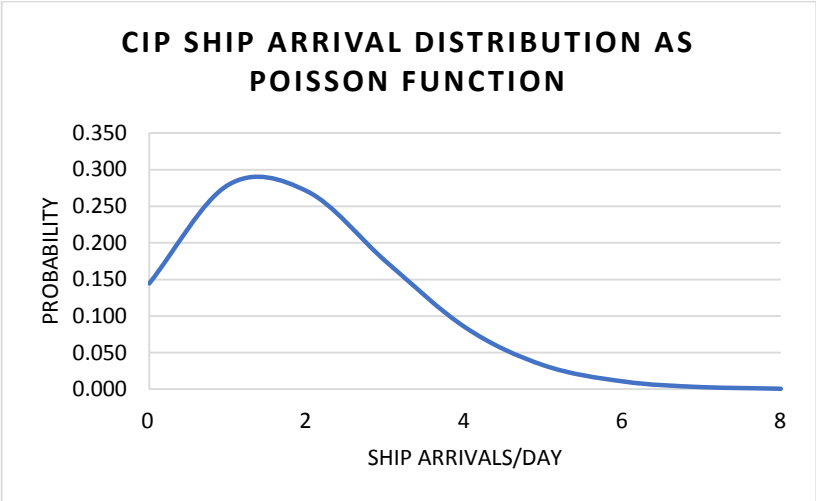

Figure 5 Ships arrival distribution as Poisson Function

6.2 Queuing Theory Application

The queuing model was solved for the different number of berths ranging from 3 to 7. The results are presented in Table 4. The table shows the berth utilization, the average ships in queue, average ships in the system, average ship waiting time, average time spent in the system, and the probability of having zero ships at all berths. The results show that by increasing the number of berths leads to the reduction of waiting time. The waiting time approaches zero when the total number of berths at the CIP is 4. It is also important to point out that the probability of having idle berths also increases as the number of berths increases. However, it is vital to

determine whether the construction of 7 berths is a feasible strategy. The total cost of creating the 7 berths must be examined and evaluated.

Table 4 Queuing model output

Number of berths	Berth utilization, U	Ave. ships in queue, $\overline{m}$	Ave. ships in system, $\overline{n}$	Ave. ship waiting time (days), $\overline{w}$	Ave. time spent in the system (days) $\overline{t}$	Probability of idle berths, P_0
3	0.73	1.457	3.649	0.753	1.886	0.0827
4	0.55	0.272	2.463	0.140	1.273	0.1056
5	0.44	0.065	2.256	0.033	1.166	0.1104
6	0.36	0.016	2.207	0.008	1.141	0.1115
7	0.31	0.004	2.195	0.002	1.134	0.1117

6.3 Cost Analysis

It is vital in this study to determine the point at which savings in total waiting time cost per year are less than the cost of construction of a new berth (in this case, USD 20.6 million). The following cost function is used (Saeed & Larsen, 2016):

$$TC = C_a * N + W_c * V_s * q_i \tag{4}$$

where TC is the total cost of a berth, C_a is the annualized capital cost per berth, N is the number of berths, W_c is the average waiting cost per ship per day, V_s is the number of ship calls of the port per year, and q_i is the average waiting time per vessel per berth.

Given that one twenty-foot equivalent unit (TEU) is equal to 14 tons, the average vessels that are called at the CIP carry approximately 1299 TEU. According to the Harper Petersen & Co. index, the charter price for container ships carrying 1100 TEUs was USD 6000 per day in January 2020. The rental price for a container is around USD 150 per month or USD 4.83 per day. For 1299 TEU carrying vessels, this results to USD 6285 per day. The total waiting time cost per vessel is the sum of the charter price per day and the rental price per day, which is USD 12,285 per vessel per day. The cost of construction of the most recent finger pier, which increased the berthing capacity by one, in the CIP was PHP 1 billion or approximately USD 20.6 million. For this study, the assumed annualized capital cost C_a is also USD 20.6 million because the project duration of the construction of the finger was 360 days or almost a year (OPASCOR, 2018).

Table 5 presents the results of the application of Equation 4 for the different number of berths. The results show that the total cost is minimum when the number of berths is three. The construction of more than three berths will drastically decrease the waiting cost, but the construction cost, and consequently the total cost will increase.

Table 5 Cost Computation

No. of berths	$C_a * N$ (USD million)	$W_c * V_s * q_i$ (USD million)	Total cost (USD million)
3	61.8	6.20	68.00
4	82.4	1.15	83.55
5	103	0.27	103.27

6	123.6	0.07	123.67
7	144.2	0.02	144.22

The CIP recently completed the construction of a finger pier that added an additional berthing space, increasing the total to four. On the basis of this study, it is not suitable to conclude that the Cebu Port Authority over-invested if the concept of 'option value' used in cost-benefit analysis is considered. An expected increase in future traffic may validate the current number of berths. Thus, the present policy in the CIP may be fairly justified even if it initially involves some excess capacity. The research can thus conclude that on the basis of this analysis that in order to relieve congestion in the CIP, the port authorities must take actions elsewhere.

7. CONCLUSION

The Philippines, having an archipelagic nature, relies heavily in maritime transportation to facilitate the movement of goods and people. In order to support the growing demand of international trade, port authorities are taking different measures to address the issue. A measure that could relieve congestion is to increase the number of berths in the port, consequently increasing the number of servers that can accommodate the ships. It is costly to construct a new berth so the decision to construct one must be carefully considered.

This study applied the concept of queuing theory in determining the optimum number of berths for the Cebu International Port that will minimize the waiting, service and total costs. The input data used in this study composed of the ship arrival and departure times for the month of January 2020. Further information such as the number of berths, waiting time costs, and construction cost were acquired through interview and queries.

The chi-squared statistical test was applied to check the distribution pattern for ship arrival times. One of the basic assumptions of the queuing theory is that the ships or customers arrive randomly at berth and follow the first-come first-served queue discipline. The results revealed that the pattern of the ship arrivals follow that Poisson law of random distribution, which validates the basic assumption of the proposed methodology.

The queuing model was applied for the different number of berths ranging from three to seven. The average waiting time, server utilization, average ship queue, and the probability of idle berths were computed for each number of berths. A cost analysis was also conducted to determine the viability of the construction of berths. In order to conduct this analysis, the total costs for different numbers of berths were estimated to determine the optimal number of berths. The total cost is the sum of the waiting cost and construction cost. The waiting cost comprises the cost to lease a container and the ship charter cost.

The results of the study reveal that the current number of berths in the Cebu International Port is deemed to be adequate at three berths and exceeding this will no longer be cost-efficient. This initially contradicts the need for the newly-constructed finger pier which brought the number of berths total to four. However, this study does not yet consider the option value in the cost-benefit analysis and an expected increase in future ship traffic can therefore justify this number of berths in the CIP. Based on this study, the researchers can conclude that in order to further release congestion, port authorities must take other actions.

8. RECOMMENDATIONS

This study can serve as a base for future studies that trace out the reasons for congestion and other measures for addressing it. This field of research can be related to port operations, operational inefficiencies, complex custom clearances, inefficient use of equipment, inland connection and communication, etc. It is also suggested that questionnaires and interviews should be distributed to the different maritime transportation stakeholders to identify the bottlenecks at the port that causes congestion.

The next step for the future development of this study is also to acquire more data that can be used to accurately determine the dynamic service times in a port. Conducting forecast studies that can reveal the future demand for ship traffic can also be done to verify port infrastructure developments and aid in the determination of the future number of berths. Furthermore, it is also important to recognize that terminal and port authorities cannot address the traffic planning and congestion challenges alone. The goal of traffic planning for ports in the future cannot simply be focused on the flow of goods through the port alone, rather, the interaction between the port system and the rest of the multimodal transport network it is in should be considered as well.

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