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The Capacity Planning of Bay Terminal as An Expansion of Chittagong Port for Encountering Congestion Problem Using Queuing Model Integrated with Economic Factors

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Abstract

Chittagong Port is the main port Bangladesh which handles almost 95 percent of the export-import of the county. Besides Bangladesh, it is also used by its neighboring countries, Nepal, Bhutan and India and makes it the second busiest port in the Bay of Bengal region and 58th globally. With the economic growth of the country, export-import also increases and all that pressure comes in the Chittagong Port. But it has not seen that much development accordingly. As a result, congestion problem has become a common issue here which on the process is disrupting the economic progression of the country resulting in huge economic loss every year. This paper conducts a study in finding the solution of this problem. In that process, numbers of jetties on the port, container terminal capacity, crane requirement per berth were calculated needed to withstand the problem.

Introduction

The fact that the Chittagong Port has risen six places in the latest Lloyd's List to become the world's 58th busiest container port is welcome news. Unfortunately, Bangladeshi companies are not in the mood to celebrate the achievement because extreme container ship congestion is currently wreaking havoc on the country's economy. Imported goods and raw materials are now taking an estimated eight to twelve days to unload.

Exporters have taken the brunt of the blast. They are not getting timely supplies of raw materials due to container vessel congestion. Obviously, the delay would make it practically impossible for them to deliver goods on time to their customers.

It is now clear that the amount of cargo handled by the country's ports will continue to increase as the country's foreign trade grows apace. The volume of both inbound and outbound container cargoes will increase as a result of the developing economic zones. In this scenario, the Chittagong Port will have a difficult time handling the potential cargo load. The port, which handles approximately 95 percent export-import freight, is in need of more and more equipment in order to transport cargo quickly. Congestion also ensures that the cargo will miss its connecting ships or trucks to various destinations and issues with scheduling

Objectives

The objectives are given below

1. To evaluate the optimal number of jetties required.

2. To determine the number of cranes to be set up at each berth.

3. To find the increment of container terminal capacity for the future expansion of the facilities.

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Research Methodology

In this paper, the berthing problem of ships in Chittagong port is analyzed using multi-server queuing models. But this deterministic approach will lead to differing degrees of berth capacity. Therefore, the planning of port facilities should reflect the standpoint of both economies and engineering factors. Therefore, we developed an equation (2) which meets its demand.

Following steps will follow during this research work:

Step 1: A queuing model will construct for solving the container handling problem. To construct this model, we will maintain these following steps:

• Multi-server queuing model will be studied in detail.

• Correlation of the multi-server queuing theory and the container handling problem will be made based on the forecasted containers coming for a specific period of time.

• Necessary Data will be collected directly from Chittagong Port Authority (CPA).

• Assumptions and notion will be made.

• Problem will be formulated

• Constraints will be formulated

Step 2: The problem will be solved manually by using multi-server queuing theory with infinite system capacity.

Step 3: An equation will be formulated for considering economic factor.

Step 4: The optimal number of jetties required will be solved by using the developed equation mentioned in step 3.

Step 5: Compare the results.

Step 6: Calculation of container terminal capacity.

Step 7: Determination of the cranes required per berth/jetty.

The port's operation mechanism can be compared to a standard queuing process. Ships arrive at the port as passengers seeking services, and the port's facilities support the ships as servers. The term "services" applies to cargo handling and the use of jetties for ship berthing. Making decisions in one or a combination of the following is a large part of solving waiting line problems that may occur in practice in Chittagong port:.

a) The number of jetties necessary to service incoming ships, b)The number of cranes required at each berth,

c) Potential facility expansion: Capacity of container terminals is being increased.

Keeping all these factors in mind, a detailed study was done on these factors implementing our developed formulations which considers both engineering and economic factors. Here calculations were done considering two scenarios: [1] Present and [2] 2035 (forecasted). All the solutions were given considering the load will be faced by Chittagong port at the year of 2035.

Theoretical Background

Chittagong Port Profile

Bangladesh's biggest and largest seaport, Chittagong Port, handles approximately 92 percent of the country's import-export trade. As a consequence, its role in the national economy is critical. According to Lloyd's, it is the world's 58th busiest container terminal. The new port site was built in 1887, and by 1910, four jetties had been constructed to handle 0.5 million tons of cargo annually. The Port Commissioners and the Port Railway shared ownership of the port at the time. In July 1960, the Port Trust was formed to replace the dual administration of Port Railways and Port Commissioners. The government has enacted the Chittagong Port Authority Ordinance in 1976 to deal with the rapid growth and expansion of the port and abolished the Port Trust, effectively dissolving Chittagong Port, following Bangladesh's independence in 1971 [3].

The world's ports have changed drastically since the 1970s, when containerization became the standard of international trade. Trade unionism was rife in the late 1990s. The development of the First Mooring Terminal in the first decade of the twenty-first century marked a major expansion. Despite various constraints, the port of Chittagong continues to adapt to changing trade patterns by constructing facilities to meet business needs. The Port of Chittagong's responsibility is to provide the necessary facilities and services for the safe and efficient handling of sea-borne export and import cargo.

Location

The port of Chittagong is located in the Karnafully River estuary, its major berths / terminal being about nine nautical miles from the outer anchorage of the port on the coast (Figure 1).

Bay Terminal

Bangladesh government and Chittagong Port Authority also addressed the problem of congestion of ships at Chittagong Port and so proposed a bay terminal which is actually a deep-sea port near the current facility of Chittagong port. The location of this bay terminal is also selected which is at the coast of Halisahar, Chittagong comprising an area of 7 kilometers. This is a fast-track project of Bangladesh government but the container terminal area, berth numbers, crane capacity and number of cranes per berth is yet to be determined.

The Bay Terminal was designed to ease capacity constraints at the nearby

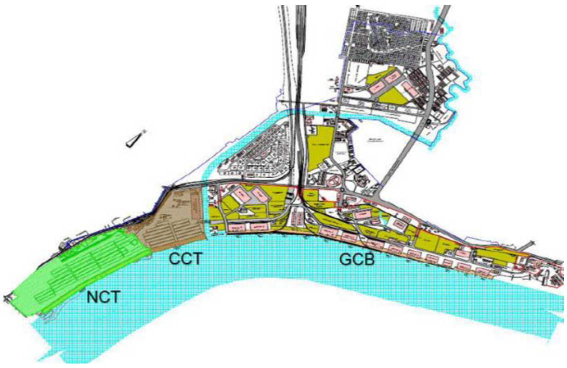

Figure 1. Chittagong Port.

Chittagong Port. The overall draft of the Port of Chittagong is 9.2 meters, necessitating the use of smaller ships to move cargo to and from the bay's large ocean freighters. In addition, the construction of a new port near the Chittagong port, known as the Bay Terminal, was planned. The Bay Terminal would not legally be a deep-sea port since its total draft would be up to 13 or 14 meters, less than the 15 needed for this designation, but it would give larger ships direct access to the port.

Port Congestion

Port congestion arises when vessels arrive at the port and are unable to load or unload, as the capacity of the port is already complete. It's the only option for the ships to line up and wait to get a spot at the port for their turn. And the total wait time at the ports has increased. Port congestion generates strain on the owners of cargo, shipping lines, and port management in turn. The management of the port needs to improve productivity in ship handling, develop the facilities of the ports and recruit more staff. Collectively, these factors cause shipping companies to raise operating costs as they may lose their reputation in transporting goods at the time promised. The congestion at the port is, therefore, an extremely dangerous challenge to maritime logistics.

Engineering Approach (Queuing Theory)

The theory of queueing is the study of waiting in different guises. It uses queueing models to describe the different types of queueing structures that occur in practice (systems that include queues of some sort). Formulas for and model show how, under a number of conditions, the corresponding queuing system should operate, including the average amount of waiting that will occur. These queuing models are also very helpful in deciding how to operate the most efficient way of running a queueing system. Excessive costs include the provision of too much service ability to run the system. But failing to have adequate capacity for service results in unnecessary waiting and all its unfortunate consequences. The models require a suitable balance to be found between the cost of service and the amount of waiting. The basic mechanism that most queueing models believe is as follows. Service-requiring clients are created by an input source over time. These clients enter the method of queueing and join a queue. A member of the queue is chosen for operation at such times by some law known as the discipline of the queue. The service required is then carried out by the service process for the client, after which the client leaves the queueing system.

Problems and Issues with the Engineering Approach

The main challenges of the engineering approach can be divided into three categories. To begin, this deterministic approach will result in varying degrees of berth capacity depending on the values used in major variables such as the number of cranes per berth, normal operating hours, and the berth utilization ratio extracted from the ship waiting period.

However, the results could differ depending on the number of cranes per berth and other variables. Because a typical berth now has at least three cranes rather than two cranes, the overall utilization was found to be significantly higher than the expected berth capacity in the ports (some highly efficient overseas terminals can even put five or six cranes). Another significant disadvantage of this strategy is that it is overly reliant on the W/S ratio, which is more perceptive than other success metrics, as well as the risk of selecting the incorrect parameter values[4]. Second, the infrastructure strategy focuses solely on the operational and physical capacities of the berth, ignoring the economic potential for ships and freight affected by harbor congestion, despite the fact that the port is being prepared by benevolent social planners seeking to profit from the social surplus [5]. If adopted, the engineering solution is unlikely to support the national/regional economies involved, but it achieves the goals of port operators by increasing profits and revenues or lowering costs.

Third, if ports are centrally organized, applying the same standard berth capability calculation formula throughout the country while ignoring various regional and physical characteristics will result in inefficient resource allocation, leading to overinvestment or underinvestment. Port ecosystems with different physical and economic ecosystems have different costs and revenues for growth. But, if a single standardized berth capacity is used as the national norm, the cost-benefit analysis of port construction may be distorted, and policy directions may be ambiguous.

Economic Factor Approach

The decision on port capacity requires planners, at least in theory, to incorporate not only engineering and operational factors, but also economic ones since there is a trade-off relationship between the cost of facilities and the quality of service. The purpose of this paper is mainly twofold. The first one is to review the current practices adopted by Chittagong Port (Queuing Theory) in estimating berth and port capacities. The other is to suggest a new approach to estimate the optimal port capacity from the standpoint of a national economy and show how the traditional approach can integrate economic factors.

Dwell Time

It is the average storage time of containers in the yard area, although the dwell time changes between 6-9 days on the average in many big ports of the world, this is around 12 days in Chittagong Port (ADB Report on Chittagong Port, 2020).

Current Practices of Berth Capacity Estimation (Engineering Approach): The Korean government (MOMAF) have calculated the total annual capacity of the container berths using an engineering approach for the past two decades. When it comes to developing container berths, the government must take into account the following factors:

1. The number of container cranes that will be installed in each berth

2. The number of working hours a day and days a year would each crane be able to provide

3. How much freight a crane can carry compared with its design requirements

4. What would be the actual output of the official handling rate from the specification.

5. How much time will a ship wait at berth.

6. How often would neighboring crane movements interfere with each other.

Even though some input variables and parameter values have changed over time, the government has continued to use this engineering data to predict container berth size. The estimation formulae used in the Korean cases can be generally classified into three types:

Traditional formula

Applied to Busan Container Terminal Operating Corporation (BCTOC), Pusan East Container Terminal (PECT), Gamman terminals in Busan and Ganging Phase-1 terminal.

The following formula (Eq. 1) was used for major port developments in Busan and Gwangyang:

$$V = N \times C \times E \times K \times H \times D \times O \times G \times U' \times S \quad (1)$$

Where V is a berth's annual capacity and N is the appropriate number of berths required. The crane power per hour (VAN 1.5 TEUs or 1.57 TEUs) is denoted by the letter C. E is a crane's efficiency ratio in relation to its official rate calculated from its requirements (72%); after removing the interfering effect between cranes (90 percent), K is the efficiency. The regular working hours (18–24 h) are denoted by the letter H. D is the number of working days in a year (330–360 days); the berth utilization rate (45–70%) is denoted by the letter O. For docking and undocking hours (0.9), G is the vessel movement change coefficient.

In using the formulae above, the following assumptions have been frequently used in planning:

Berthing hour: The service time derived from the queuing theory.

Ship arrival pattern:

• Arrival time of general ships: Poisson distribution.

• Arrival time of container ships: close to exponential distribution.

• Service time distribution: similar to overlapping two normal distributions (Figure 2).

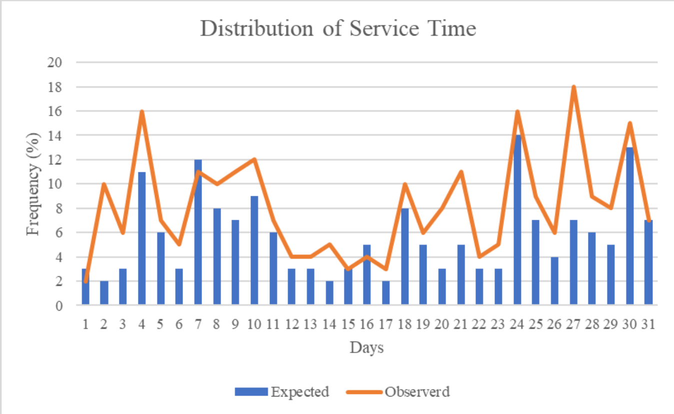

Figure 2. Distribution of Service Time.

Model Development

The issue can be modeled as a problem with no system limit for multi-server queuing theory; arrival can be from a source that is potentially infinite. Only the first come first serve priority rule is implemented for simplification. The probability distributions of arrival and service processes are needed prior to solving a typical queuing problem. To evaluate the accuracy of the fit of the real data to the standard probability distributions, the Chi-square test can be used. In an attempt to match the model to M/M/s, Chi-square testing considering Poisson distribution was carried out for the arrival process. With Poisson distribution and service time with exponential distribution considering infinite server and infinite queuing space, M/M/s (∞) denotes the queuing model for arrival. It is seen that the arrival process may be fitted nicely with Poisson distribution. The distribution of service time per ship is plotted in Figure 1 and it is clear that the service process does not satisfy the assumed exponential distribution in the M/M/s (∞) model. So, the entire berthing problem of the Chittagong port is considered as M/G/s (∞) queuing model. M/G/s (∞), which is almost same as M/M/s (∞) model except that the distribution of service time is non-exponential [6].

The working procedure is given below

1. Queuing model is used to find engineering limitations of the existing facility.
2. Linear Trend with seasonality forecast is used to predict the probable arrival rate at the year of 2035.
3. By using the forecasted value, the minimum number of facilities required is determined by queuing model.
4. An equation is formulated to determine the economic number of facilities required integrating the waiting time from the queuing model by using the equation used by MOMAF.
5. Terminal area calculation and crane requirement per jetty is showed.
6. All the results are analyzed and concluded with findings and recommendations.

Model Formulation

Number of Jetty Estimation: Engineering Integrated with Economic Approach

The proposed model is developed on the basis of equation (1) that is used by the Ministry of Marine and Fisheries (MOMAF), South Korea which implies

$$N \propto V/(C \times E \times K \times H \times D \times O \times U' \times S \times G) \quad (2)$$

But this previous equation doesn't include economic factors which have a significant influence in this calculation. So, it is not able to provide accurate number of jetties. Besides, it doesn't consider any engineering factors too, mean waiting time, which is very important to integrate in equation for getting optimal number. That's why this proposed model works on it to get more accuracy in calculation.

Parameters

N = The number of jetties required at the facility (port)

V = The annual capacity of a berth

GDP= Nominal Gross Domestic Product percentage

C= The crane capacity per hour (VAN × 1.5 TEUs or 1.57 TEUs)

E=The efficiency ratio of a crane in comparison to its official rate from its specifications.

K=The efficiency after subtracting the interfering effect between cranes (90%)

H=The daily working hours (18–24 h)

D=The annual working days (330–360 days)

O=The utilization rate of berths (45–70%)

G=The vessel movement adjustment coefficient for ship's docking and undocking hours

W=The mean waiting time

Here we have taken GDP as the parameter of economic factor as we know it influences the berth requirement proportionally. And no. of container vessels coming at a particular jetty (forecasted) will also have a promotional relation to the no. of jetties.

N∝GDP percentage

Whereas the number of years to come (forecasted) and mean waiting time from queuing calculation will have a proportional relation. Applying the economic approach to port capacity estimation requires estimation of vessel and cargo' mean waiting time in port. [1] Besides, the school of engineering approach is heavily dependent upon the waiting-to service time ratio (W/S ratio) to estimate berth capacity [2] which includes mean waiting time. Thus, integration of mean waiting time creates a relation between engineering approach and economic approach.

N∝W, Mean waiting time

∴N∝W × GDP percentage

Now, comparing the equations, we can say,

N∝ (V × w × GDP Percentage)/(C×E×K×H×D×O×G)

Keeping all these criteria in mind we have developed a new equation integrating economic factors based on equation (2).

N= (V × w× GDP Percentage)/(C × E × K × H × D ×O × G×〖 (U^' × S) 〗^2 × 10)

(Table 1 & Figure .3)

Chittagong Port (Present)

Chittagong port now has annual berth capacity of 2,903,996TEU as of 2020 at the existing facility which is taken as V as the annual capacity of a berth for the equation; as an economic factor, we have taken GDP percentage into the calculation which is 8.1% that Bangladesh was experiencing in 2019. The

Table 1. Model Validation.

Port Name	Previous Model	Developed Model	Actual
Shanghai Yangchuan Port	34	30	30
Port of Singapore	70	68	67
Port of Hong Kong	28	25	24

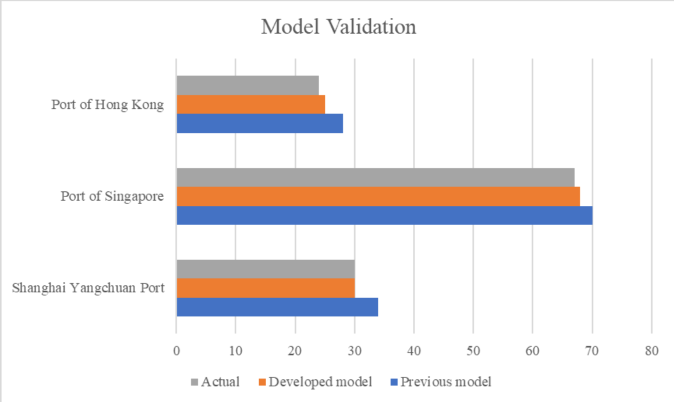

Figure 3. Implementation of the Model.

GDP of 2020 is not taken into consideration due to the recession faced by the economy because of Covid-19 pandemic globally; C the crane capacity per hour (VAN × 1.5 TEUs or 1.57 TEUs) which we found 24.5 for Chittagong Port (2020); E the efficiency ratio of a crane in comparison to its official rate from its specifications (72%); K the efficiency after subtracting the interfering effect between cranes (90%); H the daily working hours which is 19h at the port of Chittagong; D the annual working days (360 days); O the utilization rate of berths (70%); G the vessel movement adjustment coefficient for ship's docking and undocking hours (0.9); And from the queuing theory calculation, we have taken mean waiting time, W which is 3.55 days per ship into calculation.

Using this information, we'll calculate N, the number of berth facility (jetty) should be present there at the port for optimum operation using Eq. (2):

N=(2903996TEU×3.55×8.1)/(24.5×0.72×0.9×24×365×0.7×0.9×〖(2.4321×0.97)〗^2×10)

= 17.0031

≈ 17

The existing facility of Chittagong Port supports only 6 cargo berths and 11 container berths, 17 in total. And our equation also shows that result quite accurately, which confirms validity of the equation.

But we want to reduce the waiting time by 35.5% and making it mean waiting time, W is 1.00 days/week. For that, the number of berthing facilities should be increased, and that number would be:

N=(2903996TEU×1.00×8.1)/(24.5×0.72×0.9×24×365×0.7×0.9×〖(2.4321×0.97)〗^2×10)

= 26.9563

≈ 27

∴ The number of jetties should be introduced = (27 – 17)

= 10 jetties

Data Calculatio

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 (Table 2).

The Formula is shown below:

χ^2 =∑_(j=1)^g ((fj-Fj)²)/Fj

Where fj is the actual frequency, Fj is the frequency for Poisson distribution, g=12. The result of the chi-square test is χ^2= 8.41

Table 2. Chi-Square Calculation.

No. of ships (Xi)	Actual Frequency (fj)	$Xi_{\times} fj$	Poisson Distribution (Pn)	Frequency $F = T \times Pn$	Chi-square X^2
0	0	0	0.01	0.31	0..31
1	0	0	0.01	0.31	0.31
2	3	6	0.08	2.48	0.11
3	4	12	0.14	4.34	0.03
4	4	16	0.17	5.27	0.31
5	11	55	0.18	5.58	5.26
6	3	18	0.15	4.65	0.59
7	2	14	0.11	3.41	0.58
8	2	16	0.07	2.17	0.01
9	1	9	0.04	1.24	0.05
10	1	10	0.03	0.62	0.23
11	0	0	0.01	0.31	0.31
	SUM=T=31	SUM=156	SUM=1.00	SUM=31	SUM=8.41

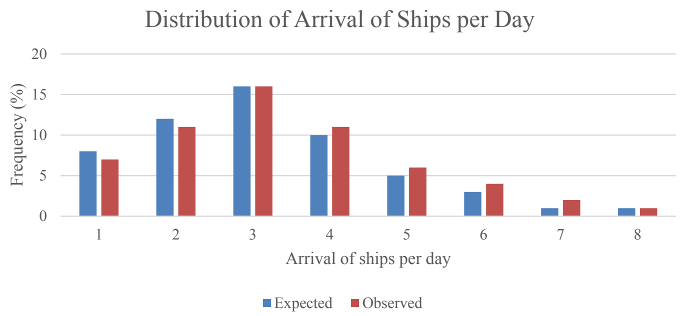

Figure 4. Distribution of arrival of ships per day.

DF= g-λ-1 = 12-1-1 = 10. Where λ is the number of parameters of the Poisson distribution, α =0.10. The value of 〖χ²〗_α=15.99.

∴ χ²< 〖χ²〗_α

Since the calculated Chi-square is less than the Chi-square alpha from the Chi-square chart, 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 (Fugure 4).

Implementation of Queuing Model

Chittagong Port (Present): Base Case

From the collected data,

s = 17, No. of cranes per berth = 2, μ = 0.3125×2 = 0.625 ship per day, λ = 11 ships per day, average no. of container per ship = 900 (Approx) (Table 3).

Table 3. Calculated Value for Present.

Parameter	Value
Lq	39 ships per day
Wq	3.55 days per ship
Ws	5.15 days per ship
Ls	57 ships per day
Po	4.83×10^{-9}

Here, λ/μ= 11/0.625=17.6

∴s < λ/μ

According to queuing model, for a finite queue length, the number of jetty available is insufficient.

Let, s = 18, No. of cranes per berth = 2, μ = 0.3125×2 = 0.625 ship per day, λ = 11 ships per day, average no. of container per ship = 900 (Approx.)

Chittagong Port (2035 – Forecasted): Base Case

From forecast, λ = 20 ships per day, μ = 0.625

Here, λ/μ= 20/0.625=32

So, the number of servers should be s ≥ 32. But putting s = 32, the value of Po shows math error. So, according to the queuing model, the minimum no. of servers should be s ≥ 33.

Let, s = 33, No. of cranes per berth = 2, μ = 0.3125×2 = 0.625 ship per day, λ = 20 ships per day, average no. of container per ship = 900 (Approx.) (Table 4)

Table 4. Calculated Value for 2035 (Minimum Server Requirement).

Parameter	Value
Lq	26 ships per day
Wq	1.29 days per ship
Ws	2.89 days per ship
Ls	58 ships per day
Po	1.53×10^{-15}

Implementation of Economic Factor Integration

Chittagong Port (2035 - forecasted)

Chittagong port will have annual berth capacity of 3,852,346TEU as of 2035 (forecasted) at the existing facility which is taken as V as the annual capacity of a berth for the equation; As an economic factor, we have taken GDP percentage into the calculation which is 5.86% that Bangladesh will be experiencing in 2035 (forecasted); C the crane capacity per hour (VAN × 1.5 TEUs or 1.57 TEUs) which will be 30 for Chittagong Port (2035-expected); E the efficiency ratio of a crane in comparison to its official rate from its specifications (74%); K the efficiency after subtracting the interfering effect between cranes (90%); H the daily working hours which is 22h at the port of Chittagong; D the annual working days (360 days); O the utilization rate of berths (80%); G the vessel movement adjustment coefficient for ship's docking and undocking hours (0.9); And from the queuing theory calculation (forecasted), we have taken mean waiting time, W which is 1.29 days per ship into calculation.

Using this information, we'll calculate N, the number of berth facility (jetty) should be present there at the port for optimum operation using equation (2):

N=(3852346TEU×1.29×0.0508)/(30×0.74×0.9×24×365×0.8×0.9@× 〖(2.361×0.97)〗^2×0.1493×10)

= 33.9347

≈ 34

At the year of 2035, the port will need 34 jetties to meet the demand at an optimum service rate.

∴ the number of jetties should be introduced (Bay Terminal)=(34–17) jetties

=17 jetties

The existing facility of Chittagong Port supports only 6 cargo berths and 11 container berths, 17 in total. But at the existing facility, there is no scope of introducing any new jetty. Therefore, construction of a bay terminal is proposed. And the number jetties on the bay terminal will be 14.

The coastal length of bay terminal is 7 km (7000 meter) and the draft will be 9.2 meter. At this draft, 300-meter ships will be operating in this new port extension. And 65-meter clearance is needed at before and after the ship. That means, a total of 130-meter clearance is required. So, total area required for each jetty/berth is 415 meters.

According to our calculation, permissible length per berth

= (7000 ÷ 17) meters

= 415 meters

So, the optimal number of berths suggested is justified.

Optimal Value Calculation (2035)

Taking the optimal value, s = 34, No. of cranes per berth = 5, μ = 0.3125×5 = 1.5625 ship per day, λ = 20 ships per day, average no. of container per ship = 900 (Approx.) (Table 5).

Table 5. Optimal Value for 2035.

Parameter	Value
Lq	Approx. 1 ship per hour
Wq	0.0199 day per ship
Ws	0.64 days per ship
Ls	13 ships per day
Po	2.76×10^{-6}

Terminal Area Calculation

The required container terminal storage area can be computed in rough terms as follows:

T = yearly throughput in TEUs = 3,852,346TEU as of 2035 (forecasted), D = 12 days, d = 6 days, a = 21.60 m 2, U = 0.5 taken for Chittagong Port, H = 4.5, h = 1.5, Z = 0.7

Now, applying this information in equation, we get:

A = storage area in ha

= (T× (D + 2d) ×a) / (365×Z×10^4× (H + 2h) ×U)

= (3,852,346TEU × (12+2×6) ×21.60) / (365×0.7×10^4× (4.5+2×1.5) ×0.5)

= 101.4481 ha

The container terminal capacity of Chittagong Port has to be increased to 101.4481 ha (Hectare) by 2035. Under the Phase Two development plans provide for the container terminal to expand to 70ha with a 1850m quay by 2025. But after that it won't be possible to add new container terminal area around the existing facility. So, it will be needed to build a bay terminal.

∴ Container terminal capacity of the bay terminal will be

= (101.4481 – 70) ha

= 31.4481 ha

Crane Requirement per Jetty/Berth Calculation

Assumptions

Port equipment capacity = 3000 TEU/day (2035)

1. Draught = 9 meter
2. Working time/berth time ratio = 0.9
3. Average output per gantry crane = 30
4. K = Loss of output for opening and closing hatches = 0.95
5. Port is working 24 hours,
6. Average cranes/berth = X (Assumed)

Now, applying this information in equation, we get:

Average throughput/day = 24 × (average output per crane) × (average number of cranes allocated) × (1-K) × (working time/berth time)

3000 = 24 × 30 × X × 0.9 ×0.95

X = 4.8783

≈ 5 Cranes/ berth (Bay Terminal)

So, by the 2035, it will be needed to launch 5 cranes in operation per berth of capacity 30 TEU/ day.

Result

According to data analysis and calculation of this paper, the results are:

(1) Number of jetties, needed to serve the arriving ships: 34 jetties.

∴ The optimal number of jetty of the bay terminal should be, (34-17)=17

∴ S ≥ 17

(2) Number of cranes to be set up at each berth of Bay Terminal: 5 cranes per berth of capacity 30TEU/day.

(3) Future expansion of the facilities: Increment of container terminal capacity: 101.4481ha.

But it is not possible to facilitate these implementations at the existing facility, therefore, a bay terminal is proposed near the Chittagong port with additional 17 jetties of which 2 will be cargo berths and the container terminal capacity of the bay terminal will be 31.4481 ha. Technically, the Bay Terminal would not be a deep-sea port, since its overall draft would be up to 13 or 14 meters, less than the 15 needed for this classification, but it would allow larger ships to access the port directly.

Limitations

1. In this study, the calculations were done for only the base case of Chittagong port.

2. This paper provides the measured dwell time of container that stays in the container terminal. But the vessel turnaround time (cargo dwell time) was not calculated.

3. The capacity of the cranes were assumed which needs a developed multiple linear regression model to solve.

4. The leaving time of a ship after unloading all containers and the time it takes for a ship to anchor from the queue to the berth is highly variable and thus could not be considered in the calculation.

Future Scope

Some effort may be given in the regarding topic to improve our developed model with more precision. Firstly, in this study only base case was considered. But according to the real scenario High Case and Low Case may also be considered with the Base Case. Secondly, since the rationale of container dwell time and vessel turnaround time (cargo dwell time) provides a strong point for upgrading and modernizing Chittagong port's capacity and facilities, it may be included in further studies. Thirdly, a multiple linear regression model can be developed to calculate the capacity of cranes rather assuming it.

Conclusion

Considering the future expected marine congestion problem at Chittagong port, an attempt is made in the present paper to provide an appropriate guideline to the management of the port authority for the future expansion of berthing facilities. At first data were collected and conducted a statistical analysis which shows, the data set follows Poisson distribution. And this information leads us to the queuing model selection which is: M/G/s (infinity) / first come first service (fcfs). Then, using this model calculation was done for two scenarios: existing facility (17 jetties) and our calculated facility (34) jetties for the year of 2035. The current facility shows waiting time of 5.15 days per ship and our solution (34 jetties) shows waiting time of 0.64 days per ship which decreases the waiting duration significantly by the year 2035. That also validates our developed formulae. Secondly, we developed an equation (2) which integrates economic factors to overcome the limitations of engineering method. We added GDP percentage as the economic factor showing the overall growth of the country. The GDP was taken 8.1% (2019/present) and for 2035, it was forecasted and it shows 5.86% growth. And mean waiting time was integrated too in the equation which maintains the relation between engineering method and economic method. Another two equations were applied for calculation of terminal container capacity and number of cranes per berth. Here, the crane capacity was assumed to be 30TEU/day. The validation of the equation (2) was given by applying three scenarios of 3 ports: Shanghai Yangchuan Port, Port of Singapore and Port of Hong Kong. And by giving quite accurate answer, the equation was proven valid. The proposed method may help the Chittagong Port Authority to utilize the application of the advantages of theoretical study into the practical field thus reducing the congestion problem. It may also play an important role in the economic development of our country.

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