Modelling the Queue at the Scan Station of Tema Port: An Application of Queuing Theory

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Date Received: April 6, 2015; Date Revised; May 30, 2015

Abstract - *The long hours spent in queues by imported consignment of goods waiting to be scanned causes congestion at the Tema Port. This study was conducted to find ways of reducing the time spent in queues by imported consignment of goods at the Tema Port. The main objective of this study was to minimize the time spent in queues by imported consignment of goods designated for the two scanners (Scanco and Nick-TC) for examination at the Tema Port.*

The study employed the technique of queuing theory for the analysis. We found that, the Scanco scanner had a faster service rate than the Nick-TC scanner when both were considered under the M/M/1 model where the two scanners served two independent queues.

However, under the M/M/2 model where the two independent parallel scanners served one queue of designated consignments, the number of consignments (mean system size) in the queuing system reduced to 8.3984 per hour with an average waiting time of 0.5339 hours. Based on the findings, the following policy recommendations were made: The Ghana Ports and Harbours Authority, and the Government of Ghana must formulate policies to permit the two current existing scanners to serve only one single queue in order to ease the congestion caused by long hours of waiting in a queue.

Keywords: *Congestion, Consignment, Queuing System, Queuing Theory, Scanner.*

INTRODUCTION

Due to the uneven distributions of natural resources and technological capabilities on the surface of the earth, nations across the world cannot survive without international trade. This is to say that, in modern times, no country can produce all the commodities that are needed to satisfy the wants of her people. With the development of transportation and communication, a country can safely depend on other countries for the supply of goods it produces. Ghana is one of such countries that greatly depend on other countries for the goods it cannot produce.

The import depending economy of Ghana has built up waiting delay for imported consignment accessing scan examination service at Tema Port. The waiting delay has resulted in long unwarranted queues causing congestion which consequently halt other operations of Tema Port and Harbour. This means that, the Tema Port is excessively crowded with trucks of imported consignment designated for scan examination service.

This problem of frequent occurrences of congestion on the road links was widely discussed by Van Schijndel and Dinwoodie (2000) and Notteboom (2008). They analyzed closely relationships between ports and transport infrastructure around them. Many other studies also included methods and proposals for improvements in hinterland connections (Konings, 2007; Rodriguea *et al*, 2009; Roso *et al*., 2009).

Nijkamp and Blaas (1994), suggested solutions for transportation problems like: careful programming of new transport investments, promoting sustainable ways of transportation and improving decision-making process in transportation planning. Pedersen (2005) and Carisa *et al* (2011) all did a lot of work on hinterland connections, common among which are optimization models which include intermodal simulations.

Ghana Ports and Harbours Authority have identified that one of the reasons for the congestion is the long unwarranted queues of the arrival of imported consignments queuing up for scan service. The main objective of this study was to minimize the time spent in queues by imported consignment of

P-ISSN 2362-8022 | E-ISSN 2362-8030

goods designated for the two scanners (Scanco and Nick-TC) for examination at the Tema Port.

METHOD

Data Collection

Primary data was used because the administrative data of the Tema Port are designed and recorded for operational reasons which are different from the research purposes of this study. During the process of collecting data the authors interviewed some drivers, transporters and clearing agents to share their views on the delays and suggest possible remedy. The data collection was observed at four different departments. Thus,

i. Recording the observed number of new arrival of trucks of imported consignment joining Scanco scan queue within every one (1) hour for seven hours over eight days.

ii. Recording the observed number of new arrival of trucks of imported consignment joining NICK-TC scan queue within every one (1) for seven hours over eight days.

iii. Recording the observed number of newly scanned examined trucks of imported consignment by Scanco scanner within every one (1) hour for seven hours over nine days.

iv. Recording the observed number of examined trucks of imported consignment by NICK-TC scanner within every one (1) hour for seven hours over nine days.

The authors noticed that throughout the year, the logistics handling at the Tema Port and the operations of the scan examination services was independent with respect to time and days. Therefore, the authors selected a period of two weeks and hours for collecting the data in a random choice of observation. The sample size used for this study was at least 350 trucks of clearing imported consignment. The same target of sample size was applied at all the four (4) different departments of the data observation. The authors determined the size of the sample to use based on analysis made on the administrative data of daily recorded total number of trucks of imported consignment that arrive for scan examination and daily recorded total number of trucks of imported consignment that are scanned serviced for both Scanco scan and NICK-TC scan obtained from the data base of the Tema Port.

Queuing Theory

Queuing Theory provides a mathematical basis for understanding and predicting the behaviour of communication networks. It involves the mathematical study of waiting line. The formulation of queues occurs whenever demand for a service exceeds the capacity to provide that service. Queuing theory provides a means for decision makers to study and analyze characteristics of the service facility for making better decision. The ultimate goal is to achieve an economic balance between the cost of service and the cost associated with waiting for that service. Queues (or waiting lines) help facilities or businesses provide service in an orderly fashion. Forming a queue being a social phenomenon, is beneficial to the society if it can be managed so that both the unit that waits and the one that serves get the most benefit.

The theory is based on building a mathematical model representing the process of arrival of customers who join the queue, the rules by which they are allowed into service, and the time it takes to serve the customers. We identify the unit demanding service, whether it is human or otherwise, as customer. The unit providing service is known as the server.

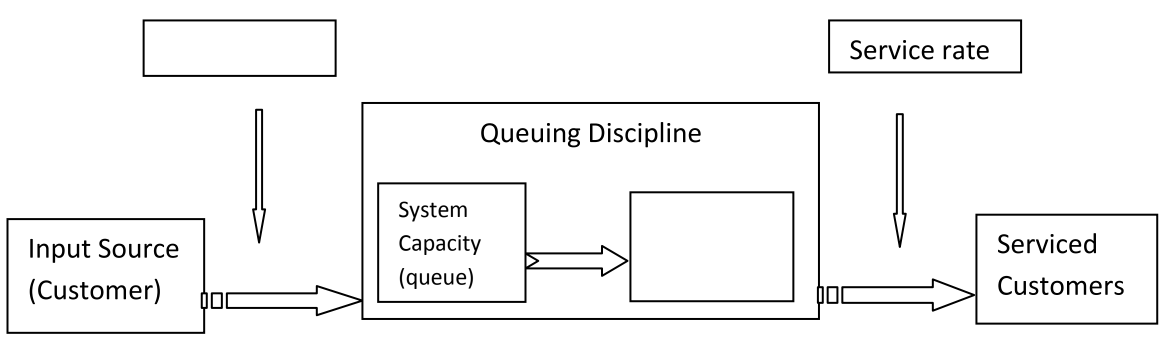

Figure 1 Basic structure of a queuing system

Components of Model

Input Source: the size of the 'calling population' may be modelled as infinite or finite. What is the arrival distribution? (Poisson or Exponential Distribution)

Queuing Discipline: refers to the order in which members of the queue are selected for service. Queue discipline is a parameter that explains how the customers arrive at a service facility. First-Come, First-Serve (FCFS) is normally used. Other rules are Last-Come, First-Serve (LCFS), First-Come, Last-Serve (FCLS), Priority Scheduling and Random Selection for Service (RS).

System Capacity: the queue is where customers wait before being served. A queue is characterised by the maximum permissible number of customers that it can contain.

Service Mechanism: The uncertainties involved in the service mechanism are the number of servers, the number of customers getting served at any time, and the duration and mode of service. Networks of queues consist of more than one servers arranged in series and/or parallel. Random variables are used to represent service times, and the number of servers, when appropriate. If service is provided for customers in groups, their size can also be a random variable.

Little's Law

In the Steady – State queuing process, $L = \lambda W$,
where λ is the mean arrival rate, L is the expected number of units in the system, and W is the expected waiting time in the system in steady state. Denote the expected number in the queue and the expected waiting time in the queue in steady state by L_q and W_q , respectively. These are related by a similar formula: $L_q = \lambda W_q$.

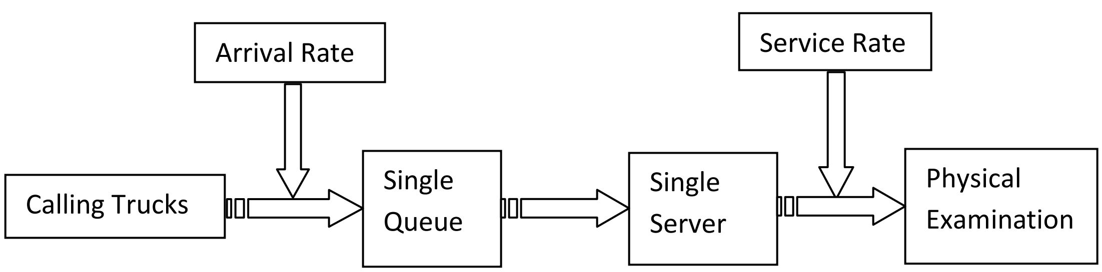

Figure 2 Structure of M/M/1 queuing model Service Mechanic

In this model the inter-arrival time and service rate follow markovian distribution or exponential distribution which is a probabilistic distributions, so this is an example of stochastic process. In this model there is only one server. In this model we make the following assumptions: Customers (trucks of imported consignment) are assumed to be patient; System is assumed to have unlimited capacity; Customers arrive from an unlimited source; and the queuing discipline is assumed to be first in first out (or first come first serve).

The various parameters that are to be evaluated in a queuing model and their formulae for this model are given below.

Utilization factor or Traffic intensity, $\rho = \frac{\lambda}{\mu}$

The following formulae are valid only if arrival rate is less than service rate.

$$f(x) = P(X = x) = \rho^x (1 - \rho),$$

where, $x = 0,1,2, \dots$ the number of customers (trucks of imported consignment) at any instant. With this formula we can find out what percentage x number of customers are in the system. If x is taken as zero the formula yields the percentage of time the server is idle.

Consequently, the Performance Measures for M/M/1 queuing result are as follows:

The expected number of customers at any time in the system:

$$L = \frac{\rho}{1-\rho} = \frac{\lambda}{\mu-\lambda}.$$

The expected number of customers in the queue at any time is:

$$L_q = \frac{\rho^2}{1-\rho} = \frac{\lambda^2}{\mu(\mu-\lambda)}.$$

From the Little's Law (or Little's formula), we know and can obtain;

Expected time a customer spends in the system:

$$W = \frac{L}{\lambda} = \frac{1}{\mu - \lambda}.$$

Expected time a customer spends in the queue:

$$W_q = \frac{L_q}{\lambda} = \frac{\lambda}{\mu(\mu-\lambda)}.$$

P-ISSN 2362-8022 | E-ISSN 2362-8030

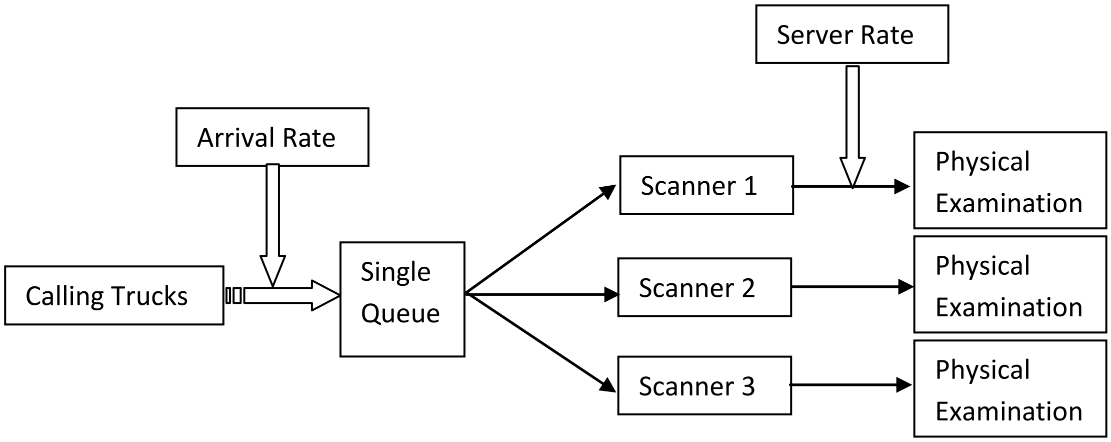

Figure 3 Structure of M/M/s queuing model

The difference between the earlier model and this model is the number of servers. This is a multi-server model whereas the earlier one was single server model. Similar to the M/M/1 queuing model, we make the following assumptions: Customers (trucks of imported consignment) are assumed to be patient; System is assumed to have unlimited capacity; Customers arrive from an unlimited source; the queuing discipline is assumed to be first in first out.

If more than one server is available when a new customer arrive (which necessarily implies that the waiting room is empty) then the incoming customer may enter any of the free servers.

Let λ and μ be the rate of the Poisson process for the arrivals and the parameter of the exponential distribution for the service time, respectively.

Assumptions:

1. s number of servers. (s > 1)
2. All servers have the same service rate μ.
3. Single queue for access to the servers.
4. Mean arrival rate λ

Let x denote the number of customers (trucks of imported consignment), then

For $x = 0$,

$$P_0 = P(x) = \left[\sum_{x=0}^{S-1}\left(\frac{\rho^x}{x!} + \frac{\rho^s}{(s-1)!\,(s-\rho)}\right)\right]^{-1}.$$

The probability of x number of customers in the system is given by $P(x)$.

For $1 \le x \le s$,

$$P(x) = \frac{\rho^x}{x!} * P_0.$$

For $x > s$,

$$P(x) = \frac{\rho^x}{s!s^{x-s}} * P_0.$$

Performance Measure for the M/M/2 queuing result are as follows

The expected number of customers in the system is:

$$L = \rho + \frac{\rho^{s+1}}{(s-1)!\,(s-\rho)^2} * P_0.$$

The expected number of customers in the queue is:

$$L_q = \frac{\rho^{s+1}}{(s-1)!\,(s-\rho)^2} * P_0.$$

The expected time a customer spends in the queue is:

$$W_q = \frac{L_q}{\lambda}.$$

The expected time a customer spends in the system is:

$$W = W_q + \frac{1}{\mu}.$$

RESULTS AND DISCUSSION

Descriptive Statistics

The summary statistics displayed in Table 1 indicates that the Scanco scan has faster service than the Nick-TC scan. The average arrival rate of imported consignment joining the queue of Scanco scan is 8.508 with a standard deviation of 1.030. The Nick-TC scan has an average arrival rate of imported consignment joining the queue of 7.222 with a standard deviation of 4.31. Also, the average service rate of imported consignment by Scanco scanner is 8.857 with a standard deviation of 2.602.

P-ISSN 2362-8022 | E-ISSN 2362-8030

Table 1 Descriptive Statistics for the Variables under the Study

Variables	Mean	Median	Tr. Mean	St. Dev.	Minimum	Maximum
Ar_Scanco	8.508	8.556	8.508	1.030	6.667	9.778
Ar_Nick	7.22	5.11	7.22	4.31	2.44	12.22
Sv_Scanco	8.857	8.850	8.857	2.603	4.750	12.750
Sv_Nick	7.45	7.75	7.45	2.75	3.25	12.13
Cm. Ar	15.73	14.44	15.73	4.06	11.00	21.67

The Nick-TC scan have average service rate of imported consignment of 7.446 with a standard deviation of 2.75. Thus, the Scanco scan has a larger average rate of arrival and service of imported consignment, and a smaller variability in the number of arrival and service of imported consignment than do the Nick-TC scan.

Basic Properties and Performance Measures for M/M/1 Queuing Model

From table 2, the Scanco scanner shows a traffic intensity of 0.961 which is greater than 0.5. This indicates that the congestion is very intense and growing. The Scanco scan has at least 24.364 number of imported consignment in the entire system with each spending an average waiting time of 2.864 hours in the entire system. Again, at least 23.403 number of imported consignment are in the queue for scan service and each spends an average waiting time of 2.755 hours in the queue excluding the imported consignment in scan service.

Table 2. Basic Properties and Performance Measures for M/M/1 Queuing Model

	Basic Properties	
QueueNotation	**M/M/1 Scanco**	**M/M/1 Nick**
ArrivalRate, λ	8.5079	7.2222
ServiceRate, μ	8.8571	7.4464
UtilizationFactor	0.960574	0.969891
Throughput	*8.5079*	*7.2222*
ServiceChannels	*1*	*1*
SystemCapacity	∞	∞
InitialState	*0*	*0*
	Performance Measures	
MeanSystemSize	*24.3636*	*32.2132*
MeanSystemTime	*2.8637*	*4.46030*
MeanQueueSize	*23.4034*	*31.2433*
MeanQueueTime	*2.75078*	*4.32602*

From table 2, the Nick-TC scanner shows a traffic intensity of 0.970 which is greater than 0.5. This indicates that the congestion is very intense, pressure signal, and growing. The Nick-TC scan has at least 32.212 number of imported consignment in the entire system and each spends an average waiting time of 4.460 hours in the entire system. Again, at least 31.242 number of imported consignment are in the queue for scan service and each spends an average waiting time of 4.326 hours in the queue excluding the imported consignment in scan service.

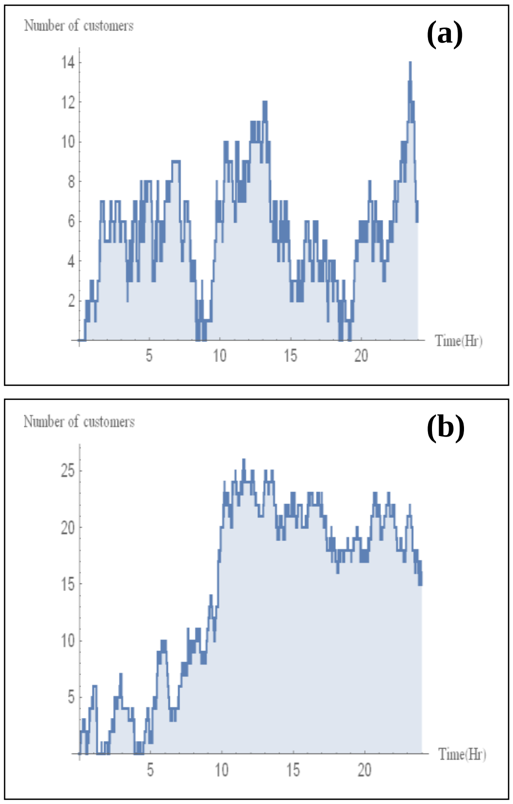

Figure 1: Simulate different types of queue: (a) Scanco (b) Nick

Basic Properties and Performance Measures for M/M/1 Queuing Model

Table 3 shows that by providing or allowing the two (2) identical independent parallel scanners to serve a single incoming queue, the result sufficiently suggest that within an hour, the number of imported consignment that arrives joining the queue is 15.730 on the average. The traffic intensity is our utilization factor of the congestion. For traffic intensity of 0.8880 which is greater than 0.5 indicates that the congestion is very intense, and is a signal of pressure.

Table 3: Basic Properties and Performance Measures for M/M/2 Queuing Model

Basic Properties	
QueueNotation	M/M/2
ArrivalRate, λ	*15.7301*
ServiceRate, μ	*8.8571*
UtilizationFactor	*0.887994*
Throughput	*15.7301*
ServiceChannels	*2*
SystemCapacity	∞
InitialState	*0*
Performance Measures	
MeanSystemSize	*8.3984*
MeanSystemTime	*0.5339*
MeanQueueSize	*6.6224*
MeanQueueTime	*0.4210*

The results indicate that at least 8.3984 number of imported consignment will be in the system, with an average waiting time of 0.5339 hours. Also, the number of imported consignment that will be in queue for scan service is 6.6224, with an average waiting time of 0.4210 hours.

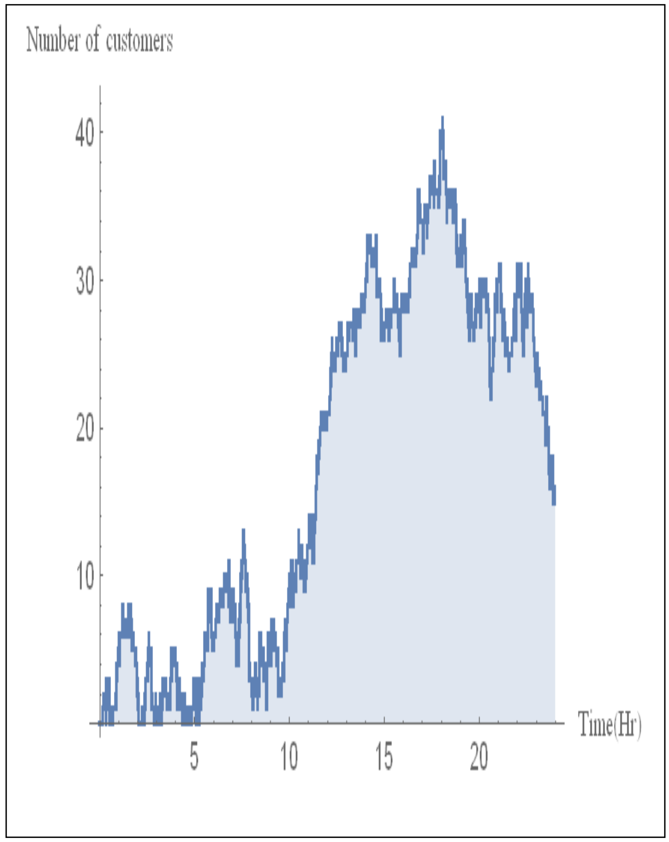

Figure 2: Simulation of M/M/2 queue model Arrival rate

CONCLUSION

The two scanners at the Tema Port were analyzed independently and found out that the Scanco Scan has a faster service rate with at least 24 trucks of consignment and an average waiting time of 2.864 in the system than the Nick-TC Scan with 32 trucks of consignment and an average waiting time of 4.460 in the system.

From the analysis of queuing theory and method, by providing or allowing the two identical independent parallel scanners (Old Scan and New Scan) to serve only one single queue where the next calling truck in queue is served by the available and idle scanner will reduce the number of trucks of imported consignment to at least 8.3984 and reduce the waiting time in the entire system to 0.5339 hours. We therefore recommend that the two scanners be put together to serve a single queue.

ACKNOWLEDGEMENT

Authors are thankful to the following students Philip Kojo Ochire and Sulemana Issifu for their hardwork that made this manuscript successful.

REFERENCES

Carisa, A., Macharisb, C. & Janssens, G.K. (2011). Network analysis of container barge transport in the port of Antwerp by means of simulation. *Journal of Transport Geography*, 19, 125-133.

Konings, R. (2007). Opportunities to improve container barge handling in the port of Rotterdam from a transport network perspective, *Journal of Transport Geography*, 15, 443-454.

Nijkamp, P. & Blaas, E. (1994). *Impact assessment and evaluation in transportation planning*. Kluwer Academic Publishers, Dordrecht.

Notteboom, T. (2008). *The relationship between seaports and the intermodal hinterland in light of global supply chains: European challenges*. Discussion paper no. 2008-10, March, OECD/ITF, Paris.

Rodriguea, J.-P. & Notteboom, T. (2009). The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management*, 36, 165-183.

Roso, V., Woxenius, J. & Lumsden, K. (2009). The dry port concept: connecting container seaports with the hinterland. *Journal of Transport Geography*, 17, 338-345.

Pedersen, M. (2005). *Optimization models and solution methods for intermodal transportation*. Report 2005-3, Centre for Traffic and Transport, Kongens Lyngby

Van Schijndel, W.-J. & Dinwoodie, J. (2000). Congestion and multimodal transport: a survey of cargo transport operators in the Netherlands. *Transport Policy*, 7, 231-241.

P-ISSN 2362-8022 | E-ISSN 2362-8030