Truck Operations Planning at a Container Terminal

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Abstract

Truck transportation represents a considerable component of cargo transportation for many port container terminals worldwide. Therefore, cost optimization of its associated operations is an important challenge for a port’s management. Moreover, the traffic of heavy-duty trucks close to the ports has a negative environmental impact that aggravates the already severe CO₂ emission pollution of port host cities. The transport related CO₂ emissions engage: (i) the emissions generated in the forward and return trip of the trucks, and (ii) the emissions generated while trucks are waiting (idle in the queue) for loading/discharge at the port gates and yard. Considering though that truck arrivals are rarely pre-advised, truck arrival rates differ throughout the day and thus it very difficult to set the capacity of the loading equipment (e.g. straddle carriers) in order to obtain a satisfactory service level for the entire day. Therefore, long queues are formulated during peak hours, where numerous trucks remain at the port’s gates with almost zero speed while generating unnecessarily high CO₂ emissions. This paper aims to develop a simulation-based methodology for evaluating tactical decisions for truck operation planning that incorporates both economical and environmental parameters. The applicability of the proposed methodology is demonstrated for the Container Terminal of the Port of Thessaloniki, Greece.

Keywords: Container terminal operations, CO₂ emissions, appointment system

1. Introduction

For the year 2004, 90% of the global exports with a value of 8.9 trillion dollars were moved by ocean, while 90% of this cargo was transported by intermodal containers (Economist, 2005). 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. the ports of Piraeus, Thessaloniki, Koper, Rijeka, Varna, and Constanta in South Eastern Europe).

Amidst this environment of intense competition in which the continuous improvement of operations especially in Container Terminals (CT) is of critical importance, there is another issue that further complicates decision making, which is the environmental impact of CT operations. Thus, in the last decade, it has become more apparent that ports need to do a better job at balancing growth and development with environmental considerations.

Air emissions management is such an important field of research. The resolution on Clean Air Programs for Ports proposed by International Association of Ports and Harbors (2007) set the basis for action. Air emissions from port-related activities are increasing and may continue to increase, as result of the growth in cargo volumes transported, unless important steps are taken.

Air pollution is a shared concern in various port communities around the world. International regulations have been developed to address emissions from ocean-going vessels, in particular oxides of nitrogen with the implementation of MARPOL ANNEX VI of International Maritime Organization. However, this regulation is not effective enough to curb vessel emissions to meet local air quality concerns in several important port cities where port-related emissions contribute significantly to the air problems for these regions.

More and more, ports are recognizing the importance of “green” goods movement and are taking important steps to address air quality issues by reducing the negative impact that diesel emissions have on the environment and public health. Most port/maritime operations depend on the durability and strength of diesel engines in trucks, cargo handling equipment, locomotives, harbor craft and ocean-going vessels. As a result, port/maritime-related activities are a source of diesel emissions. Some ports are located near urban areas that are densely populated. Depending on the topography and meteorology of the area and location relative to other sources of air emissions, air pollution from ports can potentially impact local communities. With dependence on the diesel engine along with the necessity to protect public health and the environment, there is a special need to reduce air pollution at ports.
This paper focuses on developing a methodological framework for evaluating tactical decisions for reducing air emissions in a port container terminal incorporating both economical and environmental parameters. Specifically, the paper studies CO₂ and PM emissions of trucks generated in the delivery/receipt operation. Although diesel engines are significant sources of various emissions, we selected CO₂ for its impact on greenhouse effect, and PMs due to the increasing toxicity classification by health authorities that can cause lung damage and aggravate respiratory diseases such as asthma. Moreover, the paper examines potential interventions that improve both queuing theoretic performance measures and total emissions. These interventions include capacity planning for matching loading equipment availability and stochastic demand (truck arrivals) or demand leveling through the adoption of an appointment system. Therefore, we study only organizational type of interventions which usually improve operational performance, while ignoring other interventions that reduce emissions without affecting operations, such as equipment replenishment, adoption of cleaner fuels, emission control technologies and idle-reduction technologies. Such an approach is new in the literature; however similar research efforts are discussed in next section.

The methodological tool adopted is process simulation based on Arena® software. The applicability of the proposed methodology is demonstrated for the Container Terminal of the Port of Thessaloniki, a CT that utilizes a straddle carrier direct loading/unloading system. The model validation and verification is based on the flow data of the CT for the years 2006 and 2007. The rest of the paper is organized as follows. A literature review on air emissions reduction policies and the appointment system is presented in Section 2. The description of the problem under study is discussed in section 3, while section 4 includes the model development. The case of Thessaloniki’s port CT is presented in section 5. In the final section we sum up with conclusions and future research directions.

2. Literature Review

There are several papers that propose methodologies for optimizing port/container terminal operations. However, only a few papers study the impact of low service rates of CT loading equipment on truck waiting times that causes congestion at the terminals gates. Apart from capacity planning interventions based on queuing theory principles, a new for the field practice, that of the Appointment System (AS), has been introduced as a policy for minimizing truck
waiting times through the allocation of truck arrivals along the CT’s operating hours. The AS was initially introduced in the health sector, for improving patient waiting times. The theoretical bases of appointment system was set by Lindley (1952) that used a G/G/1 queuing model with one serving point, considering a general distribution for calculating inter-arrival times. He concluded that a system where arrivals where scheduled in fixed time intervals where more efficient compared to a system where arrivals where stochastic. Brahimi and Worthington (1991) considered a finite capacity, multi-server queue, with inhomogeneous arrival rate and discrete service time distribution. They initially aim to develop a multi-server queuing model for systems with discrete service time distributions and then formulate a methodology for using discrete distributions to estimate continuous service time distributions to some sufficient degree of accuracy. Denton and Gupta (2003) developed a two stage stochastic linear programming model in order to determine the optimal appointment times for a sequence of jobs with uncertain durations. More recently, Huynh and Walton (2008) aim to regulate the number of trucks that a CT should handle in order to maximize the efficiency of the AS applied, while Namboothiri and Erera (2008) aim to identify the effect of applying an AS on the productivity and thus profitability of a drayage company. They propose an optimization based scheduling model in order to determine the optimum set of appointment reservations for a truck fleet and the best routes and schedules of truck fleets given a predetermined set of appointments. This may reduce congestion, increase cargo movements and thus profitability for the drayage company. Finally, Tsitsamis (2009) examines the implementation of an AS in a specific CT and provides guidelines for optimization of its operation based on extensive simulation.

Finally, the research on environmental impact of truck congestion in ports is limited. Specifically, Giuliano and O’Brien (2007) discuss the environmental impact of truck congestion at the Ports of Los Angeles and Long Beach, in terms of operational performance and truck emissions generated. They investigate whether the application of an AS may reduce truck queues at the terminals gates and thus truck emissions based on extended interviews with port and container terminal managers, trucking industry representatives and long shore labor, public agency representatives. The main difference with our research is that our work moves further into quantifying the environmental impact of applying an AS, in terms of various gasses generated by heavy duty trucks at CTs, through the development of a generalized methodology, based on simulation experimentation.
3. Problem Description

We consider a typical port CT and we focus on its operation related to delivery/receipt of containers to/from trucks. Figure 1 depicts the operation under study. The truck arrives at the terminal’s gate, delivers the necessary documents and waits for the IT system to assign an empty seat in the parking area (queue #1). The truck is driven to a specific place in the terminal’s yard and waits for the loading equipment (e.g. straddle carrier) to load or unload the container (queue #2). When the service operation is completed, the truck departures, receives the load documents and pass through the exit gate (queue #3). Thus, the system includes three servers and the trucks are served in all of them following the same sequence.

![Figure 1. Container Loading/Unloading Operation](image)

In our basic scenario, truck arrivals are not pre-advised; thus truck arrival rates are not controllable and depend only on the truck route before or after calling the container terminal. Thus, truck arrival time is not only a random variable, but also its mean value fluctuates along the day (non-stationary stochastic process).

On the other hand service rates in three servers depend on each server’s capacity which is measured by the number of activated gates and the number of cranes or straddle carriers operating throughout the terminal’s working hours. These rates cannot be fully adjusted as well, due to limitations on the number of available cranes/straddle carriers and the working schedules of operators. Thus, matching of demand and service is not an easy process and it is very difficult...
to set the required capacity for obtaining a satisfactory service level all day long. Thus, long queues are formed during the peak hours, while the equipment 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.

This chain effect for container terminal operational performance, also affects the urban environment pollution caused by the emission generated from all these truck with their engines running idle while waiting in queues. Thus, the most important performance measure from queuing theory is the average total waiting time in CT’s queues, which can be converted to CO₂ and PM emissions, taking into account the hourly emissions of typical heavy duty truck engines running idle.

4. Model Development

The problem described in the previous section is a typical queuing problem with three consecutive servers. However, the solution of a problem with non-stationary arrival process is not possible by adopting queuing theory. For this reason we opted to develop an appropriate simulation model and run alternative “what-if” scenarios using this model. To this end, we employed the Arena® process simulation tool. Figure 2 depicts the relative model, which incorporates the three-stages delivery/receipt operation of the CT presented in the previous section.

The proposed interventions for improvement of the service level in this system involve: (i) the purchase of additional resources (one or two additional straddle carriers) and (ii) the allocation of truck arrivals along the yards operating hours, through the application of an appointment system.

The model of Figure 2 can be used for studying policies related to increased or decreased capacity of servers (straddle carrier) by altering the model parameters accordingly. However, to model policies that incorporate appointment systems, the simulation model was expanded with two more modules that a) match arrivals with specific time windows (the width of the window is a decision parameter) and b) reschedule trucks that do not arrive within their appointment window (Tsitsamis, 2009).
Figure 2. The generalized Arena® simulation model

5. Case Study

The examined container terminal is that of the Port of Thessaloniki, Greece. Figure 3 illustrates the layout of the container terminal of Thessaloniki that was used for the graphical representation of the Arena® simulation model. The CT has two gates for trucks entering the yard and one gate for trucks departing. Three straddle carriers are utilized to transport the containers between the storage area and the parking area for trucks. 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. Service times in gates are quite shorter than loading/unloading times. Thus, the loading/unloading server of Figure 1 is the bottleneck in the system.

The CT is open for trucks for container delivery/receipt 12 hours a day from 08:00 to 20:00. Figure 4 depicts the mean arrival rate for the quarters of an hour. These values are obtained by analyzing historical data of the port for the period 2006-07 (Mallidis, 2007). We observe that arrival rate varies from 1-2 trucks per quarter in the morning and evening to 10 trucks per quarter around noon and thus, capacity planning is a cumbersome task.
The generalized model of Figure 2 was adapted to include the particular characteristics of the CT under study and the real system values of its parameters has been entered in Arena®. Model validation was assessed by comparing model performance metrics, obtained from model test runs, to their counterparts in the system under study. Model verification was done by inspecting simulation program logic, by performing simulation test runs and inspecting sample path trajectories, and by performing simple consistency checks based on queuing theoretic relations.
Although the simulation program generates several results regarding the system operation, we only need the mean total flow time for a truck from the time it arrives before the input gate and enters the relative queue to the time it leave the container terminal. Figure 5 depicts the evolution of mean total flow time along the working hours of a day.

Figure 5. Mean total flow time along days working hours.

Figure 5 also depicts the mean total flow time evolutions for the other two interventions we examine, namely (i) increasing straddle carrier capacity by one, and (ii) adopting an appointment system.

To convert these total flow times into CO₂ and PM emissions we use the technical data appear in Khan et al. (2006). They report that the engines of heavy-duty trucks emit 4484g CO₂ per hour running idle, while these emissions increase by 25% when air-conditioning is used. They also report that PM emissions depend on the type of fuel injection used. Specifically, mechanical fuel injection (MFI) equipped vehicles emit 4gr PMs per hour running idle, while vehicles with electronic fuel injection (EFI) emit only 1gr/hr.

Tables 1 and 2 summarize the daily and annual CO₂ and PM emissions respectively for the current CT operation as well as the corresponding emissions after adopting each one of the proposed interventions. The annual emissions are calculated assuming air condition operations for 25% of time. The results of Table 2 are obtained assuming that half of the trucks are using MFI and the other half EFI.
Table 1. Total truck CO2 emissions [tn]

<table>
<thead>
<tr>
<th>Options</th>
<th>Current situation</th>
<th>Extra straddle carrier</th>
<th>Appointment system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Emissions</td>
<td>64.2</td>
<td>15.2</td>
<td>19.7</td>
</tr>
<tr>
<td>Daily Emissions (with air-condition)</td>
<td>80.2</td>
<td>19.0</td>
<td>24.6</td>
</tr>
<tr>
<td>Annual total emissions</td>
<td>24544.7</td>
<td>5813.9</td>
<td>7535.5</td>
</tr>
</tbody>
</table>

Table 2. Total truck PM emissions [kg]

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Current situation</th>
<th>Extra straddle carrier</th>
<th>Appointment system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Emissions</td>
<td>35.8</td>
<td>8.5</td>
<td>11.0</td>
</tr>
<tr>
<td>Daily Emissions (with air-condition)</td>
<td>44.7</td>
<td>10.6</td>
<td>13.7</td>
</tr>
<tr>
<td>Annual total emissions</td>
<td>13684.6</td>
<td>3241.5</td>
<td>4201.3</td>
</tr>
</tbody>
</table>

The results displayed in tables 1 and 2 indicate that the adoption of the appointment system apart from the improvement in the CT’s operation reduces the annual emissions generated by idle operation of truck engines by 17009 tn of CO2 and 9483 kg of PMs. The reduction in annual CO2 and PM emissions are also huge in case the CT uses an additional straddle carrier (18731tn and 10443kg respectively). However, the availability of such an extra carrier has a considerable cost (the cost of purchasing a straddle carrier that can reach the price of 850K€).

6. Summary and Discussion

Concluding, this paper aimed to present an effective methodological simulation-based framework for reducing the environmental impact (specifically CO2 and PM emissions) caused by ineffective truck loading/unloading operations. 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 improve significantly the terminal environmental burden. Future research directions include the
determination of more emissions generated by other transportation means in a container terminal, as well as the examination of policies to reduce them.

References


