# Yard management for improving the efficiency of a Container Terminal

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JEL Classification Codes: C15

## Abstract

*Cost and time efficient port operations are vital nowadays due to the increasing port competition worldwide. In many cases, efficiency may overcome strategic positioning, i.e. a shipping line may prefer to call at a port which is able to handle efficiently a large mother vessel, and take advantage of economies of scale, even if it is not situated near to the main international shipping routes.*

*In the era of continuously increasing containerized cargo traffic, yard space management of a container terminal (CT) is of critical importance. Yard congestion constitutes one of the major problems that CTs face today and has a negative impact on their efficiency. Inadequate space in a CT yard increases a ships turnaround time and thus the amount of sunk cost that a shipping line will have to bare. Increased operating costs, reduce attractiveness and thus competitiveness.*

*Under this context the goal of this paper is to develop a decision support tool, applying queuing theory, that will assist Port Operators to (a) model the delivery and receipt operation of a CT and (b) adopt one of the following operational policies (i) purchase of an extra straddle carrier and (ii) application of an appointment system.*

*The applicability of the proposed methodology is identified through an illustrative case study. The examined container terminal may be that of Thessaloniki. The paper findings may be used to provide general guidelines and specific suggestions for improving the performance of this operation, resulting in a faster container turnover which in turn decreases container yard congestion.*

Keywords: container terminal management, yard management, capacity planning

## Introduction

Queuing theory has many applications in various applied research fields such as, production process and logistic operations, through cost and time efficient management of material flows in a system *(Raman et al, 2007), (Bhaskar and Lallement, 2008)*. It can also be applied in the field of maritime logistics as a decision support tool for port management strategies *(Canonaco, 2007),* and generally in all fields of the service provision sector.

This paper will deal with the application of queuing theory in the field of maritime logistics focusing on Thessaloniki's container yard performance. The city of Thessaloniki is geographically situated at crossroads linking the Balkans with the Western Europe and plays a strategic role in promoting Greek and foreign initiatives. E.U has recognized Northern Greece and Thessaloniki as a bridge for developing Balkan economies *(www.usconsulate.gr)*. Thessaloniki's most important asset is undeniably its port. High delays and cost inefficiencies through the Bosporus path extra 2 day's (Sony map route planner) *combined with*, natural channels for large mother vessels, short distances to Sofia and Bucharest, (approximately 300 and 700 km respectively) and efficient rail and road networks, which connect the port with the international hinterland, increase substantially Thessaloniki's port importance as an intermodal logistics hub to the Balkan's. The port is pivotal for the growth and competitiveness of Northern Greece's Economy.

It is envisioned that around the Port a significant number of companies could establish their headquarters, hence creating new job opportunities money circulation and thus economic growth. There are many examples of cities that owe their tremendous growth to their ports. One example is the city of Rotterdam. The centrality of the port of Rotterdam combined with the tax incentives that the government provides to companies and the successful privatization policies it has achieved result in the creation of corporate networks and intense economic activities.

Clearly, port operations have value added effects to the host city and country. Such a strategy could be a viable intervention for the city of Thessaloniki for overcoming one of its most important problems, namely unemployment which reaches approximately 12% (www.Greekembassy.org). The motivation of this paper derives from the above fact.

The purpose of this paper is to develop, through the application of queuing theory, a tactical decision framework that will assist decision makers to (a) quantify the service performance of a CT and (b) select among two operational policies (i) purchase of an extra straddle carrier and (ii) application of an appointment system, the one that improves the terminals overall performance.

The rest of the paper is organized as follows. In section 2, this work will describe the operations of a typical CT. In section 3 the examined queuing models will be proposed. In section 4, some general recommendations will be analyzed, while in section 5 the case study will be presented. In section 6 the results will be presented while in section 7 the manuscripts conclusions will be summarized.

## Container Terminal Operations Description

We consider a typical container terminal where containers are discharged from the ship on the Terminals quay or directly on wagons. The containers discharged on the quay will be transshipped on other vessels, thus transported with straddle carriers at a transshipment storage area, or transported by trucks and thus transferred at the Terminals storage area. The latter will then be transported by straddle carriers at the parking area and then loaded on trucks waiting to receive them. We will only deal with the containers transported by trucks. In the following section we will present all necessary steps for the development of the examined models

## Model Development

***Step 1: Identification of the mean service rate***
In this work, we focus on the service rate of the straddle carriers used to serve the trucks. The optimum productivity of a straddle carrier is expressed in TEU (Total Equivalent Unit) moves per hour (Th.P.A. IT Department).

***Step 2: Calculation of the mean arrival rate of a TEU per unit time***
The mean arrival rate $\lambda$ we will be calculated by applying Little's Law: $L = \lambda \times W$ (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 containers waits in the system.

**Table 1: Variables of Little's law equation**

| *Parameters* | |
|---|---|
| Total number of containers in the system | L |
| Average number of days a container resides in the system | W |
| Mean arrival rate of a TEU(20 foot cntr) per unit time | $\lambda$ |

***Step 3: Application of the queuing model***
Required that $\mu>\lambda$ 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 needed to select and pick the container

Phase 2: Time needed to transport a TEU at the parking area and loaded 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).

$E(X) = \int_0^\infty x f(x) dx$ = mean service time $1/\mu$, where

1) $F(x) = [ke^{-kx} * (kx)^{a-1}]/\Gamma(a)$ for a=2
2) $\Gamma(\alpha) = (\alpha-1)!$ ó $\Gamma(2) = (2-1)! = 1! = 1$ (Ross, 2006, 237)

So $E(X) = \int_0^\infty x \cdot [ke^{-kx}(kx)]dx = k^2 \int_0^\infty x^2 e^{-kx} dx = 2/k$ = mean service time $1/\mu$

The parameters of the model are depicted in Table 2, while Table 3 summarizes the operational characteristic.

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

| *Parameters* | |
|---|---|
| Mean service time TEU's/min | $1/\mu$ |
| Mean service rate TEU's/min | $\mu$ |
| Mean arrival rate TEU's/min | $\lambda$ |
| Parameter k | 2/k |
| Standard deviation of service time(min) | $\sigma = \sqrt{2}/\kappa$ |

***(Ross, 2006)***

**Table 3: Operational Characteristics M/Erlang(2,k) queuing model**

| *Operating Characteristics* | |
|---|---|
| Average number of trucks in waiting line | Lq= $\lambda^2\sigma^2+(\lambda/\mu)2/2(1-\lambda/\mu)$ |
| probability that no units are in the system | P(0)= $1-(\lambda/\mu)$ |
| Average number of trucks in the system | L= Lq+$\lambda/\mu$ |
| Average time(min) a truck spends in the waiting line | Wq= Lq/$\lambda$ |
| Average time(min) a truck spends in the system | W= Wq+1/$\mu$ |
| Pprobability that an arriving truck has to wait for service | Pw= $\lambda/\mu$ |

***(Sweeney, Anderson, Williams 2005)***

**Purchase of an extra Straddle Carrier**

The purchase of an extra straddle carrier will improve the terminals mean service rate. Required that $\mu>\lambda$ the systems performance will be again quantified with the use of a M/Erlang (2,k) queuing model.

**Application of the appointment method**

Trucks are rarely pre-advised or have an appointment (*Giuliano and* O'Brien, *2006)*. So the terminal cannot be prepared for the trucks that will pick a container. A 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.

We will quantify below, with the use of a D/G/1 queuing model the results of the appointment method. Not being able to specifically identify the operating characteristics of the D/G/1 queuing model we used the G/G/1 queuing model assuming that the standard deviation of interrarival times is equal to zero. This assumption means deterministic interrarival times. Looking into the G/G/1 queuing model we can only get upper and lower bounds for Wq because we want the arrival times to be constant we will assume that the standard deviation of the arrival times is equal to zero. The parameters and the Wq bounds are depicted on Tables 5 and 6, respectively.

**Table 5: Parameters of the D/G/1 queuing model**

| *Parameters* | |
|---|---|
| *Mean service time TEU's/min* | $1/\mu$ |
| *Mean service rate TEU's/min* | M |
| *Mean arrival rate TEU's/min* | Λ |
| *Parameter k* | 2/k |
| *Standard deviation of service times(min)* | $\sigma(s) = \sqrt{2}/\kappa$ |
| *Standard deviation of interarrival times* | Deterministic |

**Table 6: Upper and Lower bound of the D/G/1 queuing model**

| *Bounds* | |
|---|---|
| *Lower bound* | *[λ*σ2(s)-1/μ (2-λ/μ)]/2(1-λ/μ)* |
| *Upper bound* | *λ [σ2(s) + σ2(a )]/2(1-λ/μ)* |

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

By applying Little's law, the queue characteristics are shown on Table 7.

**Table 7: Application of the D/G/1 queuing model**

| *Operating characteristics* | |
|---|---|
| *Average time a truck spends in the waiting line* | *Wq* |
| *Average waiting time a truck spends in the system* | *W= Wq+1/μ* |
| *Average waiting time of a truck in the waiting line* | *Lq= λ x Wq* |
| *Average waiting time of a truck in the system* | *L= Lq + λ/μ* |

After illustrating the operating characteristics of the queuing models utilized in order to quantify the results of the aforementioned policies, this work will move further into proposing some general recommendations that improve a CT's operation characteristics.

## General Recommendations

a) Positioning of the 20-foot containers as close as possible near the berth (for exports) and near the gate (for imports). The 40-foot containers may have their point of gravity in the centre of the terminal. This reduces the travel distance and the number of moves to 1 for the 20 and 40-foot containers. A truck can transport either 2 20-foot containers or 1 40-foot container. By placing the 20-foot containers that are to be imported away from the gate the straddle carrier will have to cover high travel distances twice. For the 40 foot container a straddle carrier will only have to make one journey so placing it in the middle would be more time efficient than placing them in front of the 20 foot containers that are to be imported.

b) Building categories of stacks or piles. Containers for the same voyage number, for 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 false move. This will also reduce the travel times of the straddle carriers due to the fact that all movements and travel distances of the straddle carriers will be located in one specific route and not around the terminals yard.

c) Dispersion of groups for one vessel over the yard to at least as many locations as queue 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 window as well.

In order to achieve efficient operational design, data quality and availability are of pivotal importance. Information systems that collect transparent and up-to-date information can provide managers instant access to the system so he/she can continuously keep track of the situation and schedule their actions (Rijsenbrij and Saanen, 2006). We have to make clear that these are general recommendations that could be applied by the terminals management and whose effects have not been quantified. The next paragraphs will present two specific recommendations, an increase in the mean service rate with the purchase of an extra straddle carrier and the application of an appointment method. The results of these recommendations will be quantified with the use of two queuing models.

## Case study

An illustrative case study is presented in order to identify the applicability of the proposed methodology. The examined container terminal will be that of Thessaloniki. To specify the scope of the case study and facilitate the model formulation, 8 assumptions are postulated below.(1)the average amount of TEU's in the system is 7730 of which approximately 48% represent the 20foot containers and 52% the 40foot containers (ThPa IT department)(2)from the total number of containers we deduct 20% which represents the number of containers transhipped and transported by rail(4)The containers transhipped are stored in a specific container area and do not affect the yard occupancy rates (5) the containers transported by rail are loaded on wagons, while discharged from the ship, by a trans trainer without occupying space in the terminals yard. The latter implies that the containers which reside in the system and thus occupy space in the terminals yard are the containers transported by truck (6) Each truck can transport either one 40foot or one 20foot container(7)three straddle carriers are used to transport the containers after unloaded from the ship to the storage area and another three from the storage are to the parking area and then on the trucks waiting to receive them (8)The optimum productivity of a straddle carrier is 14 moves per hour (ThPA's IT Department). So for three straddle carriers the mean service rate is 3*14=42 container moves per hour and (8) the average number of days a container resides in the system is 10(Data obtained by ThPA's IT department).

## Results

Table 8 provides a comparison of the results of the three configurations examined in the paper.

**Table 8: Comparison of the operating characteristics of the queuing models**

| Operating Characteristic's | M/Erlang (2,k)-3 straddle carriers | M/Erlang (2,k) 4 straddle carriers | Appointment system D/G/1 |
|---|---|---|---|
| Average waiting time(min)in the System W | 5.71 | 2.27 | 2.85 |
| Average waiting time(min)in the waiting line Wq | 4.28 | 1.205 | 1.428 |
| Average number of Trucks in the waiting line Lq | 2.4 | 0.675 | 0.80 |
| Average number of Trucks in the system L | 3.2 | 1.275 | 1.6 |

Looking into the operating characteristics of the D/G/1 queuing model we observe significant improvements in all operating characteristics compared to those derived from the initial M/Erlang(2,k) with three straddle carriers. The average waiting time in the system has decreased from 5.71 to 2.85 minutes, the average waiting time in the waiting line has decreased from 4.28 to 1.428 minutes, the average number of trucks in the system has decreased from 3.2 to 1.6 and the average number of trucks in the waiting line has decreased from 2.4 to 0.8. Moving further into the comparison of the results of the recommended interventions, the application of the appointment method and the increase in the mean service rate, and before interpreting the results and derive conclusions we must indicate the factors below (1) Regarding the appointment method we have selected the worst case which represents the highest mean waiting time in the waiting line Wq= 1.428 minutes. (2) We can also see very small differences in the operating characteristics between the two methods shown in table 8 in favour of the purchase of an extra straddle carrier. (3) Finally we should consider the costs of purchasing an extra straddle carrier which can reach 850,000€ (Th.PA IT department). Taking into consideration all the parameters mentioned above we move into recommending the application of the appointment method. We do not recommend the port’s management to purchase an extra straddle carrier since the differences between the two alternatives are very small, with potential of further improvements, while at the same time the cost of an extra straddle carrier is very high

## Conclusions

This paper aimed to present the significance of queuing theory as an operational research tool applied in port operations. We have developed an illustrative case study in order to demonstrate the applicability of our methodological framework through the identification of Thessaloniki’s container terminal current operating characteristics and the proposition of recommendations that increase significantly the terminals performance. Thessaloniki’s container terminal has significant potential to play a role of an intermodal hub terminal for the markets of Bulgaria and Romania. Optimizing Thessaloniki’s container terminal 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.

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