Yard management for improving the efficiency of a Container Terminal

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Abstract
Cost and time efficient operations are vital for port management nowadays due to the increasing port competition worldwide. A critical operation in the era of continuously increasing containerized cargo traffic is yard space management of container terminals (CTs). Inadequate space in a CT's yard increases a ships turnaround time and thus the amount of sunk cost that a shipping line will have to bare. This in turn reduces a CT's attractiveness and thus competitiveness.
This paper aims to develop a generalized decision support methodology, applying queuing theory that will assist port operators to (a) model the delivery and receipt operations of a CT and (b) improve the service characteristics for specific yard management operations. Two alternative ways for improving a CT's service level are examined. The first involves the purchase of additional resources and the second involves the leveling of arrivals at the CT's gate along its operating hours.
The usage of the proposed methodology is demonstrated through its application on Thessaloniki's CT while the obtained results will be discussed

Keywords: port management, yard space management, queuing theory

Introduction

The transportation of all types of goods stored in containers resulted in the design and development of bigger and more efficient ships that exploit economies of scale, allowing for greater amounts and types of products to be transported over longer distances. Under this perspective global shipping operators prefer until today to call at a port which is able to handle efficiently a large mother vessel even if it's not situated close to main international routes. The latter poses a significant burden to ports globally and specifically to peripheral ports that do not only have to compete with mega hub ports (e.g. Rotterdam) but also with numerous other peripheral ports (e.g. Thessaloniki, Varna, and Constanta, located in South Eastern Europe). Amidst this environment of intense competition it is of critical importance for peripheral ports to continuously improve their CT operations. To be more specific, by achieving efficient delivery and receipt operations, a CT minimizes a ships turnaround time, reducing therefore its yard occupancy rates. The latter increases the CT's reliability and thus attractiveness to global shipping lines. High yard occupancy rates constitute one of the most important bottlenecks that CT's face today and can be mainly attributed to stochastic truck arrivals. To be more specific and since truck arrivals are rarely pre-advised, the CT's cannot be prepared for the trucks that will receive a container and therefore fail in serving them on time. The latter increases the average time a container resides in the terminal, and as a consequence the terminal yards fill rate.

Under this context the purpose of this paper is to develop through the application of queuing theory (see *Raman et al., 2007, Bhaskar and Lallement, 2008, Canonaco, 2007)* a generalized tactical decision framework that will assist decision makers to (a) monitor the delivery and receipt characteristics of a CT (b) improve the CT's service level by either purchasing additional resources or by allocating truck arrivals over the yards operating hours.

The rest of the paper is organized as follows. In section 2, we define the problem under study. In the third section, the methodological framework is presented and the alternative solutions are discussed in detail. The case of Thessaloniki's port CT is presented in the following section along with the results of the proposed operational policies. In the final section we sum up with conclusions and future research directions.

Problem Description

We consider a typical container terminal and we focus on its operations related to truck service. We assume that truck entry gates operate for a specific time interval every day. Truck arrival time is a random variable and it depends on the truck route before or after calling the container terminal. Moreover, the arrival rates per hour differ along the day and it very difficult to set the capacity of the loading equipment (e.g. straddle carriers) to obtain a satisfactory service level all day long. Thus, long queues are formed during the peak hours, while the straddle carrier utilization ratio is low for low arrival rate hours. This in turn may increase the CT's yard occupancy rates (since many truck drivers prefer not to enter a long queue but to return next day), posing a significant burden on the port's management as ships have to stay idle for days due to inefficient space in the yard for container discharge.

Methodological framework

In this section we analyze the structure of the methodological framework, which includes three steps and addresses (i) the current situation regarding the CT's delivery and receipt operations and (ii) the effects of two alternative intervention types on the CT's service performance.

Step 1: Identification of the mean service rate
The nominal service rate of a loading machine depends on various parameters such as machine capacity/speed, size-shape-organization of yard and driver experience. Thus, the estimation of service rate must be based on historical data of the specific or similar container terminal. The service rate of a straddle carrier for example is expressed in TEU (Total Equivalent Unit) moves per hour.

Step 2: Calculation of the mean arrival rate of a TEU per unit time
The mean arrival rate λ we will be calculated by applying Little's Law: *L= λ x W* (Sweeney, Anderson, Williams 2005), where L represents the total number of containers in the system and W represents the average number of days that a container resides in the system.

Step 3: Application of the queuing model
Required that μ>λ τhe next step will be to apply a M/Erlang(2,k) waiting line model with parameters (k,a). This model was selected based on the fact that a straddle carrier's service time is composed of the following 2 phases.

Phase 1: Time required for selecting and picking a TEU

Phase 2: Time required for transporting a TEU at the parking area and loading it on the waiting truck

We assume that the two phases are exponentially distributed. So the time of the completion of the second phase is Erlang(2,k). Naturally, the distribution type should be checked by fitting real data.

In case of Erlang(2,k), the mean service time is expressed below as:

$$E(x) = \int_0^\infty x \cdot f(x)\,dx$$

$$f(x) = \left(k \cdot e^{-k \cdot x} \cdot (k \cdot x)^{a-1}\right) / \Gamma(\alpha)$$

Where f(x) represents the Erlang probability density function, with

shape coefficient α=2.

Therefore the mean service time is expressed as:

$$E(x) = \int_0^\infty x \cdot \left(k \cdot e^{-k \cdot x} \cdot k \cdot x\right)dx = 2/k = 1/\mu$$

The parameters of the model are depicted in Table 1, while in Table 2 the models operating characteristic are presented.

Table 1: Parameters of M/Erlang(2,k) queuing model

Parameters	
Mean service time TEUs/min	1/μ
Mean service rate TEUs/min	μ
Mean arrival rate TEUs/min	λ
Parameter k	k
Standard deviation of service time(min)	$\sigma = \sqrt{2}/k$

(Ross., 2006)

Table 2: Operating Characteristics of the M/Erlang(2, k) queuing model

Operating Characteristics	
Average number of trucks in waiting line	$L_q = [\lambda^2\sigma^2 + 2(\lambda/\mu)]/2(1-\lambda/\mu)$
Average number of trucks in the system	$L = L_q + \lambda/\mu$
Average time(min) a truck spends in the waiting line	$W_q = L_q/\lambda$
Average time(min) a truck spends in the system	$W = W_q + 1/\mu$

(Sweeney, et al., 2005)

The proposed interventions for increasing service level involve: (i) the purchase of additional resources, more specifically the purchase of an additional straddle carrier and (ii) the allocation of truck arrivals along the yards operating hours, through the application of an appointment system.

i) Purchase of an additional straddle carrier

Since the purchase of an additional straddle carrier will only result in an increase of the systems mean service rate μ, the effects of this policy will be again quantified using the M/Erlang (2,k) queuing model as above.

ii) Application of an appointment system.

A truck pre-advice containing a certain time frame and the containers ID could enable the terminal to spread the workload and make the container faster available at the time the trucks arrive. It can also enable the terminal to even out peaks, by providing only a limited number of available appointments at that time *(Giuliano and* O'Brien, *2006,* Lam et al., 2007*)*.
The impact of applying the appointment method on the delivery and receipt performance of the CT will be quantified with the use of a D/G/1 queuing model. Not being able to specifically identify the operating characteristics of the D/G/1 queuing model, we will consider a G/G/1 queuing model assuming that the standard deviation of inter-arrival times is equal to zero. The latter implies deterministic inter-arrival times.
Since the G/G/1 queuing model provides only upper and lower bound values for W_q and assuming that the standard deviation of inter-arrival times is equal to zero the lower bound always takes negative values and is thus rejected. The next step is the calculation of the upper value bound for W_q (Table 4) using the mean service rate, the mean arrival rate and the standard deviation of service time obtained for the current policy (Table 3). The final step will then be to apply Little's Law in order to calculate the remaining operating characteristics of the examined queuing model using the equations of Table 2.

Table 3: Parameters of the D/G/1 queuing model

Parameters	
Mean service time TEUs/min	$1/\mu$
Mean service rate TEUs/min	μ
Mean arrival rate TEUs/min	λ
Parameter k	$2/k$
Standard deviation of service times(min)	$\sigma(s) = \sqrt{2}/k$
Standard deviation of interarrival times	0

Table 4: Upper and Lower bound of the D/G/1 queuing model

Bounds	
Lower bound	$[\lambda\sigma^2(s)-1/\mu(2-\lambda/\mu)]/2(1-\lambda/\mu)$
Upper bound	$[\lambda\sigma^2(s)+\lambda\sigma^2(a)]/2(1-\lambda/\mu)$

www.ntu.edu, the G/G/1, G/M/1, G/G/m, M/G/m/m queues (2002), 12-13

Along with the interventions proposed above, there are some general recommendations that can be applied in almost all CT's as they improve its service characteristics. These recommendations are the following:

a) Considering that a truck can transport either 2x20-foot containers or 1x40-foot container, the positioning of the 40-foot containers in the centre of the terminal and the 20-foot containers as close as possible near the berth (for exports) and near the gate (for imports) reduces the straddle carriers travel distance and the number of moves to 1 for the 20 and 40-foot containers.

b) Containers with the same voyage number, the same port of destination and the same weight class are preferably stacked on top of each other. As upon loading, one can always take the top one first reducing any false moves. This will also reduce the travel times of the straddle carriers due to the fact that the straddle carriers will follow one specific route and not travel around the terminals yard.

c) Dispersion of groups of containers over the yard to at least as many locations as the number of quay cranes working on the vessel. To avoid clashes it is always recommendable to spread containers for vessels that are planned to call the terminal in the same time window as well.

In order to achieve efficient operational design policies, data quality and availability are of pivotal importance. Information systems that collect transparent and up-to-date information provide to managers instant access to the system so he/she can continuously keep track of the situation and schedule his/her actions (Rijsenbrij and Saanen, 2006).

Case study

The examined container terminal is that of Thessaloniki's Port (Th.P.A.). The average amount of TEUs in the system is 6184 (for year 2007) of which approximately 48% represent the 20-foot containers and 52% the 40-foot containers. The average number of days a container resides in the system is 10. Three straddle carriers are utilized to transport the containers after discharge from the vessel to the storage area and another three from the storage area to the parking area and then on the trucks waiting to receive them. The nominal capacity of each straddle carrier is 14 moves per hour, while each truck transports either one 20-foot or one 40-foot container (Th.P.A IT department).

The operational characteristics of the three configurations discussed in the previous section are depicted in Table 5.

Table 5: Comparison of the Operational Characteristics of the three configurations examined.

Operating Characteristic's	Current situation	Additional straddle carrier	Appointment system
Average waiting time(min)in the System W	5.71	2.27	2.85
Average waiting time(min)in the waiting line W_q	4.28	1.21	1.43
Average number of trucks in the waiting line L_q	2.40	0.67	0.80
Average number of trucks in the system L	3.20	1.27	1.60

Charts 1 and 2 also illustrate these results. Specifically, Chart 1 presents the average truck waiting times in the system and in the waiting line, while Chart 2 shows the average number of trucks waiting in the system and the waiting line.

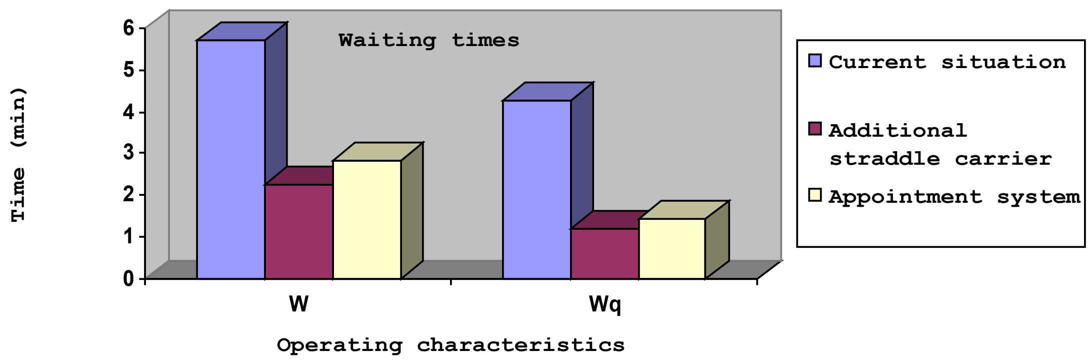

Chart 1: Average waiting times in system (W) and waiting line (Wq)

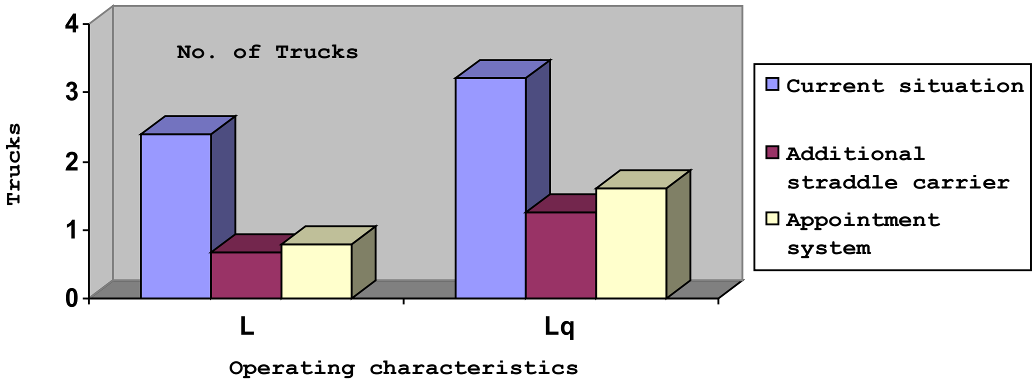

Chart 2: Average number of trucks waiting in the system (L) and in the waiting line (Lq)

The appointment system exhibits significant improvements in all operating characteristics compared to those derived from the current situation with three straddle carriers. The average waiting time in the system and the waiting line has decreased from 5.71 to 2.85 minutes and from 4.28 to 1.43 minutes respectively, while the average number of trucks in the system and in the waiting line has also decreased from 3.2 to 1.6 and 2.4 to 0.8 respectively. Considerable improvements are also observed when increasing the number of straddle carriers from 3 to 4. Specifically the average waiting time in the system and in the waiting line has decreased from 5.71 to 2.27 and 4.28 to 1.21 respectively, while the average number of trucks in the system and in the waiting line has decreased from 3.2 to 1.27 and from 2.40 to 0.67. Comparing the operating characteristics of the recommended interventions (purchase of an extra straddle carrier or the application of the appointment method) the results indicate slight improvements in truck waiting times and number of trucks waiting in favour of the option that involves the purchase of an extra straddle carrier. More specifically the average waiting times in the system and in the waiting line has decreased from 2.85 to 2.27 and 1.43 to 1.21 respectively while the average number of trucks in the waiting line and in the system from 1.6 to 1.27 and 0.80 to 0.67, respectively.

The numerical results displayed in Table 5 indicate that if the CT's management decides to purchase an extra straddle carrier it will exhibit improved operating characteristics compared to the policy that involves the application of the appointment system. Considering though (i)the cost of purchasing an extra straddle carrier that can reach the price of 850,000€ (Th.P.A IT department (ii) the upper bound value of W_q considered for the appointment method and (ii) the small differences observed between the operating characteristics of the proposed interventions, the application of the appointment system is proposed with potential of further improvement.

Finally, the considerable improvements observed in the systems service characteristics after applying the proposed interventions addresses the significance of queuing theory as a decision support tool for port management operations.

Summary and Discussion

Concluding, this paper aimed to present a simple, although effective methodological framework based on queuing theory, for improving the utilization of resources in a port's container terminal. An illustrative case study demonstrates the applicability of the methodological framework through the identification of Thessaloniki's container terminal current operating characteristics and the proposition of recommendations that increase significantly the terminals performance. Since the port has significant potential to play a role of an intermodal hub terminal for the markets of Bulgaria and Romania, optimizing Thessaloniki's container terminal operations is of pivotal importance for the city of Thessaloniki and Greece in general. Future research directions include the adoption of simulation techniques to provide more accurate modelling of non-stationary arrival rates.

References

Anderson, D.R., Sweeney, D.J., Williams, T.A., 2005, An introduction to Management Science, Thomson-South Western.

Bhaskar, V., and Lallement, P., 2008, *A four-input, three-stage queuing network approach to model an industrial system*, Applied Mathematical Modeling 33, 3465–3487.

Canonaco, P., Legato, P., Mazza, R., Musmanno, R., 2007, A queuing network model for the management of berth crane Operations, Computers & Operations Research 35, 2432 – 2446.

Giuliano, G., and O'Brien, T., 2006, The terminal gate appointment system at the ports of Los Angeles and Long Beach an assessment, Metrans Seminar, 13 September 2006.

Lam, F.S., Park, J., and Pruitt, C., 2007, *An Accurate Monitoring of Truck Waiting and Flow Times at a Terminal in the Los Angeles/Long Beach Ports,* Final Report METRANS Project AR 05-01.

Mallidis, I., 2007, The Port of Thessaloniki as an Entry Logistics Hub for S.E Europe: Prerequisites and Potential, Master Thesis, Department of Econometrics, Erasmus University Rotterdam, Rotterdam, Netherlands.

Raman, D., Nagalingam, S., Gurd, B.W., and L.G. Grier, 2009, Quantity of material handling equipment — A queuing theory based approach, Robotics and Computer-Integrated Manufacturing 25, 348–357.

Rijsenbrij, J.C., and Saanen, Y.A., 2006, *Design of system and operation of container terminals*, *Performance improvement policies, Stacking strategies,* Revision 10, 84, 88.

Ross, S., 2006, *A first course in probability, New Jersey,* Pearson, Prentice Hall.

Internet sources

Boss, S.K., 2002, *The G/M/1, G/G/1, G/G/m and M/G/m/m Queues (www3.ntu.edu.sg, 15/01/2010)*, used in order to identify the operating characteristics of the D/G/1 queuing model.