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# Impact of overbooking reservation mechanism on container terminal's operational performance and greenhouse gas emissions

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ABSTRACT

Truck appointment systems facilitate coordination between container terminals and drayage trucks in container pick-up operation reservation. However, in many cases, trucks with a reservation do not arrive at the scheduled appointment. As the number of no-shows increases, the container terminal's productivity will plummet, and drayage trucks that failed to get reservations will lose their opportunity to get service. This research proposes an overbooking reservation mechanism (ORM) to alleviate the negative impact of these no-shows. This research scrutinizes the detailed process mapping of the existing reservation mechanism, proposes an ORM, and conducts agent-based simulations to evaluate the ORM's performance against the regular and go-show reservation mechanisms at different levels of no-shows and working occupancies. The application of an ORM can improve productivity and service levels while minimizing such negative externalities as queue length, overtime, and greenhouse gas emissions. High overtime intensities only appear when the container terminal's workload is exceptionally high, at 200% of maximum capacity, with a low level of no-shows. Even in exceptionally high demand conditions, the drayage trucks wait only up to 16 min before receiving service.



## Introduction

Maritime transportation networks carry more than 70% of global trade commodities (UNCTAD, 2019). The seemingly captive market of maritime business elicits fierce competition among the participating business actors. Numerous trade uncertainties, such as the dynamics of market digitalization, rising protectionist sentiment, the increasing consolidation of liner shipping, and growing pressure to maintain a sustainability agenda, have made maritime business even more competitive (UNCTAD, 2019).

The hinterland transport chain plays an essential role in the competitiveness of a maritime transport network. Despite the short distances involved in the hinterland transport chain in proportion to the total distance covered in global maritime transportation, inefficiencies in coordination between container terminals and inland transporters have a substantial impact on the overall effectiveness of the transportation service. As global shippers seek ever more efficient logistics partners to transfer their commodities in a shorter time and at a lower price, drayage trucks remain the dominant and quickest means of reaching inland customers (UNCTAD, 2019). Motivated by this fact, this research focuses on mitigating coordination inefficiencies in pick-up operations between container terminals and drayage trucks.

Inefficient coordination harms at least three primary stakeholders: the container terminals, the drayage truck companies, and the surrounding environment. For the container terminals, inefficient coordination results in the imbalanced allocation of resources. Terminals are bustling during peak time, but they are underused when there is low service demand. For the drayage truck companies, their vehicles wait a long time to pick up a container, especially during peak periods. Finally, the surrounding environment is affected by numerous negative externalities, such as air pollution and road congestion (Aregall, Bergqvist, & Monios, 2018).

Truck appointment systems have been present as popular initiatives to improve container pick-up operations at container terminals. A truck appointment system enables the scheduling of the container pick-up operation. In some regions, notably the European Union and the United States, the government enforces the use of appointment systems through legislation (Giuliano and O'Brien, 2007; Giuliano et al., 2008). However, many container terminals procure the system simply to achieve regulatory compliance. They pay much less attention to building a well-designed appointment

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system that can improve the container pick-up operation. Consequently, these initiatives often involve minimal participation by drayage trucks (Giuliano and O'Brien, 2007).

Some drayage truck companies use the truck appointment systems to reserve a pick-up but fail to show up at the scheduled appointment (Morais and Lord, 2006). Such no-shows decrease the effectiveness of the appointment system. This research highlights this critical issue with the reservation mechanism of the truck appointment system, which governs the allocation of container pick-up appointment requests to the container terminal schedule. While many studies have explored ways to improve the reservation mechanism, it appears that no study has incorporated no-shows in the formulation of a solution (Huynh et al., 2016). In response, this research focuses on the overbooking reservation mechanism (ORM) to alleviate the negative impact of no-shows.

Using agent-based simulation, the researchers evaluate the performance of the proposed ORM, comparing it to the regular and go-show reservation mechanisms in terms of the container terminal's landside operational performance (Rizaldi, Wasesa, & Rahman, 2015; Steenken, Voss, & Stahlbock, 2004) and the greenhouse gas emissions involved in a container pick-up operation (Do et al., 2016). In terms of the landside operational performance, the container terminal's productivity (the number of trucks serviced in a working day), service level (how long a truck has to wait before receiving a container), and the average queue length that emerged from the pick-up operation were evaluated. In terms of greenhouse gas emissions, the trucks' emission of carbon dioxide ($CO_2$), nitrogen oxide (NOx), particulate matter (PM), and total hydrocarbon (THC) during the pick-up operation were also evaluated.

## Related literature

In maritime business, the hinterland transportation chain has lagged behind its ocean-going counterpart in implementing strategies to reduce environmental hazards. An extensive review by Aregall et al. (2018) shows that only 20% (76 out of 365) of global ports have implemented concrete initiatives to improve the environmental performance of hinterland transport. These facts are not in line with the World Ports Sustainability Program and the Paris Agreement on combating climate change (COP 21). The latter advocates for the acceleration and intensification of actions and investments needed for a sustainable, low-carbon future (UNECE, 2010; UNFCC, 2016).

The European Union (UNECE, 2010) has identified four main challenges facing the hinterland regions in the maritime business. These are the increasing demand for international transport, rapid technological development, the involvement of stakeholders in the port region and beyond, and a commitment to reduce greenhouse gas emissions, air pollution, and road congestion. Despite the popularity of existing initiatives, such as infrastructure expansion, dry ports, and the extension of the working hours at container terminals (Acciaro and Mckinnon, 2013), the truck appointment system is the only area that overlaps with all the challenges mentioned above. This system is, in essence, information technology in the form of an inter-organizational system (Kumar & Van Dissel, 1996; Wasesa, Stam, & van Heck, 2017) aiming to improve the coordination conducts of container pick-up operation between the container terminal and the drayage trucks.

To evaluate performance, existing studies typically adopt the operational metrics of container pick-up conduct, such as container terminal resource utilization, service levels, queue length, and container reshuffling frequency (Aregall et al., 2018; Rizaldi et al., 2015; Wasesa, Nijdam, Muhammad, & Van Heck, 2012; Huynh et al., 2016; Li et al., 2020). Despite the rising scrutiny of a port's operational sustainability practices, limited research exists that incorporates environmental metrics in evaluating the improvement proposition (Aregall et al., 2018; Chen et al., 2013; Li et al., 2016; Morais and Lord, 2006). Few articles have incorporated environmental concerns in designing and evaluating container pick-up operations (Chen et al., 2013; Do et al., 2016; Li et al., 2016). Chen et al. (2013) proposed a genetic algorithm that uses the bi-objective model to optimize the arrival patterns of drayage trucks and reduce their associated emissions. Their results indicate that regulating the truck arrival pattern can reduce truck emissions substantially. More recently, Li et al. (2016) and Do et al. (2016) evaluated several different yard-crane strategies and time-slot assignments to minimize greenhouse gas emissions.

Recent studies have emphasized the critical importance of no-shows in designing the reservation mechanism (Li et al., 2016; Zhang et al., 2019). In response, this research focuses on designing ORM (Laganga and Lawrence, 2012; Weatherford and Bodily, 1992; Zacharias and Pinedo, 2014). The researchers posit that the application of an ORM can eliminate numerous inefficiencies caused by no-shows, resulting in more efficient and environmentally friendly container pick-up operations.

## Existing conditions: regular reservation mechanism

At container terminals that do not implement a truck appointment system (i.e., a go-show mechanism is in place), drayage trucks can arrive at any time to request a container pick-up. Under these conditions, container terminals cannot predict the number of container pick-ups they need to cater for. This conduct is familiar to the walk-ins appointment conduct (Morikawa and Takahashi, 2017). The walk-ins conduct leads to numerous issues, such as the unbalanced allocation of resources, severe air pollution, and congestion in the seaport area. With an appointment system in place, container terminals can expect improvements in the conduct of container pick-up operations (Huynh et al., 2016).

The basic feature of an appointment system is the facilitation of pre-arrival and on-arrival procedures. The pre-arrival procedure is a prerequisite for the drayage trucks to receive approval to conduct the pick-up. This procedure ensures the requested container is already present at the container yard and the associated paperwork has been approved. Next follows the on-arrival procedure, which is the physical execution of the container pick-up operation. Without the pre-arrival procedure (i.e., the walk-ins appointment conduct (Morikawa and Takahashi, 2017)), the likelihood exists that a drayage truck will arrive at the container terminal and request a container that is either not present yet or has unapproved documentation. The truck is consequently forced to wait outside the container terminal yard. This situation will lead to decreasing truck utilization from the drayage operators' point of view. The accumulation of waiting trucks causes excessive levels of road congestion and air pollution.

A truck appointment system enables the scheduling of the container pick-up operation. Drayage truck companies can reserve pick-up time slots at their preferred time. Subsequently, the corresponding container terminal can obtain essential information to plan its operations, such as the expected arrival time of trucks and resource workloads. Fig. 1 depicts the workflow of a pre-arrival procedure that incorporates the regular appointment reservation mechanism portrayed in the standard Business Process Modeling Notation (BPMN) format (Recker et al., 2009).

The reservation process starts when a drayage truck company requests an appointment for a specific time slot via the truck appointment system. The container terminal operator then checks the availability of the requested time slot. If the slot is still available, the terminal conducts documentation details clearance. Upon completing documentation clearance, the container terminal reserves

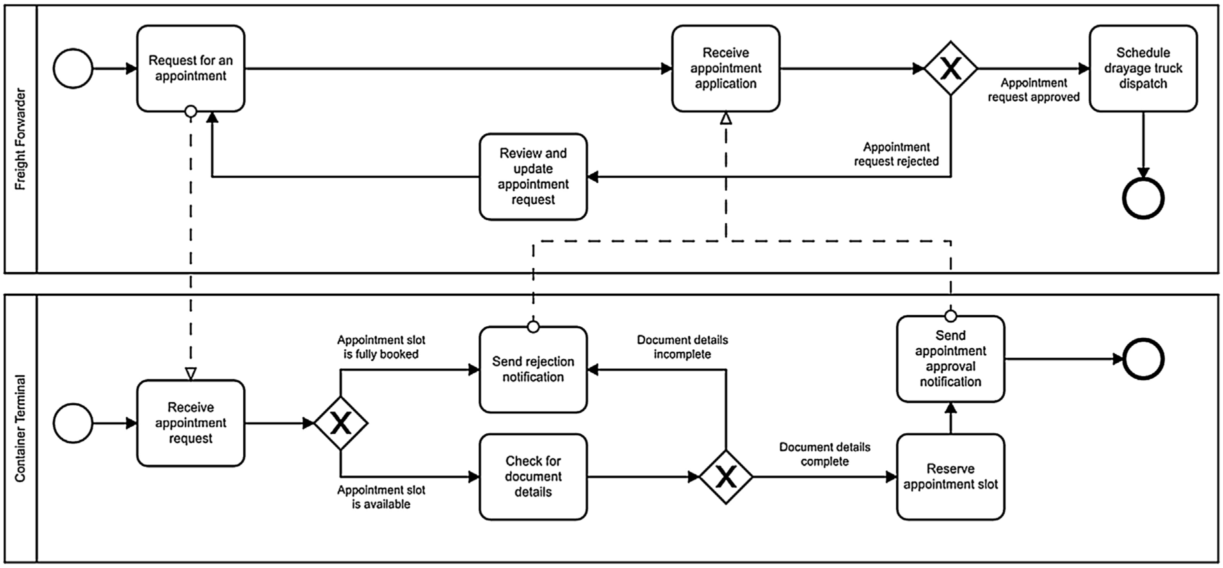


**Fig. 1.** Regular reservation mechanism.

the requested time slot and sends a reservation approval notification. If the requested slot is full or the documentation details are not complete, the terminal will send a reservation rejection notification instead. In that case, the drayage truck company will review the reservation rejection notification, update its request, and resubmit an appointment request.

The regular reservation mechanism does not consider the critical importance of no-show occurrences (Pinedo et al., 2015). A no-show occurs when a drayage truck does not arrive for the appointment at the reserved time. As the number of no-shows increases, the productive use of the container terminals will plummet, and prospective customers (i.e., drayage trucks that failed to get reservations) will lose their opportunity to get service. This situation results in revenue losses for both the container terminal and the drayage truck companies (Caballini et al., 2020; Li et al., 2020).

## Solution proposition: overbooking reservation mechanism

To alleviate the negative impact of no-shows, the researchers propose an ORM (Laganga and Lawrence, 2012; Zacharias and Pinedo, 2014). This mechanism has been implemented successfully in many service industries (Pinedo et al., 2015) such as airlines and healthcare. Unlike regular reservation mechanisms that limit the number of incoming reservations according to the maximum service capacity, the ORM allows the number of incoming reservations to surpass the maximum service capacity of the container terminal.

In the proposed solution, the static overbooking reservation mechanism setting is adopted (Laganga and Lawrence, 2012; Lee et al., 2013; Pinedo et al., 2015). In this setting, the container terminal determines the number of additional reservation time slots days before the actual execution of the service. The overbooking ratio reflects the number of extra time slots that the container terminal would add. An overbooking ratio value of 50% means that the container terminal accommodates 50% more incoming reservations than the actual capacity. The container terminal must determine the overbooking ratio carefully. Setting the overbooking ratio too low will not result in adequate compensation for no-shows. On the other hand, setting the overbooking ratio too high could lead to service overload (Lee et al., 2013).

Fig. 2 depicts the workflow of a pre-arrival procedure that incorporates the proposed ORM. At the beginning of a working period (e.g., weekly or bi-weekly), the container terminal determines the overbooking ratio for each day of that period. When a drayage truck company sends a reservation request, the container terminal will check the availability of the requested time slot. If no company has reserved the requested time slot, and if the request passes the document clearance procedure, the drayage truck company will receive confirmation of a priority time slot reservation. The drayage truck company issued such confirmation is guaranteed of a container pick-up at the requested time.

If a drayage truck company has already been awarded the priority time slot, the container terminal will evaluate whether the terminal can reserve an overbooking time slot for a second requesting drayage truck company. A drayage truck company with an overbooking reservation will receive service in the requested time slot if the company that had the priority reservation is a no-show. If the company with the priority reservation keeps its appointment, the second company with the overbooking reservation has to wait for service in the next available time slot.

When the container terminal offers a drayage company an overbooking appointment, the drayage company has two options: (1) It can accept the offer, taking the risk of spending unproductive time waiting for a service that will not materialize if the company with the priority reservation fulfills its appointment. (2) It can reject the offer and try to win a priority reservation in a different time slot.

## Simulation setup

To evaluate the ORM performance, agent-based simulation experimentation was conducted using NetLogo (Wilensky and Rand, 2015). The researchers implemented significant modifications to the simulation model developed in previous research (Huynh & Vidal, 2012; Rizaldi et al., 2015; Wasesa et al., 2012). The container pick-up service appointments of a single container yard served by a yard crane were analyzed. This single-server setting allowed the researchers to eliminate the interference effect of multiple servers and focus on the ORM's impact on the performance of the container pick-up operation.

Fig. 3 depicts the graphical user interface (GUI) of the simulation environment. The simulated container terminal area has a dimension of 40 (length) $\times$ 6 (width) $\times$ 4 (height) twenty-foot equivalent unit (TEU) containers. The people, shown in the light-grey area on the upper right of the GUI, represent the drayage truck companies that have requested a container pick-up. Beneath it, in the

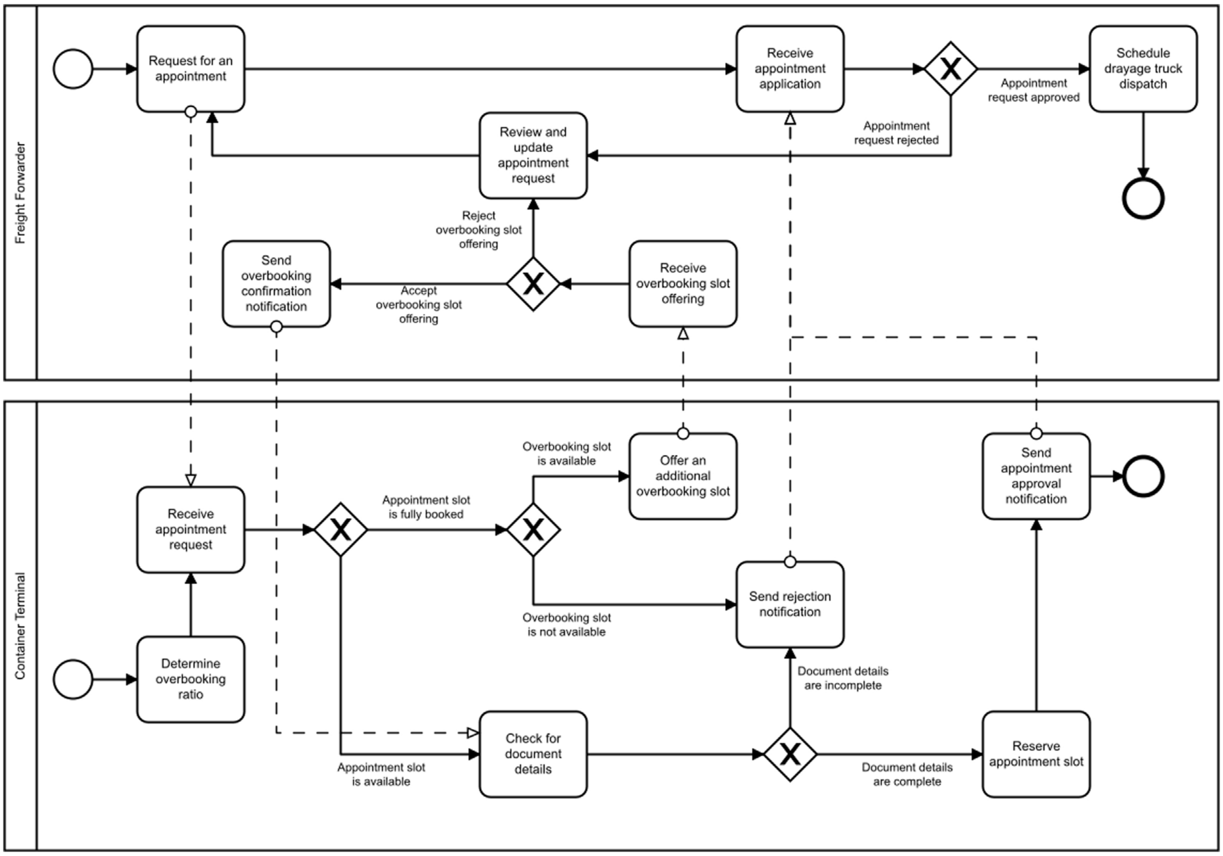


**Fig. 2.** Overbooking reservation mechanism.

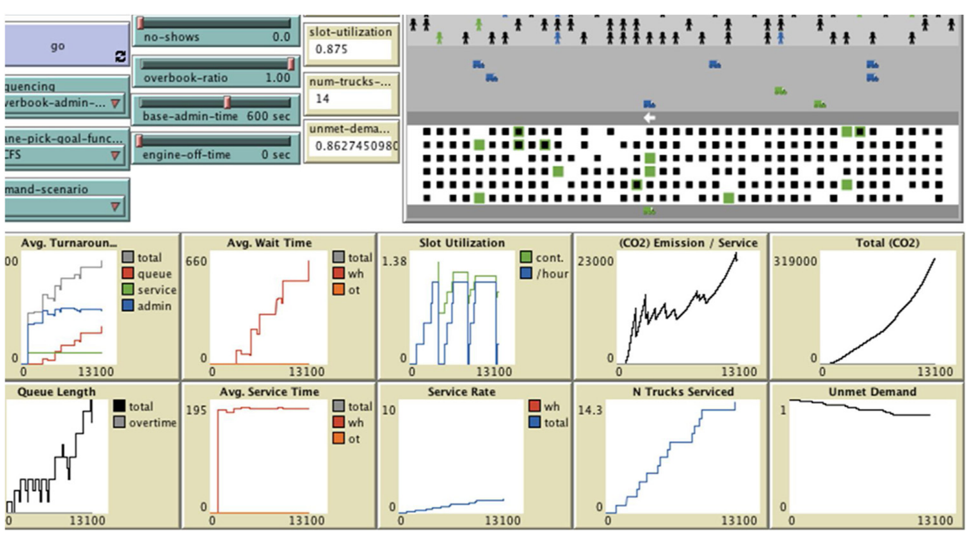


**Fig. 3.** Graphical user interface of the agent-based simulation.

dark-grey area, the drayage trucks are waiting for service inside the container terminal area. At the bottom of the GUI, we can monitor several performance charts indicating several simulation outputs. To align the simulation with the real conditions of a yard crane's operation, the researchers adopted a terminal's operational parameters, such as crane speed and yard measurements, from existing research (Huynh and Vidal, 2012).

Table 1 shows an overview of the design of the simulation experiment. Each simulation run represents the reservation and operational activities of container pick-up services for one day (12 business hours plus overtime). Each business hour consists of four 15-minute fixed time slots. A single time slot is dedicated to a unique container pick-up service. The researchers also added an overtime period, whenever unserved trucks remain at the end of the official business hours. The first two working hours were treated as a transient warm-up period and were not incorporated in the analysis.

As stated, the simulation experimentation's main objective is to evaluate the ORM's performance, henceforth denoted by the shortened abbreviation ÖB.T̈he ORM was simulated with three

**Table 1**
The design of the simulation experiments.

| Simulation parameter | Values |
|---|---|
| Simulation replications | 30 |
| Total working hours in a day | 43,200 s (12 h) |
| Warm-up period | 7,200 s (2 h) |
| Service slot length | 900 s (15 min) |
| Number of service slots per hour | 4 |
| Appointment mechanism | Go-Show (GS), Regular Reservation (RR), Overbooking — 25% Ratio (OB25), Overbooking — 50% Ratio (OB50), Overbooking — 100% Ratio (OB100) |
| Service demand | 50% (2 trucks/hour), 100% (4 trucks/hour), 200% (8 trucks/hour) |
| No-show occurrence rate | 0%, 25%, 50%, 75% |
| Operational metrics | Number of trucks serviced, service waiting time, queue length |
| Air pollution metrics | $CO_2$, CO, $NO_x$, PM, and THC |

overbooking ratios: 25% (OB25), 50% (OB50), and 100% (OB100). This research applies incremental levelling of those three overbooking ratios to investigate the ORM limitation in accommodating more incoming reservations than the container terminal's actual capacity. Simulations of the regular reservation mechanism (RR) and the go-show mechanism (GS) were also conducted. Each reservation mechanism is simulated at different levels of no-show occurrence rates and service demand. In total, an evaluation was done of five mechanisms (GS, RR, OB25, OB50, OB100) on four levels of no-show occurrence rates (0%, 25%, 50%, and 75%) and three levels of service demand (50% (2 trucks/hour), 100% (4 trucks/hour), and 200% (8 trucks/hour)). At the 25% no-show occurrence rate, the simulation randomly triggers one no-show event per four available time slot of an hour. At the 50% (2 trucks/hour) service demand, the simulation randomly triggers only two service requests per four available time slot of an hour. In total, $5 \times 4 \times 3$ experiment scenarios were run. Each simulation scenario was run with 30 replications.

The reservation mechanisms were assessed based on the container terminal's operational metrics, queue length, and air pollution generated by the trucks. First, the container terminal's productivity (the number of trucks serviced in a working day) and service level (how long a truck has to wait before receiving a container) were evaluated. Secondly, the average queue length that emerged from the pick-up operation was monitored, given that it is a negative externality that may contribute to road congestion in and around the port. Lastly, the trucks' emission of greenhouse gases, namely carbon dioxide ($CO_2$), nitrogen oxide ($NO_x$), particulate matter (PM), and total hydrocarbon (THC) during the pick-up operation were also evaluated.

## Results and analysis

In the analysis of the simulation results, the productivity performance of the container terminal was evaluated first. Fig. 4 portrays the container terminal's productivity under different reservation mechanisms, in different working periods, and at different levels of demand for service. Looking at the vertical arrangement of Fig. 4, the output charts were decomposed into three different working periods. The bottom layer shows the distribution of productivity performance during business hours, the middle layer shows the distribution of productivity performance during the overtime period, and the upper layer shows the distribution of overall productivity performance in a day. Vertically, the charts are ordered based on increments in service demand. The increments are 50%, 100%, and 200% of the container terminal's maximum capacity.

As shown in Fig. 4, the ORM (OB25, OB50, OB100) show higher productivity than the regular reservation mechanism (RR). The productivity gap grows as the demand from the drayage trucks surpasses the container terminal's maximum capacity. On the other hand, when the demand for container pick-ups decreases below the terminal's maximum capacity, the productivity gap is low. In this situation, there is less of an incentive for drayage trucks to utilize the extra overbooking time slots. However, as the demand for service surpasses the container terminal's maximum capacity, the regular reservation time slots are fully booked. Hence, more drayage trucks are willing to take an overbooking time slot as an alternative. In this high-demand situation, whenever the truck with a priority reservation does not fulfil its appointment, another truck with an overbooking appointment can claim the replacement. Thus, the container terminal can continue to maintain high levels of productivity.

Note that in conditions of high demand, the productivity level of the ORM increases as the quota of overbooking time slots is increased. However, increasing the number of extra overbooking time slots can lead to a prolonged period of overtime. As shown in Fig. 4, especially at high demand conditions (200%), the terminal has to serve the remaining trucks that cannot be served during official business hours. Nevertheless, the overtime period decreases as the rate of no-shows increases. This shows the usefulness of ORM to alleviate no-shows.

Fig. 5 portrays the impact of each reservation mechanism on the average length of the queue of drayage trucks waiting to receive containers. Under conditions of high demand, and as the offering of overbooking time slots is increased, the number of trucks that come with an overbooking reservation increases correspondingly. This leads to excessively long queues, which further increase road congestion in and around the port. As the service demand reaches 200% of the container terminal's maximum working capacity, the ORM can lead to significantly longer queues than the regular reservation mechanism. This happens when no-shows are rare (at 0% and 25%). As the rate of no-shows increases (to 50% and 100%), the expected queue length shrinks. Note that because the incoming service demand is still within the container terminal's capacity (at 50% and 100% of the maximum capacity), there is no noticeable difference in queue length. The situation holds even when the overbooking ratio is increased to 100%. Thus, by applying the ORM at a service demand level of 100%, the container terminal's productivity can indeed be increased without a noticeable increase in queue length.

In the study's analysis of the environmental impact, Fig. 6 portrays the performance of all the reservation mechanisms in terms of $CO_2$ emissions. The emissions generated by the trucks were recorded from the moment they arrived until they departed from the container terminal. The characteristics of the $CO_2$ emissions produced under all the reservation mechanisms correspond with the earlier findings concerning queue length. Under the heavy workload (at the 200% demand level), especially at no-show rates of 0% and 25%, the ORM scenarios result in a higher volume of emissions than the regular reservation mechanism. The volume of emissions increases as the offering of overbooking time slots increases. In contrast, in any other scenario, the ORM scenarios result in reduced emissions. Even at a demand level of 200% service capacity, the ORMs produce an insignificant increase in emissions compared to the regular reservation mechanism. This finding shows that an ORM can be relied on to overcome the high incidence of no-shows.

Table 2 is a more detailed overview of the simulation experiment's outputs. The table shows the performance statistics of all five reservation mechanisms: go-show (GS), regular reservation (RR), 25% Overbooking Quota (OB25), 50% Overbooking Quota (OB50), and 100% Overbooking Quota (OB100). The table

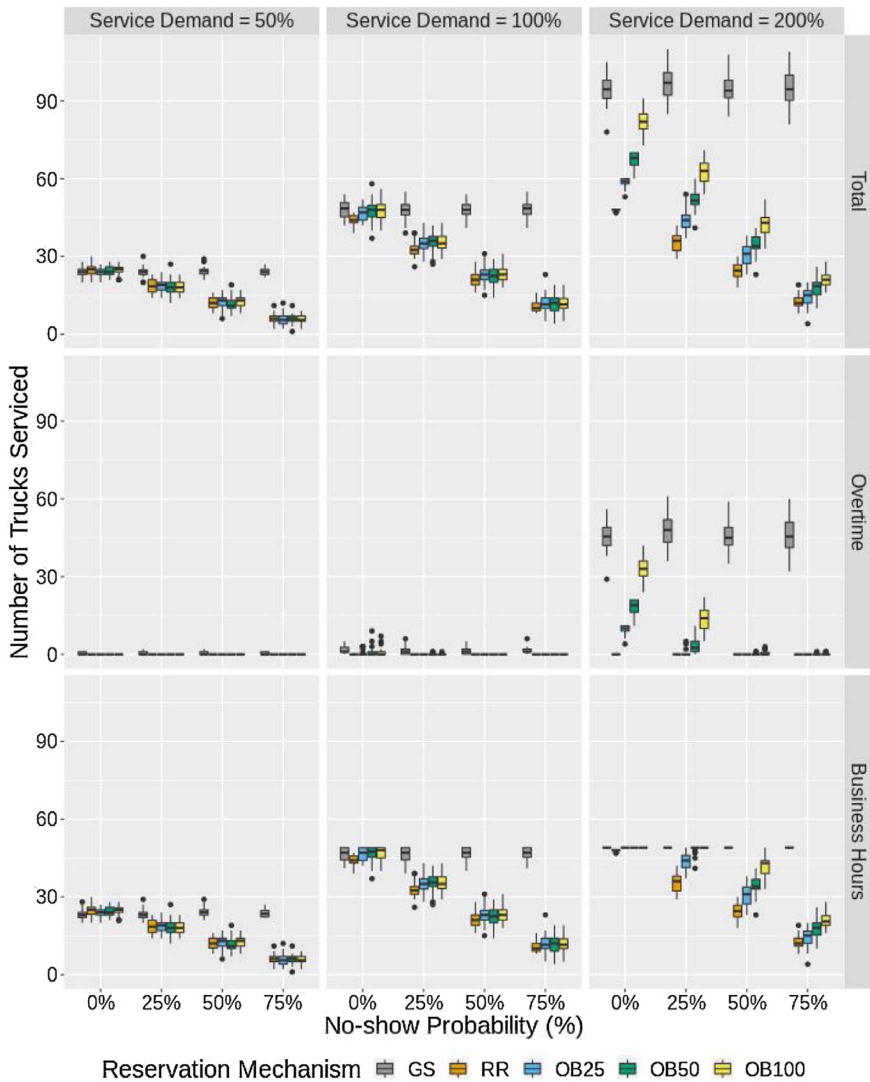


**Fig. 4.** The impact of overbooking reservation mechanisms on container terminal's productivity.

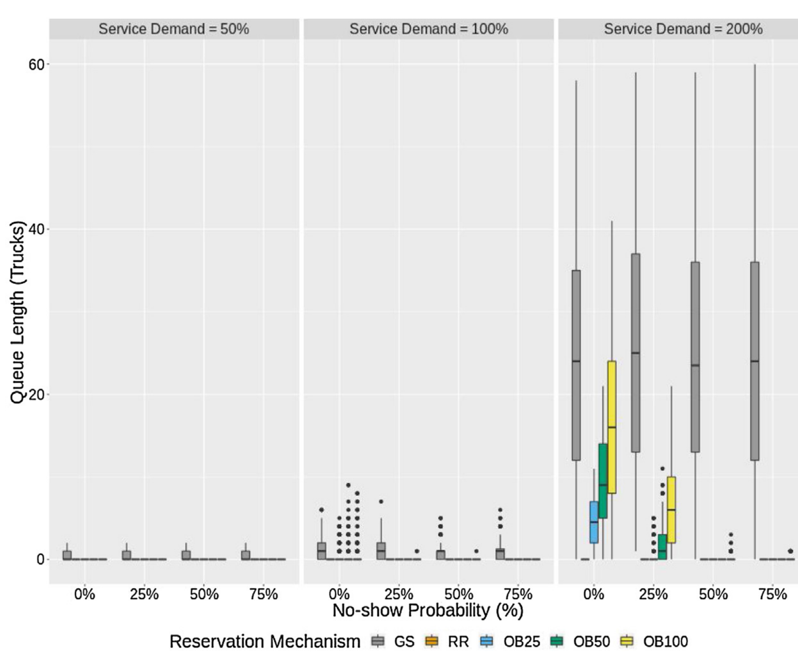


**Fig. 5.** The impact of overbooking reservation mechanisms on container terminal's queue length.

**Table 2**
Overview of the simulation results.

| Truck arrival rate | No show | Number trucks serviced – business hours [trucks] | | | | | Number trucks serviced – overtime [trucks] | | | | | Waiting time [minutes] | | | | | Queue length [trucks] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 |
| 2 Trucks/ Hour | **0%** | 23.40 | 24.73 | 23.93 | 24.43 | 24.53 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 25% | 23.33 | 18.60 | 18.53 | 18.23 | 18.20 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 50% | 24.00 | 11.97 | 12.30 | 11.73 | 12.73 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 75% | 23.63 | 5.80 | 5.80 | 6.13 | 5.90 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 Trucks/ Hour | **0%** | 46.63 | 44.07 | 46.37 | 46.50 | 46.63 | 1.73 | 0.00 | 0.60 | 0.93 | 0.90 | 0.75 | 0.00 | 0.93 | 0.98 | 1.20 | 1.14 | 0.00 | 0.43 | 0.45 | 0.57 |
| | 25% | 46.27 | 33.07 | 35.03 | 35.43 | 35.33 | 1.47 | 0.00 | 0.00 | 0.07 | 0.03 | 0.94 | 0.00 | 0.11 | 0.18 | 0.14 | 1.11 | 0.00 | 0.00 | 0.00 | 0.01 |
| | 50% | 46.57 | 21.13 | 22.63 | 22.57 | 23.17 | 1.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.66 | 0.00 | 0.07 | 0.05 | 0.05 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 75% | 46.80 | 10.73 | 12.07 | 12.10 | 11.70 | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.99 | 0.00 | 0.01 | 0.01 | 0.03 | 1.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 Trucks/ Hour | **0%** | 49.00 | 47.87 | 49.00 | 49.00 | 49.00 | 45.57 | 0.00 | 9.40 | 18.40 | 32.87 | 58.57 | 0.00 | 5.93 | 9.61 | 10.24 | 24.26 | 0.00 | 4.61 | 9.59 | 16.51 |
| | 25% | 49.00 | 35.27 | 43.37 | 48.43 | 49.00 | 47.87 | 0.00 | 0.37 | 3.43 | 13.30 | 63.41 | 0.00 | 0.81 | 3.81 | 10.58 | 25.74 | 0.00 | 0.23 | 1.96 | 6.56 |
| | 50% | 49.00 | 24.37 | 30.53 | 34.40 | 41.73 | 45.97 | 0.00 | 0.00 | 0.10 | 0.47 | 58.50 | 0.00 | 0.17 | 0.26 | 0.48 | 24.34 | 0.00 | 0.00 | 0.00 | 0.21 |
| | 75% | 49.00 | 12.33 | 14.27 | 17.90 | 20.87 | 46.13 | 0.00 | 0.00 | 0.03 | 0.10 | 57.00 | 0.00 | 0.04 | 0.08 | 0.07 | 24.60 | 0.00 | 0.00 | 0.00 | 0.05 |

| Truck arrival rate | No show | $CO_2$ emission [grams/hour] | | | | | $NO_X$ emission [grams/hour] | | | | | THC emission [grams/hour] | | | | | PM emission [grams/hour] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 | GS | RR | OB25 | OB50 | OB100 |
| 2 Trucks/ Hour | **0%** | 608.10 | 576.47 | 573.35 | 573.99 | 576.50 | 8.91 | 8.42 | 8.37 | 8.38 | 8.42 | 0.48 | 0.44 | 0.44 | 0.44 | 0.44 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| | 25% | 606.65 | 567.82 | 566.94 | 568.04 | 565.86 | 8.89 | 8.30 | 8.29 | 8.30 | 8.27 | 0.48 | 0.44 | 0.44 | 0.44 | 0.44 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| | 50% | 605.93 | 549.35 | 546.12 | 547.94 | 543.75 | 8.88 | 8.05 | 8.00 | 8.03 | 7.97 | 0.48 | 0.43 | 0.43 | 0.43 | 0.43 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| | 75% | 604.47 | 475.58 | 451.62 | 481.93 | 485.81 | 8.85 | 7.03 | 6.66 | 7.11 | 7.18 | 0.48 | 0.39 | 0.37 | 0.40 | 0.40 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| 4 Trucks/ Hour | **0%** | 667.08 | 593.99 | 697.55 | 707.57 | 747.20 | 9.76 | 8.67 | 10.18 | 10.33 | 10.91 | 0.52 | 0.46 | 0.54 | 0.54 | 0.58 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 |
| | 25% | 669.06 | 589.19 | 619.79 | 640.74 | 631.49 | 9.79 | 8.61 | 9.05 | 9.36 | 9.22 | 0.52 | 0.46 | 0.48 | 0.50 | 0.49 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 |
| | 50% | 652.96 | 574.51 | 607.30 | 606.55 | 611.66 | 9.55 | 8.40 | 8.88 | 8.87 | 8.95 | 0.51 | 0.45 | 0.47 | 0.47 | 0.48 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 |
| | 75% | 671.54 | 538.00 | 566.00 | 568.05 | 569.25 | 9.82 | 7.90 | 8.31 | 8.35 | 8.35 | 0.52 | 0.43 | 0.45 | 0.45 | 0.45 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| 8 Trucks/ Hour | **0%** | 7261.13 | 596.67 | 1477.36 | 2986.53 | 5053.03 | 106.00 | 8.71 | 21.56 | 43.59 | 73.74 | 5.59 | 0.46 | 1.14 | 2.30 | 3.88 | 0.18 | 0.01 | 0.04 | 0.07 | 0.12 |
| | 25% | 7937.73 | 591.12 | 733.05 | 1055.60 | 2084.64 | 115.87 | 8.63 | 10.71 | 15.41 | 30.43 | 6.11 | 0.46 | 0.57 | 0.81 | 1.60 | 0.20 | 0.01 | 0.02 | 0.03 | 0.05 |
| | 50% | 7237.35 | 584.37 | 641.08 | 697.94 | 745.54 | 105.65 | 8.54 | 9.37 | 10.20 | 10.90 | 5.57 | 0.45 | 0.50 | 0.54 | 0.58 | 0.18 | 0.01 | 0.02 | 0.02 | 0.02 |
| | 75% | 7233.99 | 548.66 | 581.60 | 619.58 | 649.28 | 105.60 | 8.06 | 8.54 | 9.08 | 9.51 | 5.57 | 0.44 | 0.46 | 0.49 | 0.51 | 0.18 | 0.01 | 0.01 | 0.02 | 0.02 |

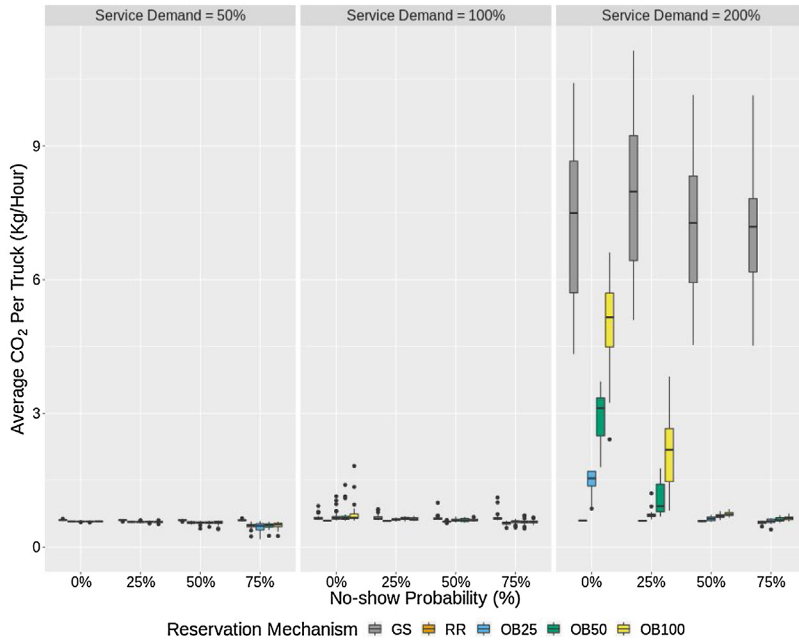


**Fig. 6.** The impact of overbooking reservation mechanisms on $CO_2$ emissions.

consists of the following statistics: the number of trucks serviced during official business hours and overtime, the average time the drayage trucks had to wait before receiving service, the average queue length of trucks waiting for service, and the emission of the greenhouse gases $CO_2$, $NO_X$, PM, and THC.

In general, the go-show mechanism performed best in terms of container pick-up service productivity. However, because there is no reservation mechanism, go-show performs worst in terms of the length of the overtime period, waiting time, queue length, and greenhouse gas emission. As indicated in Table 2, during the high-demand period (200% of the maximum working capacity), the container terminal has to serve more than 45 remaining trucks during the overtime period. During overtime, the drayage truck can wait as long as an hour before receiving service, and the queue length can go up to 25 trucks. The simulation, therefore, shows that the go-show mechanism will result in undesirable conditions.

The application of reservation mechanisms can substantially reduce all the negative externalities. In extreme conditions, the application of the regular reservation mechanism shows the best performance in the length of the overtime period, waiting time, queue length, and greenhouse gas emission. However, this mechanism performed the worst in terms of productivity. This is due to the strict limitation on using the reservation time slots – no allowance is made for additional reservations. One time slot can be reserved for one appointment only, without considering the frequent occurrence of no-shows. In response, the ORM allows for additional reservation bookings that exceed the terminal's maximum capacity.

As shown in Table 2, the application of an ORM will result in higher productivity while maintaining low negative externalities. The terminal can serve all incoming requests on time without running into excessive overtime. High overtime intensities only appear when the workload of the container terminal is exceptionally high, at 200% of maximum capacity, with a low level of no-shows. Even in exceptional conditions, the drayage trucks wait only up to 16 min before receiving service. In this situation, the ORMs also reduce overtime, waiting time, queue length, and greenhouse gas emissions.

## Conclusion

Truck appointment systems facilitate the coordination between the container terminals and the drayage trucks in container pick-up operation reservation. In many cases, trucks with a reservation do not appear at the scheduled appointment. In response, this research proposes the ORM to alleviate the negative impact of no-show occurrences. Unlike regular reservation mechanisms that limit the number of incoming reservations according to the maximum service capacity, the ORM allows the number of incoming reservations to surpass the maximum service capacity of the container terminal.

The researchers in this study encountered no existing study that incorporated the critical importance of no-show occurrences in proposing improvements to the reservation mechanism of the appointment system. Moreover, previous studies typically adopted mathematical modelling, operational research, or discrete-event simulation approaches. Those approaches tend to overlook the communication and operational sequence of the appointment reservation process in the formulation and evaluation of their improvement proposition or model. In response, this study applied business process analysis and agent-based simulation techniques to analyze, propose, and evaluate the proposed solution.

The research shows that the application of ORMs can lead to high levels of productivity and service while maintaining low levels of such negative externalities as queue length, overtime, and greenhouse gas emission. High overtime intensities only appear when the workload of the container terminal is exceptionally high, at 200% of maximum capacity, with a low level of no-shows. Even in exceptional conditions, the drayage trucks wait only up to 10 min before receiving service. In this situation, the ORMs also reduce all negative externalities. In practice, if a container terminal aims to maximize the productivity of container pick-up operation, it can set the overbooking ratio to 100% (OB100). If the rate of no show reaches an unlikely level of 0%, the trucks have to wait up to 16 min before receiving service. If the rate of no show is higher than 25%, the trucks have to wait less than 6.5 min. The results of this research offer practical insight into the usefulness and limitations of an ORM in alleviating the negative impact of no-show occurrences.

This research has limitations that open up several further avenues of research. First, in order to focus on evaluating the impact of the ORM on the performance of container pick-up operations, a single server setting was intentionally used. This was done to prevent the interference effect that a multiple-server setting might have produced. It will be of value to extend this research to multiple-server settings. A second research option is to extend the reservation mechanism by adding predictive analytics capabilities so that the system could accurately predict the no-show rate. This would allow the container terminal to optimize its overbooking quota offering. Investigating ways in which current advanced technologies, such as the Internet of things, artificial intelligence, and blockchains, could be adapted to improve the existing reservation mechanism is a third possible research avenue. Another prospective research direction is redesigning the incentives mechanism to motivate the drayage truck companies to show on time, i.e., increasing the handling fee if no-show is incurred, offering the discounted price, etc.

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