Simulation of novel algorithms to reduce truck congestion at container terminals

Original
Simulation of novel algorithms to reduce truck congestion at container terminals / Caballini, C., Sacone, S.. - ELETTRONICO. - (2021), pp. 1-6. (2021 7th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS) 16-17 June 2021) [10.1109/MT-ITS49943.2021.9529323].

Availability:
This version is available at: 11583/2922278 since: 2021-09-09T01:04:10Z

Publisher:
IEEE - Institute of Electrical and Electronical Engineering

Published
DOI:10.1109/MT-ITS49943.2021.9529323

(Article begins on next page)

Simulation of novel algorithms to reduce truck congestion at container terminals

Claudia Caballini
DIATI Department - Transport Systems
Politecnico di Torino
Torino, ITALY
claudia.caballini@polito.it

Simona Sacone
DIBRIS Department
University of Genova
Genova, ITALY
simona.sacone@unige.it

***Abstract*—Efficient managing truck flows has become a challenge for container terminals that have to maintain a high productivity while guaranteeing high service levels to truckers. Moreover, the increasing quantity of cargo to be handled in short time windows introduces congestion and security issues. This paper deals with the definition and simulation of various algorithms implementing a truck management system, with the objective or reducing congestion outside and inside the terminal, so guaranteeing security standards. An extensive simulation campaign has been performed on real data sets provided by an important Italian container terminal, demonstrating the effectiveness of the proposed mathematical approach in reducing terminal congestion and security issues. The designed methodology is general enough to be effectively applied in other container terminals realities located worldwide.**

***Index Terms*—maritime terminals, container transportation, congestion reduction, discrete event simulation, algorithms**

I. INTRODUCTION

International seaborne trade has risen significantly during the past decades. This has forced seaports to deal with increasing quantity of cargo and, consequently, to adapt their capacity and productivity to meet the growing demand. If not properly managed, truck flows cause long queues at gates and large quantity of trucks inside the terminals, which, in turn, limits the efficiency of the terminal and also generates serious external costs, such as congestion, air pollution, noise and accidents.

In the past years a lot of attention has been paid in the literature to study and optimize terminal vessel and yard subsystems, but not so much investigation has been dedicated to analyse and reduce the negative impacts of the truck cycle on terminals performances.

The objective of the present paper is the design and simulation of two algorithms devoted to improve the performance of the truck cycle in container terminals. More specifically, the objectives are the reduction of terminal congestion and traffic peaking impact on terminal operations, removing excess/non-productive traffic from RTG(Rubber Tyred Gantry crane)/RS (Reach Stacker) working areas, improving safety for staff and truckers, increasing trucker service experience.

The methodology has been tested in a large container terminal located in Northern Italy, where a "Truck Management System" informative module implementing the proposed algorithms has been successfully implemented. This application currently allows to simulate the terminal operations under different operational logics.

The literature addressing the topic of congestion issues at ports/terminals has gained increasing attention by researchers [1], [2], [3]. Talley and Ng [4] analyze port multi-service congestion, whereas Hyland et al. [5] examines a new hybrid intercontinental freight transport alternative as an alternative to conventional ocean vessel transport calling at busy ports that may be subject to disruptive delays. Veloqui et al. [6] provide a queuing model to assess the congestion issue in the port of Naples. The study pointed out that a solution could be obtained by decreasing simultaneously the service time at the gate and in the yard. In the work of Gang et al. [7] a method called "Vessel dependent time windows (VDTWs)" to control truck arrivals is proposed to reduce the gate congestion. A conventional Genetic Algorithm (GA), a multi-society GA, and a hybrid algorithm using GA and Simulated Annealing are used to solve the optimization problem. A case study based on a real container terminal in China is performed, which shows that the VDTWs method can flatten truck arrivals and significantly reduce the gate congestion. Motono et al. [8] developed a multi-server queueing model to address landside congestion in the Japanese ports of Nagoya and Hakata. The obtained results show that trailers travel times can be considerably reduced if improper transportation documents are eliminated.

The paper of Zhen [9] investigates the concept of yard congestion quantitatively in the context of yard truck interruptions, and develops a combination of probabilistic and physics-based models for truck interruptions.

Caballini et al. [10] present a mathematical model to assign appointments to the terminal gate opening time slots with the goal of guaranteeing a predefined service level to haulers while minimizing congestion inside the terminal. Later, the same authors [11] propose a combined data mining optimization approach to manage trucks operations in container terminals with the use of a TAS (Truck Appointment System).

When dealing with operations characterized by a high degree of complexity, such as container terminal operations, simulation represents an effective tool to support decision-making processes. Over the past 50 years the use of simulation models has been increasingly favoured in the development of ports and more specifically of container terminals [12]. Most of the research literature addresses operational issues, such as [12], Castilla et al. [13], [14], Meng et al. [15]

The remainder of this paper is organized as follows. Section II describes in more detail the problem under investigation. In Section III the two novel algorithms to address terminal congestion are presented, whereas Section IV reports the results obtained on the real data sets of an Italian container terminal. Finally, Section V provides some concluding remarks.

II. Problem description

As it has already been pointed out in the Introduction, the considered framework is that of maritime terminals for containerized transportation with specific focus on the operations of trucks inside the terminal. In Figure 1, a general structure of a maritime container terminal is depicted, in which the areas devoted to the different transportation modes, i.e., maritime, rail, and road transportation, are identified. The interest of this work is devoted to road transportation and, then, to the movements of trucks between their entrance/exit gate and the terminal yard. Specifically, the yard is always subdivided into sets of slots identified as areas and the different operations that trucks have to perform are addressed to areas of the yard.

More precisely, the processes that make up a generic truck cycle in a container terminal have the following features. Each truck may perform from 1 to 4 actions (also indicated as movements) that consist in the delivery of 1 or 2 containers (export operations) and/or the pick-up of 1 or 2 containers (import operations). In Figure 1 the most complex case (also called "double move"), in which two export and two import containers are managed, is considered.

Before entering the terminal, the trucker usually has to perform some documentary activities (pre-gate activities, denoted with number 1 in Fig.1), after which it can access the terminal gate (number 2 in Fig.1); it frequently happens that the truck has to queue to perform the gate-in. Once entered the terminal, the truck can leave the two export containers (activity 3 and 4 in Fig.1) in their corresponding areas, and then pick up its import containers (activities 5 and 6 in Fig.1). When all the required operations have been carried out, the truck can exit the terminal (i.e., gate-out, activity number 7).

Note that, in Fig.1 some particular terminal equipment has been depicted (such as RTG and RMG-Rail Mounted Gantry cranes, or reach stackers) but, of course, the same process is performed in case the handling means of the terminal are different.

The truck cycle in container terminals is considered to be simpler than the cycle related to ships and trains, which require a higher level of planning and scheduling. However, mainly due to the congestion phenomena generated by the arrival and departure of trucks to/from maritime terminals, increasing attention has recently been dedicated to the management and control of truck flows, which can strongly impact on the overall performance of the terminal. As a matter of fact, each area of the yard is characterized by a limited space and a limited number of handling equipments, thus the possible presence of a high number of trucks in one area can yield congestion in the area and in the surrounding space, possibly blocking a wide area of the terminal, inducing a significant increase of the processing times of trucks and a critical decrease in terms of safety.

It must also be noted that space is, in general, very limited inside maritime terminals (especially the ones operating on the Mediterranean coasts) and terminals do not have internal areas devoted to stopping trucks waiting to be served. Then, trucks tend anyway to reach the areas where they have to perform their operations and to queue near the areas, thus creating congestion in the yard.

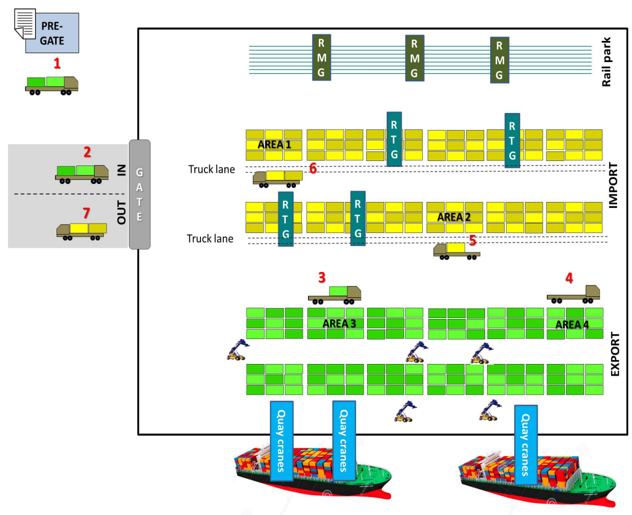

Fig. 1. A generic truck process (double move) in a container terminal.

III. The truck management algorithms

The objective of the algorithms here presented is to avoid congestion in the terminal yard areas and, consequently, assuring safety issues for truckers and terminal operation personnel. A possible way of tackling truck congestion in the yard areas relies on an effective control of the truck entrances inside the terminal. The general idea is that of monitoring the areas occupancy and regulating the truck access to the terminal in order to avoid a too high presence of means in each area.

In this sense, each area is associated with a maximum capacity. Moreover, for each yard area, an indicator of the expected load of the area, named *workload*, is continuously monitored and kept equal to the sum of the real occupancy of the area - i.e., the number of trucks already present in that area waiting to be served - and the weights of all the operations that have already been scheduled for that area. The scheduled operations refer to trucks that are already inside the terminal, that must visit the area in their cycle, but are not yet physically in the area.

Then, by defining with $\mathcal{A}$ the set of yard areas, each $a \in \mathcal{A}$ is associated with the following quantities:

- $c_a^{\max}$, which is the maximum capacity of area a, i.e., the maximum number of trucks that the area can host without creating congestion;
- $o_a(t)$, which is the occupancy (in terms of number of trucks) of area a at time t;
- $w_a(t)$, which is the workload (in terms of number of trucks) of area a at time t.

Both the occupancy and the workload of an area a are updated at specific time instants corresponding to the times of arrival/departure of trucks to/from the terminal and to the times of arrival/departure of trucks to/from the area. The way in which those updates are realized follows an event-driven dynamics that will be described in the following.

Moreover, in computing the workload, a different weight is assigned to each truck operation/job depending on the position of the job in the truck cycle. Weights concern the saturation of the capacity of the areas: the weight is higher for the first job to be performed by the truck and decreases for the following jobs. For example, as shown in Table I, if the truck cycle is complete, meaning that it is composed of 4 operations, jobs 1, 2, 3 and 4 weigh 1, 0.5, 0.25 and 0.125, respectively.

TABLE I
JOB SEQUENCING SET-UP.

Number of jobs	*job 1 score*	*job 2 score*	*job 3 score*	*job 4 score*
1	1	–	–	–
2	1	0.5	–	–
3	1	0.5	0.25	–
4	1	0.5	0.25	0.125

The proposed algorithms regulate the time at which each truck enters the terminal and they are based on checking, in different moments, whether the truck presence in the requested areas exceed the area maximum capacity.

The two algorithms which have been studied and implemented have been named:

1) *Conservative check*
2) *Conservative check with pre-gate*

In the following, they are explained more in detail.

A. Algorithm 1: Conservative check

In the first algorithm, a check is realized when the truck reaches the terminal gate (corresponding to the so-called gate-in event). The truck is allowed to enter the terminal and proceed to the yard area in which it has to perform the first operation only if, for each area that it should visit, the related operation can be assigned. This means that the workload in each area to be visited, including the truck operation, has to be less than the maximum area capacity.

If the check gives a positive result (i.e., all the workloads - including the weights associated with the truck operations-related to the areas required by the truck are less than the maximum):

- the workload of each area is updated by adding the weights assigned to each operation (Table I);
- the truck enters the terminal and goes to the area requested for its operation.

If the check is not successful, the truck remains on hold outside the terminal and an attempt is made to re-enter after a certain amount of time (e.g. 5 minutes). When the truck arrives in area a at time t, the area occupancy is updated and the requested operation for truck v is performed with a service time $T_v(t)$ computed according to the following equation:

$$T_v(t) = \frac{\sum_{i=1}^{o_a(t)} i \cdot t_s}{o_a(t)} \tag{1}$$

where t_s is the average service time for operation s.

The average service time t_s varies according to the type of operation s, being the type of operation listed as follows:

- pick-up (export) of a full container;
- delivery (or import) of a full container;
- pick-up or delivery of an empty container;
- pick-up or delivery of a “special” container (reefer, dangerous goods, etc.).

Once the operation has been executed, the following actions are carried out:

- if the truck has to execute further operations, it heads towards the next area, otherwise it proceeds towards the gate-out, i.e., it exits from the terminal;
- workloads are reassigned to the areas (in particular a position is freed in the just used area).

Since the conservative check allows the truck entrance only when all the moves are available, in this configuration there are no trucks waiting in the yard.

B. Algorithm 2: Conservative check with Pre-Gate

In the “Conservative check with pre-gate” algorithm, a conservative check is performed as for the “Conservative” algorithm. However, in this second algorithm, a preliminary check is also carried out when the pre-gate event occurs.

More specifically, when the truck shows up at the pre-gate office of the terminal, a check is performed only in relation to import areas for pick-up operations. If import areas are full, the truck cannot proceed to the gate and it remains waiting outside the terminal. The rest of the algorithm is analogous to algorithm 1.

IV. Analysis via simulation

This section presents an analysis of the results of the simulation campaign that has been performed for the two algorithms described in Section III. The two algorithms have been validated by using the real data sets provided by a real container terminal located in Northern Italy.

The real data adopted refer to the months of September, October and November 2018 on all working days, excluding Saturdays. Each simulation relates to a single day and the actual data relate to all trucks that carried out operations inside the terminal in that day. All experimental results have been generated and analyzed using a laptop Intel Core i7 2.4 GHz with 16 GB of RAM.

A. The simulation model

The simulation tool adopted to test the effectiveness of the proposed algorithms is based on a discrete-event model of the considered process. The dynamics of the process is, then, represented by defining the following main events together with the corresponding state transition functions:

- *Truck arrival*: arrival of the truck at the pre-gate office for the necessary documentary operations;
- *Truck gate-in*: the truck performs the gate-in, including all the required checks (which differs according to the chosen algorithm);
- *Start of operation*: arrival of the truck in an area and beginning of the operation/job in that area;
- *End of operation*: end of the truck operation in a specific area;
- *Truck gate-out*: exit of the truck from the terminal;

Several other minor events are included in the model in order to completely define the process dynamics coupled with the two algorithms. The discrete-event simulation is managed with standard techniques directly implemented in the realized simulation tool. It has to be noted that an ad-hoc tool has been implemented since the process dynamics together with the algorithms features required a specific model which was difficult to be realized within standard and commercial discrete-event simulation frameworks.

B. Model calibration procedure

The simulation model has been calibrated by considering the terminal structure and features together with real data related to truck operations. The validation campaign has been crucial to assess factors such as the truck travel times inside the terminal and the truck service times in the terminal areas. Specifically, with respect to the average service times in (1), the following values have been established by using the validation procedure:

- average time for picking up a full container = 6 minutes;
- average time for delivering a full container = 9 minutes;
- average time for taking or delivering an empty container = 6 minutes;
- average time for picking up or delivering a “Special” container = 9 minutes.

The validation has therefore been made by comparing the real truck turnaround time (defined as a gate-out time minus gate-in time) with the corresponding time generated by the simulation. The validation reported an average turnaround time error always lower than 5%.

C. Evaluation of performance indicators

Several performance indicators of the terminal operating with the proposed algorithms can be evaluated by means of the realized simulation tool. These indicators have generally been classified as:

- global indicators related to the whole terminal and truck movements in it;
- indicators referred to the areas occupancy and workloads;
- timing of the truck movements.

As regards the first set of indicators, the main quantities are:

- *N. Trucks*: number of trucks in the terminal;
- *N. Trucks Gate-In Cumulative*: total number of trucks that executed the Gate-In until a specific time instant;
- *N. Trucks Gate-Out Cumulative*: total number of trucks that executed the Gate-Out until a specific time instant;
- *N. Trucks Gate-In*: number of trucks that carried out Gate-In in the considered time interval;
- *N. Trucks Gate-Out*: number of trucks that carried out Gate-Out in the considered time interval;
- *N. Trucks Waiting at Gate*: number of trucks waiting outside the terminal gate in the considered time interval;
- *N. Trucks Waiting at Pre-gate*: number of trucks waiting at Pre-gate before trying to perform the Gate-In in the considered time interval (only in case Algorithm 2 is used).

In the following, some global indicators for a significant day of September 2018 are reported. Figs. 2 and 3 show the cumulative number of trucks performing GateIn and GateOut, and number of trucks executing GateIn and GateOut per minute, for Algorithm 1. It can be noted that these indicators are mainly used to verify that all trucks are served and they behave in a very similar way for both algorithms (meaning that with the use of both algorithms the system is anyway able to process all the trucks arriving in the day).

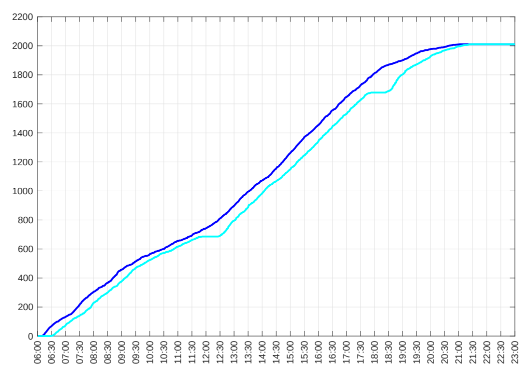

Fig. 2. Cumulative number of trucks entering the terminal (blue line) and exiting the terminal (cyan line)

The simulation determines, in each configuration, the occupation of the terminal areas along the simulated day. In particular, the simulation generates the occupancy and workload values of each area along time. In Figs. 4 and 5, the occupancy and workload of the import area C6 in a day in September 2018 are depicted. Area C6 is dedicated to import containers and it turns out to be very congested in the considered day. In Fig. 4 the green line indicates the area occupancy in the case in which no truck control is adopted, whereas the red line and blue line refer to the application of Algorithm 1 and Algorithm 2, respectively. Both algorithms strongly reduce the number of trucks at area C6 and they both maintain the number of trucks in the area lower than its maximum capacity (i.e. 10 trucks for area C6). This means that both algorithms do prevent

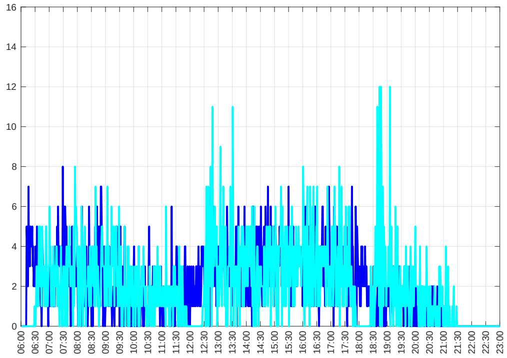

Fig. 3. Number of trucks entering the terminal (blue line) and exiting the terminal (cyan line)

congestion in the area and this is common to all the terminal areas.

Moreover, Algorithm 2, which performs a double check (at the pre-gate and at the gate), allows a slightly lower occupancy and workload of the area, on average but the two algorithms perform roughly the same way.

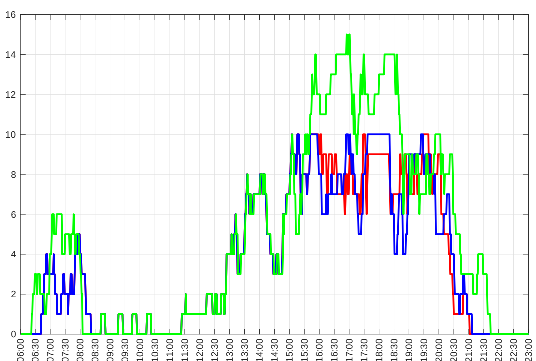

Fig. 4. Occupancy of area C06 without truck control (green line), with Algorithm 1 (red line) and with Algorithm 2 (blue line).

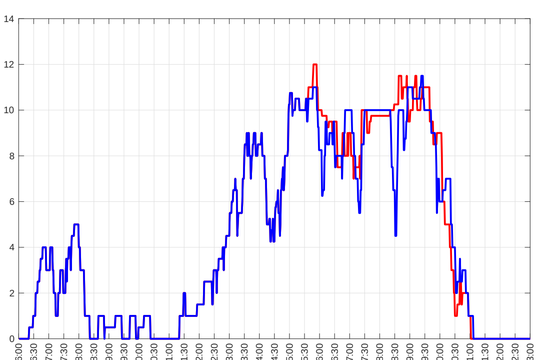

Fig. 5. Workload of area C06 with Algorithm 1 (red line) and with Algorithm 2 (blue line).

Furthermore, the areas dedicated to export operations are generally less exposed to saturation compared to the areas dedicated to import jobs.

It is clear that the complete resolution of congestion with the two algorithms induces the fact that some trucks are left outside the terminal waiting to enter it. In Fig. 6 the number of trucks waiting outside the terminal gate when Algorithm 1 is adopted, is reported. Figs. 7 and 8 show the number of trucks queuing at the terminal gate and at the terminal pre-gate, in case Algorithm 2 is used.

The number of trucks left outside the terminal when using Algorithm 1 is always lower than 20 trucks and this number can be accepted since congestion inside the yard is completely avoided. It can be noted that a buffer area immediately before or after the gate could be designed in order to suitably manage the presence of trucks waiting to begin their operations. When using Algorithm 2 the situation is improved, since some trucks remain at the pre-gate in an already existing dedicated area, and the number of trucks waiting at the gate is much lower in this case (never higher than 12 trucks).

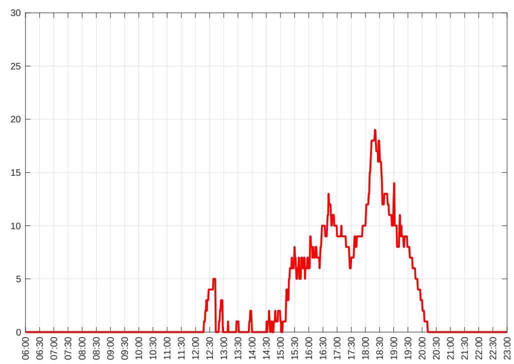

Fig. 6. Number of trucks waiting outside the gate when Algorithm 1 is adopted.

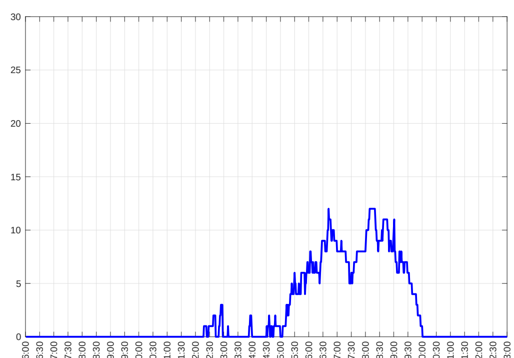

Fig. 7. Number of trucks waiting outside the gate when Algorithm 2 is adopted.

The performance indicators related to the timing of truck operations are the following:

- *Turnaround Time* = GateOut time - GateIn time;
- *Stay Time* = LastMove time - GateIn time;
- *Gross Service Time* = LastMove time- Arrival time;

in which the LastMove time refers to the time in which the last operation has been completed, and the Arrival time is, of course, the time in which the truck has reached the terminal.

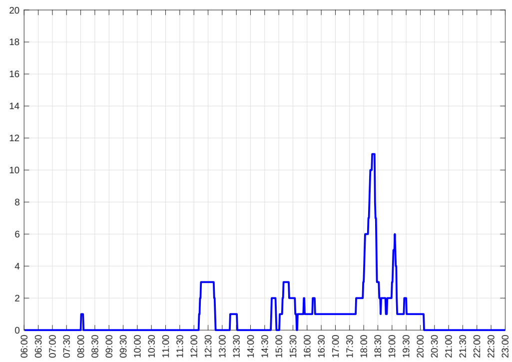

Fig. 8. Number of trucks waiting at the pre-gate when Algorithm 2 is adopted.

The daily values of these indicators have been averaged both for real data and for the simulated ones (when applying the two algorithms) for the month September 2018. The comparison is reported in Table II (where the indexes are expressed in minutes).

TABLE II
AVERAGE TRUCK MOVEMENTS KPIS (SEPTEMBER 2018).

	Real Value	Algorithm 1	Algorithm 2
Gate-In Difference		-8,91	-10,92
Gate-Out Difference		-13,58	-10,89
Turnaround Time	33,82	38,51	36,86
Stay Time	27,72	30,63	28,46
Gross Service Time	37,46	39,54	39,39

It can be noted that the KPIS for trucks movements remain very similar to the real case and this means that the algorithms do not help in reducing the terminal operating times but they allow a better management of trucks movements inside the terminal, with a significant increase in congestion reduction and safety.

V. CONCLUSIONS

In this paper we propose two novel algorithms to reduce yard congestion and increase safety measures at container terminals. One and two conservative checks are performed respectively for the two proposed algorithms, according to which trucks may or may not enter the terminal. The results obtained by simulating the two algorithms show that both algorithms prevent the congestion in the yard areas without significantly worsening the other KPIs of the overall process, with Algorithm 2 which provides a better occupancy and workloads of the terminal areas.

Further research will be dedicated to study and compare new algorithms considering a less conservative approach and the presence of a buffer area to accommodate trucks that cannot enter the terminal due to congestion and capacity constraint issues.

REFERENCES

[1] H.C. Chen, Hsiao-Chi, and S.M Liu, "Should ports expand their facilities under congestion and uncertainty?," Transportation Research Part B: Methodological, vol. 85, pp. 109–131, 2016.

[2] L. Fan, Hsiao-Chi, and W. Wilson, and B. Dahl, "Congestion, port expansion and spatial competition for US container imports," Transportation Research Part E: Logistics and Transportation Review, vol. 48 (6), pp. 1121–1136, 2012.

[3] X. Wang, and Q. Meng, "Optimal price decisions for joint ventures between port operators and shipping lines under the congestion effect," European Journal of Operational Research, vol. 273 (2), pp. 695–707, 2019.

[4] W.K. Talley, and Ng. ManWo, "Port multi-service congestion," Transportation Research Part E: Logistics and Transportation Review, vol. 94, pp. 66-70, 2016.

[5] M. Hyland, and B-M. Lama, and H. Mahmassani, and I.O. Verbas, and X. Xu, and K. Smilowitz, and B. Johnson, "Potential for a logistics island to circumvent container port congestion in a constrained environment," Transport Policy, vol. 86, pp. 50-59, 2020.

[6] M. Veloqui, and I. Turias, and M.M. Cerbn and, M.J. Gonzlez, and G. Buiza, and J. Beltrn, "Simulating the landside congestion in a container terminal. The experience of the port of Naples (Italy)," Procedia - Social and Behavioral Sciences, vol. 160 (1), pp. 615–624, 2014.

[7] G. Chen, and K. Govindan, and Z. Yang, "Managing truck arrivals with time windows to alleviate gate congestion at container terminals," International Journal of Production Economics, vol. 141 (1), pp. 179–188, 2013.

[8] I. Motono, and M. Furuichi, and T. Ninomiy, and S. Suzuki, and M. Fuse, "Insightful observations on trailer queues at landside container terminal gates: What generates congestion at the gates?," Research in Transportation Business and Management, vol. 19, pp. 118–131, 2016.

[9] L. Zhen, "Modeling of yard congestion and optimization of yard template in container ports," Transportation Research Part B: Methodological, vol. 90, pp. 83–104, 2016.

[10] C. Caballini, and J.Mar-Ortiz, and S. Sacone, M.D. and Gracia, "Optimal truck scheduling in a container terminal by using a Truck Appointment System,"The 21st IEEE International Conference on Intelligent Transportation Systems, November 4-7, 2018. Maui, Hawaii, USA, 2018.

[11] C. Caballini, and J.Mar-Ortiz, and S. Sacone, M.D. and Gracia, "A combined data mining optimization approach to manage trucks operations in container terminals with the use of a TAS: Application to an Italian and a Mexican port," Transportation Research Part E: Logistics and Transportation Review, vol. 142, 2020.

[12] B. Dragovi, E. Tzannatos, and N.K. Park, "Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool," Flexible Services and Manufacturing Journal, vol. 29 (1), pp. 4–34, 2017.

[13] I. Castilla-Rodrguez, and C. Expsito-Izquierdo, and B. Melin-Batista, and R. M. Aguilar, and J. M. Moreno-Vega, "Simulation-optimization for the Management of the Transshipment Operations at Maritime Container Terminals," Expert Systems with Applications, vol. 139, 2020.

[14] P.E.N.G. Yun, and L.I. Xiangda, and W.A.N.G. Wenyuan, and L.I.U. Ke, and L.I. Chuan, "A simulation-based research on carbon emission mitigation strategies for green container terminals," Ocean Engineering, vol. 163 (1), pp. 288–298, 2018.

[15] Q. Meng, and J. Weng, and L. Suyi, "Impact Analysis of Mega Vessels on Container Terminal Operations," Transportation Research Procedia, vol. 25, pp. 187–204, 2017.