Improvement of Transportation Efficiency Using Simulation-Based Decision Support System

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Abstract

Transportation plays a vital role in exporting and importing various goods around the world and it is also considered as an important aspect of GDP growth and gaining economic scale in Bangladesh. Due to lack of developed infrastructure, transportation cost is much higher due to the unwanted waiting time and costs. This article has proposed a new framework for simulation-based decision support systems to improve the transportation efficiency with the help of M/M/S Queuing Simulation and Queuing cost model at Chittagong Sea Port to reduce per day total ships queuing under current arrival rate. The results and analysis of the proposed model show that there is further opportunity to accommodate more ships at the seaport due to the reduction of ship queuing cost at a utilization rate of 92.10%. Nonetheless, the reduction in ship queuing cost will eventually contribute simultaneously to the improvement of container handling services and will increase the economic activities due to the escalation in the number of container handling at Chittagong Sea Port.

Keywords
Transportation, Decision support system, Queuing, Simulation, Optimization.

Introduction

The transportation system provides mobility or the ability to get from a place of origin to a place of destination for people, goods, and services. However, transportation also has a large share of global carbon dioxide emissions, which are one the leading causes of anthropogenic climate warming. Transportation is the only sector where emissions have steadily increased since the 1990s according to the Kyoto protocol, which highlights the importance of transportation efficiency improvement. There are different types of transportation systems are available in Bangladesh. Among them, our main concern is water transport system or more specifically Sea Port. Since 1888 Chittagong Sea Port, the important and main port of Bangladesh with the shore base facilities has been playing an essential part in the economic development of the country. It is considered the heart of the economy. This port creates the opportunity of flexible and cost-effective foreign trade to be carried out through this port with all the South Asian countries as well as other Asian countries for its geographical location. Moreover, sufficient and low-cost labour readily exists here. However, Chittagong port is suffering from the problems of poor operational efficiency. As a result, this port is considered for transportation efficiency improvement purpose by analyzing ships queuing process at the port by means of reducing total ships queuing cost per day in a such a manner so that Chittagong Port Authority gets more profits and ships come more often at Chittagong Sea Port rather than diverting to neighbouring seaports.

Since this paper is dealing with simulation and decision support system, so it is mandatory to have a proper idea about these topics.

Simulation

Simulation is the imitation of the operation of a real-world process or system over time. The behaviour of a system as it evolves over time is studied by developing a simulation model. This model takes the form of a set of assumptions concerning the operation of the system.

The assumptions are expressed in: -

- Mathematical relationships
- Logical relationships
- Symbolic relationships

The model solved by mathematical methods such as differential calculus, probability theory, algebraic methods has the solution usually consists of one or more numerical parameters which are called measures of performance. However, Simulation itself does not optimize the solution for the problem, it simply runs the model according to the specifications. Design of Experiments is also frequently done with simulations. Simulations are also frequently used to enhance learning, where the main purpose is not to improve a system. According to Banks et al. (2005) simulation process consists of below phases

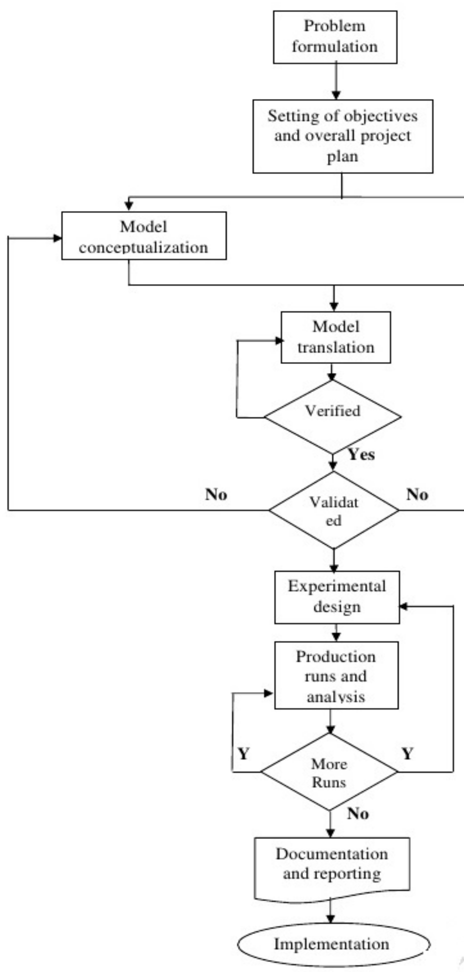


Figure 1. Simulation Process (Banks et. Al 2005)

Figure 1. shows the simulation process as a flowchart. Some differences may occur due to different simulation approaches, but in general, the processes are the same.

Decision Support System

A decision support system (DSS) is a computerized information system used to support decision-making in an organization or a business. A DSS lets users sift through and analyze massive reams of data and compile information that can be used to solve problems and make better decisions. According to Courtney (2001), Decision Support System (DSS) consists of seven phases (Courtney 2001) which are presented in Figure 2.

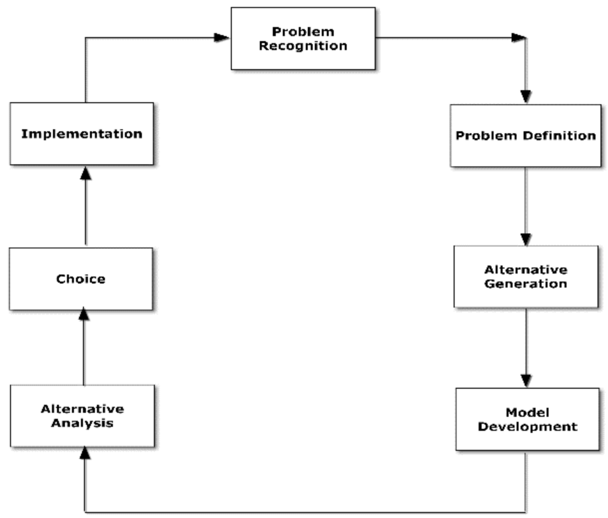


Figure 2. DSS decision-making process (Courtney 2001)

The process starts with problem recognition. After the problem has been recognized, it needs to be properly defined. Alternatives can be generated when the definition is known and the decision-making model can be developed. The different alternatives provided by the model are analyzed and a decision is then made. Finally, the decision needs to be implemented. This follows the decision process first proposed by Simon (1960). Courtney (2001) has expanded the model to include more decision-makers and their mental models, but this is mostly an issue with Group Decision Support Systems.

According to Shim et al. (2002), model-driven DSS consist of three phases: formulation, solution, and analysis. During the formulation phase, the actual problem is translated to an algebraic form. In the solution phase the model is optimized, and in the final phase results of the model are presented to the user. The formulation phase will also impact on how the solution is obtained. Most of the methods use a mathematical programming approach, e.g. a collection of mathematical functions is created and the minimum or maximum value is then obtained by using various algorithms.

Right after the proper understanding of Simulation System and Decision Support System, transportation efficiency can be improved with the help of Discrete Event Simulation which deals with queues and servers and entity.

Discrete Event Simulation

Discrete Event Simulation describes how a system evolves over time with discrete flow units or jobs. A discrete event simulation is a model (mathematical and logical) of a physical system that has changed at precise points in simulated time. Usually, DES uses queues and servers (Banks et al. 2005). The entities enter the model through a source and go into a queue. As soon as a server is available, the entity gets processed after a delay. After a delay, the entity can go into another server and may end up in a queue. The queuing facilities may involve certain design with the limited capacity to reject the customers who arrive after the capacity is reached. The customers may arrive at certain time distribution and certain queuing discipline or first come first serve. The servers that provide services to customers may have certain service time distribution or certain configuration such as serial or parallel servers. Customers waiting for service, the management of parts inventory or military combat are typical types of DES.

Since ships are diverting to neighbouring seaports due to poor operational efficiency and non-standard service time at Chittagong Sea Port, M/M/S queuing simulation is considered to improve the transportation efficiency.

M/M/S Queuing Simulation

In queueing theory, a discipline within the mathematical theory of probability, the M/M/S queue is a multi-server model. In Kendall's notation, it describes a system where arrivals form a single queue and are governed by a Poisson process, there are S servers and job service times are exponentially distributed. The performance of this queuing system where arrivals occur at rate λ according to a Poisson process , service times have an exponential distribution, with parameter μ, the buffer is of infinite size, so there is no limit on the number of customers it can contain. The model with infinitely many servers is the queue. Here ships are customers in terms of the scenario.

Formulas for M/M/s queuing simulation are as bellows: -

Arrival Rate, $\lambda = \frac{Number\ of\ ships\ arrivals\ in\ per\ unit\ time}{Inter\ arrival\ time}$

Service Rate, $\mu = \frac{1}{mean\ service\ time}$

Number or server = S

Utilization factor, U= $\frac{\lambda}{s\,\mu}$

Probability that there are no ships in system, $P_0 = \frac{1}{[\sum_{i=0}^{s-1} \frac{1}{i\,!}(\frac{\lambda}{\mu})^i] + \frac{1}{s\,!}(\frac{\lambda}{\mu})^n (\frac{s\mu}{s\mu-\lambda})}$

Average number of ships in the system L = $\frac{\lambda\mu\,(\frac{\lambda}{\mu})^s}{(S-1)!\,(S\mu-\lambda)^2}\,P_0 + \frac{\lambda}{\mu}$

Average number of ships in the waiting line(queue) L_q= (L - $\frac{\lambda}{\mu}$)

Average time a ship spends in waiting line for service, (queue) $W_q = \frac{L_q}{\lambda}$

Average time a ship spends in system, (in waiting line and being served time), W = ($W_q + \frac{1}{\mu}$)

Probability that there are "n" ships in system,

For n ≤ s $P_n = \frac{\rho^n}{n\,!}\,P_0$

For n > s $P_n = \frac{\rho^n}{s\,!\,s^{n-s}}\,P_0$

Queuing Cost Model will be used as a part of transportation efficiency improvement with this M/M/S Queuing Simulation.

Queuing Cost Model

After getting the data using M/M/S queuing simulation model, Queuing cost model is used to optimize total queuing cost and improving the overall transportation efficiency. For this purpose Queuing cost model prescribed by Zdenka Zenzerovic and Edna Mrnjavac is used for analyzing queuing cost scenario at Chittagong Sea Port. Total ship queuing costs and berth non-occupancy costs are computed as follows:

Ship queuing costs,

$C_w = C_w \times L_Q \times t$ …………………………...………… (1.1)

Non-occupancy berth (server) cost,

$C_b = C_b \times (S-\rho) \times t$ ………………………………. (1.2)

Total Queuing Cost,

C = [{ $C_w \times L_Q \times t$ } + { $C_b \times (S-\rho) \times t$ }

C = [{ $C_w \times L_Q$ } + { $C_b \times (S-\rho)$ }] ×t……………… (1.3)

If it is taken into consideration,

$W_Q = \frac{L_Q}{\lambda}$ then, $L_Q = W_Q \times \lambda$ and ρ = λ/μ

So, Eq. (1.3) can be written as Total Queuing Cost,

C = [{ $C_w \times \lambda \times W_Q$ } + { $C_b \times (S-\rho)$ }] × t……… (1.4)

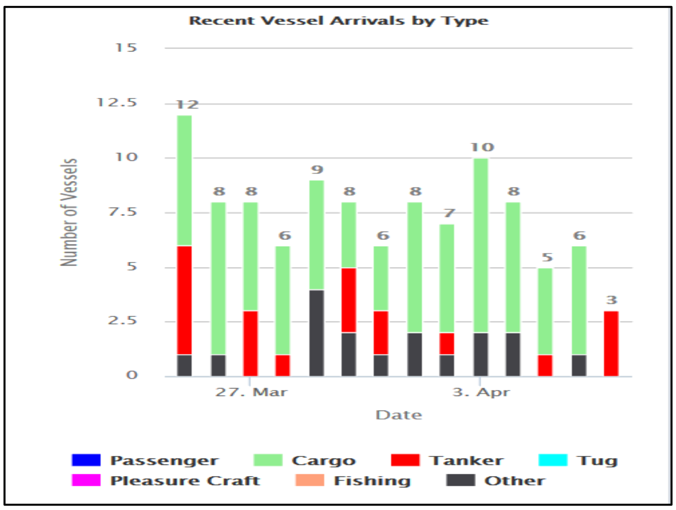
By solving Eq. (1.4) total queuing cost can be calculated at Chittagong Sea Port for efficiency improvement purpose.

Where,

- C - is the number of total costs expressed in currency units in an observed time unit (example: in USD/hour),
- L_Q - is the average number of container ships in the queue,
- S - is the number of container berths,
- ρ - is the berth occupancy rate; $\rho = \lambda/\mu$,
- t - is the length of time period for which costs are computed (e.g. day, month, year),
- C_w - is the amount of costs caused by waiting of ship, expressed in currency units for an observed time unit (e.g. in USD/hour/ship),
- C_b - is the amount of costs arising from non-occupancy of berth, expressed in currency units for an observed time unit (e.g. in USD/hour/berth).

Data Analysis of M/M/S Queuing Simulation at Chittagong Seaport

To improve transportation efficiency in terms of ships at Chittagong Sea Port, at first statistics of recent ships (vessels) arrivals is collected for time duration period of 14 days (25th March 2017 to 7th April,2017) at Chittagong Sea Port. Figure 3. describes that on average 7.42 ships came at the Chittagong Port from 25th March to 7th April 2017. Amount of vessels arrivals showed several fluctuations under the certain period for which data was collected.



Source : www.marinetraffic.com/en/ais/details/ports/2743

Figure 3. Vessel arrivals at Chittagong Port

Ships handling statistics from 2010 to 2016 was also collected from the seaport authority which is shown in Table 1.

Table 1. Ships handling statistics from 2010 to 2016

Year	Ships Handled
2010	2308
2011	2079
2012	2136
2013	2294
2014	2566
2015	2730
2016	3014
Total ships Handled	17,127
Average ships handling per year	2447
Average ships handling per month	203
Average ships handling per day	7

Source: www.cpa.gov.bd

Table 1. describes that on average 2447 ships/year and 203 ships/month were handled over the periods till 2016.

In addition, Table 2. shows in total 19 berth (servers) are being used at present for servicing ships (vessels) at Chittagong Sea Port. The number of general berths is 6 while container berths are 11 and 2 other types of berths found at Chittagong Sea Port.

Table 2. Number of Servers for Ocean-going Vessels

Total Berths (servers)	**Quantity**	**Length**	**Draft**
General Berth (Conventional Berths)	6	186	8.5 → 9.2
Container Berths	11	186	8.5 → 9.2
Others	2	186	8.5 → 9.2
Total	19		

Source: www.cpa.gov.bd

With the help of M/M/S Queuing simulation current scenario at Chittagong port was analyzed which is shown in Table 3.

Table 3. Existing data at Chittagong M/M/S simulation

Input values	
Per Ships Service Time	2.5 days
Arrival Rate, λ	7 ships/day
Service Rate, μ	0.4 ships/ day
Number or server (berth), S	19
Output Values	
Utilization factor, U	92.10%
Probability there are no ships in system, P_0	1 x 10^{-7}
Average number of ships in the system, L	26.442 ships/day
Average number of ships in waiting line, L_q	8.94 ships/day
Average time a ship spends in waiting line,W_q	1.27 day
Average time a ship spends in system, W	3.77 days

Table 3. shows that average time a ship spends in waiting line is still 1.27 days and per ships service time is 2.5 days which is far behind of international standard of 1 day. In addition, Figure 4. illustrates that maximum waiting time was found 3.6 days in 2008.However average waiting time of per ship is 1.27 days which is comparatively less at present than previous periods.

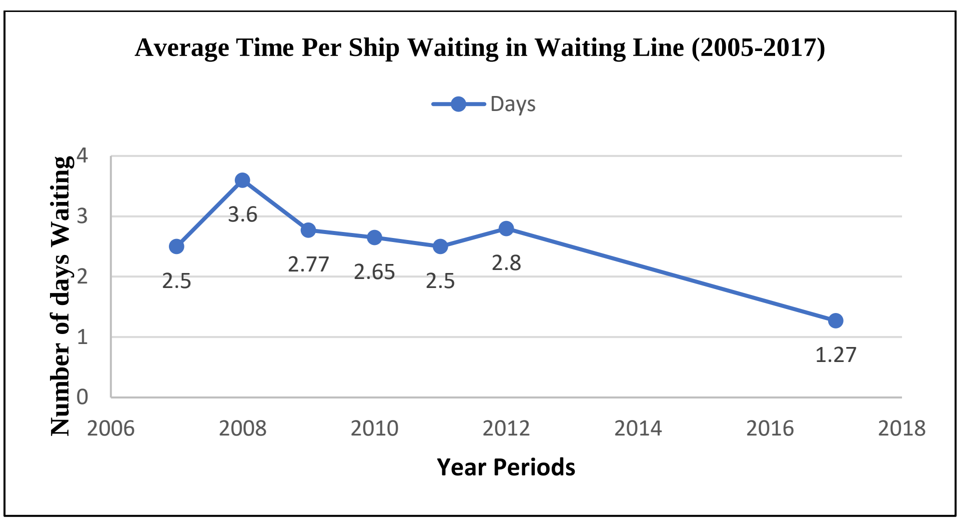


Figure 4. Average waiting time in queue by per ship at Chittagong Sea Port

After that Queuing cost model prescribed by Zdenka Zenzerovic and Edna Mrnjavac was used for analyzing queuing cost scenario at Chittagong Sea Port.For Arrival Rate of 7 ships/day at Chittagong Port,

Total Queuing Cost,

$$C = [\{ C_w \times \lambda \times W_Q \} + \{C_b \times (S - \rho)\}] \times t$$
$$= [\{12{,}500 \times 7 \times 1.27\} + \{3 \times 24 \times (19 - 17.5)\}] \times 1$$
= US \$ (111,125 +108) /day
= US \$ 111,233 /day

Besides per day under same arrival rate of 7 ships/day at present 1800 TEU containers are handled per day at Port. Clearing charger/per container at Chittagong Sea Port is US $600.

Total Cost of Clearing container, = US$ (1800 x 600)
= US$ 1,080,000/day

It has been found that for single ship per day queuing cost is US $ 15,890 under arrival rate of 7 ships/day at Chittagong Sea Port which is also higher than neighbouring seaports and per container clearing cost is US$ 600 which is only US$(150-200) at neighbouring seaports. Moreover, Chittagong Port is far too small for the new-generation ships to dock at. The port can only be accessed by vessels with a maximum 185 meters of length and 9.5 meters of depth (draft).

In addition, servicing time in Bangkok is two days and one day in Singapore whereas in Chittagong Sea Port it is still 2.5 days. However, according to a World Bank Group assessment sometimes due to inconvenience at Chittagong Port on average, it takes around 183 hours or 7.6 days to clear and unload shipments, which is high compared to other port authorities around the world. At that scenario under current arrival rate of 7 ships/day total queuing cost/day increases to US$ 665, 000 from US $ 111,125. Analyzing all the circumstances, it is clearly understandable service time and waiting time per ship at the port should be reduced to stop ships diverting to neighbouring seaports.

As a result, with the help of available 19 servers under steady state condition and maximum utilization of system respect to tolerable limits by port improvement of operational efficiency at Chittagong Sea Port was carried away.

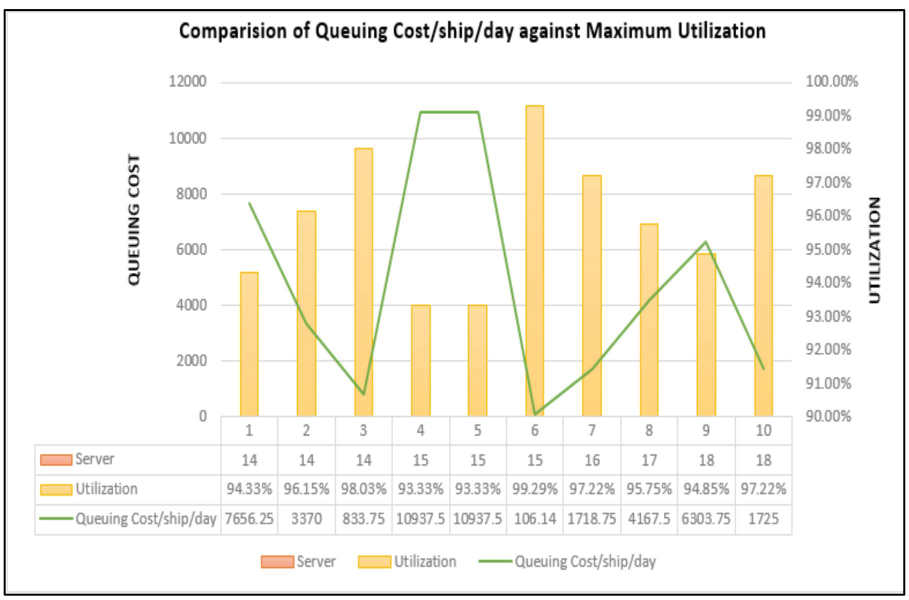


Figure 5. Queuing Cost/ship/day at Chittagong Sea Port under arrival rate of 7 ships/day considering optimization of servers (berth) via maximum utilization rate

Since Chittagong Port Authority stated to keep mandatory per ship queuing cost not less than US$ 4000/day and utilization rate not less than 50%. For this reason, according to Figure 5. under current arrival rate of 7 Ships/day at Chittagong Port, per ship queuing cost worth of US$ 4,167.5/day is proposed for effective ships (transportation) management

Under proposed queuing simulation utilization rate has been increased to 95.75% from 92.10 % and service time has been reduced to 2.3 days from 2.5 days and average time per ship spends in waiting line has been also reduced to 0.3334 days (8 hours) from 1.27 days in order to reduce queuing cost of per ship per day at Chittagong Sea Port. According to simulation still, there will be 2 servers unused out of existing 19 servers at Chittagong Port which could be used effectively to serve more ships if arrival rate of ships increases or for other purposes.

Queuing cost also has been reduced compared to previous existing queuing cost at Chittagong Sea Port which is shown in Table 4. compared to previous queuing cost at an arrival rate of 7 ships/day at Chittagong Port.

Table 4. Comparison of Queuing Cost under arrival rate of 7 ships/day at Chittagong Port

Type of Cost	**Existing Queuing Cost in US$ (per day)**	**Proposed Queuing Cost in US$ (per day)**	**Reduction in US$ Queuing Cost (per day)**
Ships queuing costs	111,125	29,172.5	82,007
Unoccupied berths costs	108	52.56	
Total queuing costs	111,233	29,225.06	

In addition, Rear Admiral Khaled Iqbal, chairman of Chittagong Port Authority (CPA) stated that in 2016, they handled 2,346,909 (TEUs) containers and 7.72 crore tons of cargo. As a result, it is expected that due to a reduction per ship service time to 2.3 days, the average waiting time per ships at the port by 0.3334 days and total queuing cost reduction of US $ 82,007 will eventually increase ships arrival rate at Chittagong port and increase amount of container handling resulting gaining economic growth in Bangladesh.

Conclusion

This thesis has proposed a new framework for simulation-based decision support systems in consideration to transportation. The lacking found from literature review has been considered in the thesis paper. As a result, Queuing cost model has been introduced for further improvement of transportation efficiency with the help of queuing simulation of M/M/S system. Since per ship service time and queuing cost of ships per day has been reduced by controlling average per ships waiting time under proposed simulation, so ships will tend less to divert to neighbouring seaports which will eventually make an increase in national economic growth due to increase number of ships arrival rate and container handling. Besides utilization has been increased by 3.65% from 92.10%.

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Biographies

Kadere Kibria is a student of Industrial and Production Engineering under the department of Mechanical and Production Engineering at Ahsanullah University of Science and Technology, Dhaka, Bangladesh. He is also a Certified Supply Chain Analyst(CSCA) by ISCEA.He is enthusiastic to learn and work with Operation and Productivity related activates i.e.: Lean Manufacturing, Six Sigma, Kaizen, Histogram, Pareto Chart, Poka Yoke so on. He has also an ambition for higher studies at abroad in near future.

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