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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.

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 market.[1]

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:

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

[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.

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(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 (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 queueing 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 Laih and Chen (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.

Dragovic 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. (2006) 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.

Munisamy (2010) 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.