IMPACT OF EXTERNAL TRUCKS' SERVICES AT THE PORT CONTAINER TERMINAL ON EXHAUST GAS EMISSIONS

Ivana Vukićević Biševac[a,*], Ivana Jovanović[a], Miloš Nikolić[a], Nataša Vidić[b], Katarina Vukadinović[a]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia

[b] University of Pittsburgh, Swanson School of Engineering, Industrial Engineering Department, Pittsburgh, PA, USA

Abstract: *We investigated the export containers delivery process to a port container terminal (PCT) by external trucks for the purpose of loading onto container ships. Containers randomly arrive by trucks to a PCT, while they are shipped according to a predefined schedule of container ships. We analyzed the arrival and service processes of trucks at the entrance gate, inspection and unloading points. In addition, we analyzed the differences between various truck service scenarios, determined the total waiting time of trucks for each scenario and observed the impact of each scenario to the levels of emissions of exhaust gases produced by these trucks.*

Keywords: *port container terminal, truck turnaround time, emission reduction.*

1. INTRODUCTION

In recent years, we are witnessing the growth of traffic at port container terminals (PCTs), as well as the higher costs of transportation, material handling equipment and labor (Vukićević Biševac et al. 2021). The increase in the carrying capacity of container ships is affecting the phenomenon „peaks in truck arrivals for delivering or picking up a container" discussed by Lange et al. (2017).

In recent literature, little attention has been paid to the problem of congestion at PCTs, as well as the problems of pollution and long truck turnaround times that arise as a result. In recent years, a number of measures have been proposed in order to reduce queues at the entrance/exit gate and congestion within a PCT.

* i.vukicevic@sf.bg.ac.rs

Previous research can be divided into two groups. The first group consists of research addressing measures to increase the number of gate lanes and the number of yard cranes.

The second research group considers measures related to the development of a system for TAM (truck arrival management) in order to smooth the peaks in truck arrivals. These systems are most often based on tariff/toll pricing policies (TTPP), terminal appointment system (TAS) and vessel dependent time windows (VDTWs) (Ma et al. 2019).

2. PROBLEM DESCRIPTION

The paper analyzes the flow of export containers that are delivered to the PCT by external trucks and shipped out by container ships. There are often queues, both in front of the entrance gate and inside the PCT. The queues at the entrance gate impact the queues inside the terminal, which leads to congestion. Congestion affects the increase in waiting times for trucks and the consequent increase in truck turnaround times at the PCT. While waiting to be unloaded, trucks emit exhaust gases that contain numerous pollutants (CO, NO_x, CO_2, CH_4, N_2O, PM, etc.) (Jin et al. 2021; Ma et al. 2019).

Trucks arrive at the entrance gate and wait for the first free entrance ramp to enter the PCT. Once they enter, they wait for the inspection of cargo/containers. After the cargo control/inspection is completed, the truck arrives at the beginning of the container yard, which is a designated storage area for export containers in a PCT before they are loaded to the ships. The truck waits for the first available yard crane to unload the container, and then leaves empty toward the exit gate. The time from the truck's arrival (or joining the queue) at the entrance gate to leaving the PCT is called the truck turnaround time at the PCT. Figure 1 shows the flow of export containers.

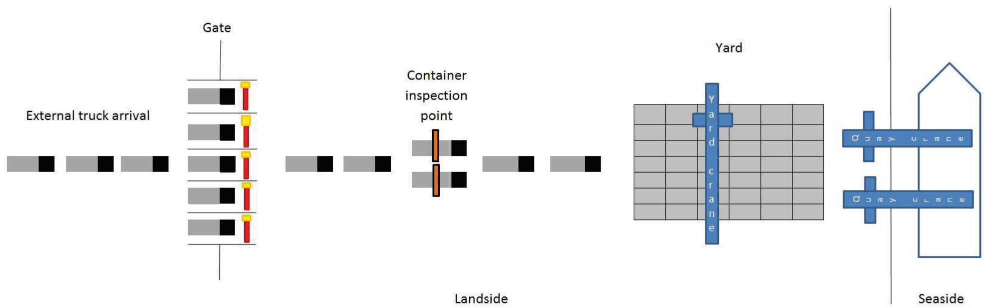

Figure 1. Schematic representation of the flow of export containers at a PCT

The PCT operator has a goal to shorten the total service time within the terminal for all users (Vukićević Biševac et al. 2021), including the truck turnaround times, and thus to reduce the pollution that occurs as a result of waiting for service.

The following chapter analyzes the impact of different arrival/service rates or intensities at the entrance gate, inspection point and unloading by yard cranes on trucks waiting times. Based on the obtained waiting times of trucks, we calculated (quantified) the corresponding pollution quantities/levels.

3. SERVICE OF EXTERNAL TRUCKS WITHIN THE 3- STAGE SERIES QUEUING SYSTEM

We implemented a discrete event simulation to study the performance of the described queuing systems at the PCT. The arrivals of trucks carrying export containers are determined by the schedule of container ships. We focused our analysis to the arrival of trucks with containers that are bound to one ship.

Ma et al. (2019) stated that the arrival of the external trucks is a non-homogeneous Poisson process that can be transformed into a piecewise-constant non-homogeneous Poisson process in time periods that are sufficiently short. Ioannou et al. (2001) stated that some ports use cutoff times for each ship, after which cargo bound to the one ship is no longer received, in order to meet ship departure schedules and operate efficiently. Ioannou et al. (2001) observed and simulated trucks' arrivals during the three days before the cutoff time. As a design consideration, Ioannou et al. (2001) used arrivals of external trucks with export containers: 0.2, 0.5 and 0.3, meaning 20% of trucks arrived during the first day, 50% arrived during the second day, and 30% during the third day.

In this paper we assumed that trucks bound to one ship arrive during the five days period. We assumed that the PCT operates for 24 hours, 7 days a week. We also assumed that the service of trucks is performed within a queuing system as FIFO (first in first out) service discipline, i.e., the first truck that arrived would be the first one served.

We assumed trucks' arrivals of 0.1, 0.15, 0.45, 0.25 and 0.05 for the five days. We assumed that trucks interarrival times were modeled by Exponential distribution (Poisson arrivals) with parameters: λ_1 = 5 trucks per hour during the first day, λ_2 = 7 trucks per hour during the second day, λ_3 = 20 trucks per hour during the third day, λ_4 = 10 trucks per hour during the fourth day, λ_5 = 2 trucks per hour during the fifth day. Using these values of arrival rates allowed us to achieve cumulative arrivals like the S-shaped curve, presented by Daganzo (2003). The PCT operator can serve approximately 1000 trucks during the five days interval, as Chang et al. (2012) stated to be the average number of containers loaded on one ship in a PCT.

Service times at three stages (phases) in the PCT were modeled as follows:

• Phase I is a service performed at an entrance gate. We assumed that the service time at an entrance gate is exponentially distributed with the parameter μ_1.

• Phase II is a service performed at an inspection point. Yoon (2007) analyzed service time at the PCT inspection point and stated that it is exponentially distributed. Service time at phase II is exponentially distributed with the parameter μ_2.

• Phase III is a service performed by a yard crane. According to Petering et al. (2008) the time taken by a yard crane to handle a single container can be modeled by a triangular distribution. The service time of a yard crane is modeled by a triangular distribution with parameters (μ_{3a}, μ_{3b}, μ_{3c}), where μ_{3a} equals the smallest, μ_{3b} equals the most often (mode) and μ_{3c} equals the largest service rate.

3.1 Simulation results

The simulation was performed using Microsoft Excel with trucks' daily arrival rates λ_1, λ_2, λ_3, λ_4 and λ_5 (as described in the previous section) and the total of 1036 trucks arrived during the simulated five days period. Using the same arrival rates we simulated trucks' service within the PCT with different service rates in individual phases of service μ_1, μ_2,

μ_{3a}, μ_{3b} and μ_{3c} (the values are given in Table 1 below). Values for varying μ_2 correlate with service rates at inspection point given by Yoon (2007).

We recorded the following: the arrival times of trucks at the entrance gate, the waiting time in front of the entrance gate, the moments of entrance and waiting times for each phase of service, as well as the moments of exit from the last phase of service.

The average trucks waiting times W_{qi} in individual phases of service depending on the service rates μ_i, i = 1, 2, 3 are shown in Table 1. From the obtained results it can be noticed that when the service rates are increased, the waiting times W_{q1} and W_{q2} are decreased, and the waiting time W_{q3} is increased. Also, it is interesting to notice the results of the scenarios 7, 7a and 7b. In these scenarios only the service rate μ_2 increases. Comparing the scenarios 7 and 7a we can see that W_{q1} is the same, W_{q2} decreases and W_{q3} increases. The similar conclusions can be done comparing the scenarios 7a and 7b, as well as 8 and 8a.

Table 1. Average waiting time per truck

<table>
<tr><th>Scenario</th><th>μ_1 [truck/h]</th><th>μ_2 [truck/h]</th><th>μ_{3a} [truck/h]</th><th>μ_{3b} [truck/h]</th><th>μ_{3c} [truck/h]</th><th>W_{q1} [h]</th><th>W_{q2} [h]</th><th>W_{q3} [h]</th></tr>
<tr><td>1</td><td>12</td><td>12</td><td rowspan="12">17.6</td><td rowspan="12">30</td><td rowspan="12">50</td><td>5.4737</td><td>2.9216</td><td>0.01046</td></tr>
<tr><td>2</td><td>15</td><td>15</td><td>1.7421</td><td>2.0360</td><td>0.0136</td></tr>
<tr><td>3</td><td>16</td><td>16</td><td>1.1144</td><td>1.5841</td><td>0.01516</td></tr>
<tr><td>4</td><td>17</td><td>17</td><td>0.6665</td><td>1.1906</td><td>0.01628</td></tr>
<tr><td>5</td><td>18</td><td>18</td><td>0.3468</td><td>0.9500</td><td>0.01738</td></tr>
<tr><td>6</td><td>19</td><td>19</td><td>0.1823</td><td>0.6820</td><td>0.01885</td></tr>
<tr><td>7</td><td rowspan="3">20</td><td>20</td><td rowspan="3">0.1093</td><td>0.4143</td><td>0.0211</td></tr>
<tr><td>7a</td><td>21</td><td>0.2819</td><td>0.02291</td></tr>
<tr><td>7b</td><td>22</td><td>0.1927</td><td>0.02536</td></tr>
<tr><td>8</td><td rowspan="2">21</td><td>22</td><td rowspan="2">0.0832</td><td>0.1936</td><td>0.02516</td></tr>
<tr><td>8a</td><td>23</td><td>0.1337</td><td>0.02675</td></tr>
<tr><td>9</td><td>22</td><td>23</td><td>0.0680</td><td>0.1308</td><td>0.02665</td></tr>
</table>

Figure 2 shows the cumulative diagrams of arrival and service of external trucks at the PCT. We can observe the formation of queues before the first and the second service phases; we do not observe large queues in front of the third phase.

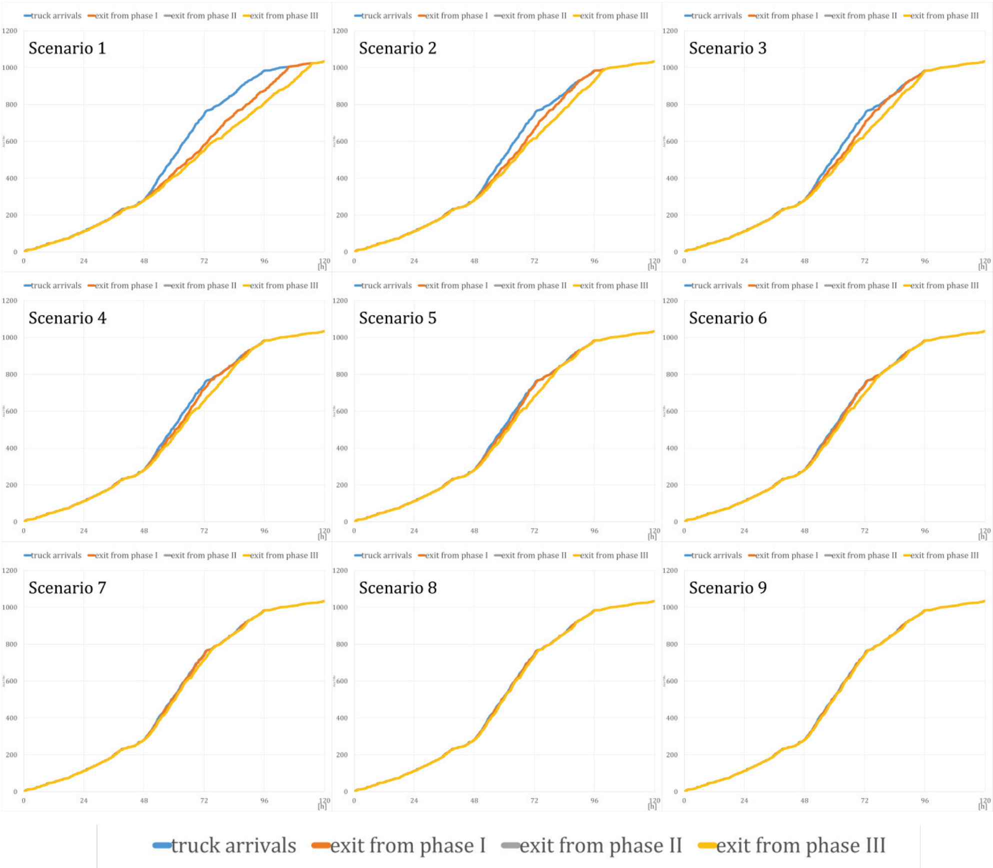

Figure 2. Arrivals and service within three phases for various scenarios

4. COST OF CARBON EMISSIONS GENERATED BY TRUCKS AT THE PCT

During the five simulated days the total of 1036 trucks delivered export containers. The total waiting time (W) for all 1036 trucks is calculated as given in (1) and presented in Table 2.

$$W = W_1 + W_2 + W_3 = 1036\,(W_{q1} + W_{q2} + W_{q3}) \qquad (1)$$

Jin et al. (2021) calcualted carbon emissions generated by one truck in each second based on the data recorded in container ports in Southern China for 83582 trucks (as given in (2)).

$$e = sp + (wav + 0{,}5C_dA\rho v^3 + wgC_r cos\theta v + wgvsin\theta v)/\varepsilon\eta \qquad (2)$$

where:

$s -$ specific fuel consumption, $p -$ engine power, $v -$ average speed, $w -$ average weight, $a -$ acceleration , $\rho -$ air density, $\theta -$ angle of slope, $A -$ frontal surface area of the truck, $g -$ gravity, $C_r -$ coefficient of rolling resistance, $C_d -$ coefficient of drag, $\varepsilon -$ truck drivetrain efficiency, $\eta -$ efficiency of engine.

Then, based on the calculated carbon emissions generated by trucks in each second and the price of carbon per Kg (estimaed by Ricke et al. 2018), they obtained an average carbon emissions cost per hour (C), which equals USD 1,348 per hour for external trucks.

Based on the total waiting time (W) obtained by the simulation and the average carbon emission cost (C), we calculated the total cost of carbon emissions ($EC = W \cdot C$) for all scenarios. These costs are given in the last column of Table 2. Comparing the scenarios 1 and 2 we can notice that when μ_1 and μ_2 are increased from 12 to 15 trucks per hour the total cost of carbon emissions decreased for more than 50% $\left(\frac{11738.88-5295.22}{11738.88} \cdot 100\ \%\right)$. Also, comparing the scenarios 2 and 3 we can see that the total cost is decreased for 28.4%. The trend of decreasing of the total cost continues to the last scenario, which has the total cost of 314.85$.

Table 2. Total cost of carbon emissions for each scenario

Scenario	W_1 $[h]$	W_2 $[h]$	W_3 $[h]$	W $[h]$	EC $[USD]$
1	5670.75	3026.78	10.84	8708.37	11738.88
2	1804.82	2109.30	14.09	3928.20	5295.22
3	1154.52	1641.13	15.71	2811.35	3789.70
4	690.49	1233.46	16.87	1940.82	2616.23
5	359.28	984.20	18.01	1361.49	1835.29
6	188.86	706.55	19.53	914.94	1233.34
7	113.23	429.21	21.86	564.31	760.69
7a		292.05	23.73	429.02	578.32
7b		199.64	26.27	339.14	457.17
8	86.20	200.57	26.07	312.83	421.70
8a		138.51	27.71	252.42	340.26
9	70.45	135.51	27.61	233.57	314.85

5. CONCLUSIONS

We analyzed the impact of different service rates or intensities of entrance gate, inspection point and yard cranes on waiting times of trucks, as well as on pollution that occurs as a result of waiting.

Based on the obtained results, we can conclude that even with a small increase in the intensity of service at the entrance gate and the inspection point, the emission of harmful gases from external trucks can be significantly reduced. Large investments are not required in order to shorten the service and waiting times of trucks. Increasing the intensity of service is also possible by changing some procedures at the entrance gate or by implementing new technologies at the inspection point.

In this paper, we only analyzed the incoming flow of trucks/containers to the PCT. The congestion at the PCT can as well be influenced by the trucks transporting import containers from the PCT. Our future research will include both directions, as well as congestion due to the flow of trucks within the PCT.

ACKNOWLEDGMENT

This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia [grant number TR36002].

APPENDIX A

[$s = 70$ g/kw. h, $p = 220$ kw, $v = 5\ km/h$, $a = 0\ m/s^2$, $\rho = 1{,}293 kg/m^3$, $\theta = 0°$,
$A = 4\ m^2$, $g = 9{,}788\ m^2/s$, $C_r = 0{,}012$, $C_d = 0{,}9$, $\varepsilon = 0{,}9$, $\eta = 0{,}45$]

REFERENCES

[1] Chang, Y.-T., Tongzon, J., Luo, M. and Lee, P.T.-W. (2012). Estimation of Optimal Handling Capacity of a Container Port: An Economic Approach, Transport Reviews, 30(2), 241–258. https://doi.org/10.1080/01441647.2011.644346

[2] Ioannou, P., Jula, H., Liu, C.-I., Vukadinovic, K., Pourmohammadi, H., Dougherty E.Jr. (2001), Advanced Material Handling: Automated Guided Vehicles in Agile Ports. CCDoTT Technical Report, Center for Advanced Transportation Technologies, University of Southern California, CA, USA.

[3] Jin, Z., Lin, X., Zang, L., Liu, W., & Xiao, X. (2021). Lane Allocation Optimization in Container Seaport Gate System Considering Carbon Emissions. Sustainability, 13(7), 3628. https://doi.org/10.3390/su13073628

[4] Lange, A.-K., Schwientek, A. K., & Jahn, C. (2017). Reducing truck congestion at ports—Classification and trends. Digitalization in Maritime and Sustainable Logistics: City Logistics, Port Logistics and Sustainable Supply Chain Management in the Digital Age. Proceedings of the Hamburg International Conference of Logistics (HICL), 24, 37–58. https://doi.org/10.15480/882.1484

[5] Ma, M., Fan, H., Jiang, X., & Guo, Z. (2019). Truck Arrivals Scheduling with Vessel Dependent Time Windows to Reduce Carbon Emissions. Sustainability, 11 (22), 6410. https://doi.org/10.3390/su11226410

[6] Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018). Country-level social cost of carbon. Nature Climate Change, 8 (10), 895–900. https://doi.org/10.1038/s41558-018-0282-y

[7] Yoon, D.-G. (2007). Analysis of truck delays at container terminal security inspection stations, New Jersey Institute of Technology, Doctoral dissertation. https://digitalcommons.njit.edu/dissertations/826

[8] Вукићевић Бишевац И., Николић М., Ђорђевић Д., Вукадиновић К. (2021). Моделирање опслуживања контејнера у лучким терминалима, Водопривреда, 53 (309-310), стр. 75-84, ISSN 0350-0519.