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Multimethod simulation approach for capacity design of a truck parking area in city ports

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ABSTRACT. The port induced freight can cause traffic congestion problems in city ports if road freight transportation is used. The secondary congestion problem arises from the pooling of the trucks at the port gates because of the delays of the port operations. The absence of the truck parking areas inside the port causes additional truck trips between the port and auxiliary truck servicing areas around the port. For reducing the impacts of the associated problems of the port induced truck traffic, truck parking areas can be used as buffer zones between the port and city. The purpose of this study is to develop a Decision Support System (DSS) with using multimethod simulation and cost optimization model for the capacity design of a truck parking area for a city port. The preliminary design of the parking area is used to estimate the development cost and outputs of the simulation model is coupled for the capacity optimization for truck arrival scenarios. The methodology is implemented for a case study of the İzmir city port in Turkey. The results of the study indicated that significantly different parking area capacities are required for different truck dwell times for the time restricted and unrestricted truck arrivals.

Keywords: Freight transportation; parking design; capacity; simulation; truck parking operation.

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Introduction

Ports are the principal hubs in the global trade where the freight change the transportation mode between sea, roads, railways and highway. In the last decade, containerization of the conventional bulk cargo has considerably increased the freight traffic at the ports (Yıldırım, Aydin, & Gökkuş, 2020). The increase of the trade demand requires comprehensive capacity expansions of the existing ports or new ports are required to be constructed. Port capacity planning requires extensive efforts for designing the port functional areas to avoid bottlenecks and provide smooth transportation of the cargo between port and hinterland. Hence, the port expansion problem not only deals with the expansion of the port storage area or quay length but the transport capacities of the hinterland link and operational capacities of the port gates should be touched (Meisel, 2009; Dekker, Van Der Heide, Van Asperen, & Ypsilantis, 2013). Especially, providing fast and effective gate operations and persuading a sustainable and urban friendly port operation are challenging tasks for the city ports adjacent to the urban areas. One of the main problems of the city ports caused from the gate and port operations are the truck pooling problems at the entrance gate and urban traffic congestion. To solve these problems, local authorities usually take precautions of restricting the truck traffic within the rush hours and construct pooling areas outside the urban areas. As a major planning policy to decrease the truck congestion, railway and inland waterway transportation are also utilized (Lonza & Cristina Marolda, 2016).

Considering the port induced traffic problems, this paper proposes a Decision Support System (DSS) to reduce the effects of the port induced truck traffic with designing a port integrated truck parking area for short term parking of the trucks. For this aim, Multimethod simulation approach is used with joining the Discrete Event Simulation (DES) and Agent Based Simulation (ABS) approaches (Maurício, Montevechi, Leal, Carvalho Miranda, & Lombordi, 2015; Paiva, Montevechi, Carvalho Miranda, & Pereira, 2017) . The developed simulation model is coupled with a cost model to design the truck parking area with optimum capacity. İzmir city port is chosen as the pilot port for the case study because of its prevailing port induced traffic and gate truck pooling problems. The case study considers merely the containerized cargo and doesn't evaluate the bulk cargo transported from the port. In the scope of the study, the capacity of the truck parking area is determined for the İzmir city port considering the regular truck arrivals (non-restricted) and the truck arrivals with the truck restricted hours scenarios.

Literature review

The truck induced urban traffic congestion problems have a great reputation for the port cities in developing countries under substantial port-city expansion conflict. In many ports, without extensive intermodal connectivity, the cargo is transferred with the trucks. In this freight process, the trucks are referred as external trucks in contrast to the yard trucks which are used for horizontal transportation inside the port functional area. The port trucking cause substantial traffic and parking problems in city roads. In literature, researchers point out the phenomena of the port induced truck traffic and its influences on the traffic congestion. For example, in his study, Hall (2015) reported the congestion problem and other environmental problems resulted from the port induced truck traffic of the Port of Vancouver and suggested precaution practices to solve this problem. In a similar study, Van Klink (2001) investigated the port congestion problem for the main functional areas of a port and stated that the inland accessibility and hinterland connectivity are significant contributors to decrease the port congestion and provide economical port operation. Zhang, Jenelius, and Ma (2017) proposed a cost model to promote transport modes other than truck transportation for reducing the effects of port induced truck traffic. The study argued that extra congestion tolls can be used to decrease the truck pooling at a port. Guan and Liu (2009) proposed a queuing model to evaluate the congestion cost at the gate of a typical port. He implemented a cost optimization study to minimize the total system cost which includes the port operation cost and truck waiting cost. His study also indicated that an optimum cost can be realized by implementing a cost optimization model for different truck interarrival distributions. Flemming, Huynh, and Xie (2013) implemented an ABS model to evaluate the gate congestion considering the car following theory for a pooled gate queue. Study results indicated that pooled queue is efficient in decreasing the truck waiting times. Wall, Rodgers, Fujimoto, and Hunter (2015) integrated the DES with a microscopic traffic simulation model and employed a traffic congestion analysis for the port of Savannah considering the growth scenarios of the freight throughput. In this study, traffic congestion problem caused by the fluctuation of truck arrivals within time is also examined and it was found that truck pooling greatly contributes to the traffic congestion. In another study, Huynh, Smith, and Harder (2016) argued that, the arrivals of the trucks should be scheduled with uniform arrivals and night time deliveries should be considered to decrease the truck congestion in ports. In their study, Giuliano and O'Brien (2007) pointed out the necessity of a truck appointment system to decrease the port congestion and also minimize the freight induced carbon emission during the gate operations. To investigate the truck congestion problem at the gate operations, Rajamanickam and Ramadurai (2015) developed a DES model. The study also comprised the truck turnout times inside the terminal, and influences of staggered booths and additional slip roads. The study indicated that the unavailability of the container dispatching schedule in the terminal obligates the truck drivers to join the queue at the earliest possible time in order to pick up/drop the containers which causes truck pooling problems.

In conducted studies, many efforts and precautions are available for decreasing the port induced truck traffic congestion problem. Some of the principal operational strategies are the diversion of the freight to railway transportation or short sea shipping (Le-Griffin & Moore, 2006; Banister & Berechman, 2001) or gate appointment strategy which allows truckers to make a scheduled pick-up or drop-off (Giuliano, O'Brien, Hayden, & Dell"Acquila, 2006; Yahalom, 2001). One of the common solutions is to implement truck restriction hours which in return may yield the decrease of the port competence. For example, in their study Regan and Hall (2018) implied the negative effects of the container trucking restrictions for the Port of Vancouver. The study reports that, the application of the truck restricted hours policy favors only the local community and excludes the actors of the logistic companies. Hence, in return the port competence will be decreased. Karakikes, Hofmann, Mitropoulos, and Savrasovs (2018) integrated ABS and traffic microscopic simulation models for evaluating the traffic and logistics measures in the wider area of Volos Port. The time restriction of the trucks is also implemented with limiting the probable truck transaction by incentivizing the trucks to night time shifts. The method is not a solid ban of vehicles but charging extra port fees for the trucks and this process is used to decrease truck arrivals and departures at peak hours of a day. In a different study, Bentolila Ziedenveber, Hayuth and Notteboom (2016) investigated the applicability of a truck appointment system and charging extra port fees for the trucks arriving the peak hours of a day. They argued that, increasing the incentive for the night time delivery will not motivate the customers and the additional costs for the logistic firms also decrease the port competitiveness.

In literature, very few studies investigate the contribution of the truck parking areas for decreasing the port induced truck traffic in urban roads. Some of the literature for the truck parking problems are as follows.

Malik, Sánchez-Díaz, Tiwari, and Woxenius (2017) investigated the truck parking practice problems in Sweden and India and proposed several precautions to improve the parking management for trucks. They reported the requirement of dedicated parking and loading zones and isolating the truck traffic from the urban roads. In a similar research, National Transport Safety Board (NTSB, 2000) carried out a comprehensive analysis for the truck parking areas and their influence on the highway safety. The study specifically focuses on the truck parking and trucker resting areas at the highways to prevent the fatigue linked truck accidents. Results of this study implies that the contribution of the truck parking areas has great contribute to solve the congestion problem in urban traffic by preventing truck pooling near the city center.

In practice, the truck parking areas are commonly used for principal ports of the world. For example, Rotterdam port offers a truck parking area for resting and servicing with a capacity of 750 trucks with a fee of 1 €/ hour and maximum 10 € / truck. Port also provides long-term parking slots for trailers and semi-trailers (Port of Rotterdam, 2019). Similarly, Hamburg port also provides parking spaces to solve the parking needs of the trucks. The port authority also maintains a goal of realizing optimal utilization of the available parking slots and to decrease the elapsed time for searching an idle slot (Hamburg Port Authority [HPA], 2018).

In previous studies, the truck traffic congestion problem is a well-recognized problem especially for city ports. The truck pooling problem in city ports are tried to be resolved with precautions of using truck appointment systems and truck restriction hour practices. Especially, implementing an hour restriction policy for the trucks was not reported as an efficient solution to solve truck pooling problems. Furthermore, it was reported that restricting the truck arrivals or charging extra fees to the day time truckers decreases the port competence. Apart from the solution efforts for the port induced truck traffic, this study underlines the importance of the port truck parking areas to solve truck pooling and parking problems in city ports. As a comprehensive solution to the problem, this study proposes a decision support system with the multimethod simulation approaches to implement optimum capacity design for truck parking areas in a pilot city port and performs a preliminary capacity design for the truck parking area by solving the following problems:

- Decreasing the truck pooling due to gate operations,
- Minimizing the truck traffic outside the port functional area
- Implementing the truck parking area as a buffer zone for sustaining an efficient truck restriction policy.

Properties of case city port: İzmir port

In the scope of the study, İzmir city port is chosen as the pilot port for the model implementation because of its truck pooling and parking area problems. The port is located inside the İzmir city of Turkey which faces continuous population growth and worsening urban traffic problems. The location of the port is shown in Figure 1. İzmir port receives 9.2 million tons of bulk cargo and 610,908 TEU containers per year with 974 container vessel calls (Deniz Ticareti Genel Mudurlugu [DTGM], 2019). The port freight traffic is estimated to be increased by 67% between years of 2018 and 2030 (Gökkuş, Yıldırım, & Aydin, 2017). Although the İzmir city port has a railway connection with hinterland, significant portion of the port's throughput is delivered to the city and its industrialized zones with the road transportation. Hence for the İzmir port, the road freight transportation is realized as the principal mode of transportation which correspond to nearly 90% of total container throughput. Remaining portion of the freight is transported with railway transportation (Izmir Port Authority [IPA], 2017). During the busy periods, it was observed that truck queues are formed at the service roads of the port entrance gates. The port induced truck traffic congestion and gate queuing is especially severe after holidays and weekends.

The existing port operates a small truck parking area for mainly loading and unloading of the bulk cargo with a capacity of 130 trucks. The parking area has an insufficient capacity for serving the existing and future truck parking needs. The parking area is also occupied with the empty containers and handling equipment which further reduce the capacity. For solving the parking space problems, privately-owned truck parking areas and container freight stations are constructed outside of the port area for temporary truck parking and the traveling truck share the urban road network. Especially, during the peak gate operations, container trucks continuously travel between the nearby privately-owned parking areas and port which generate a secondary truck traffic congestion in the adjacent roads. This secondary truck traffic also valid during the truck entrance restriction hours.

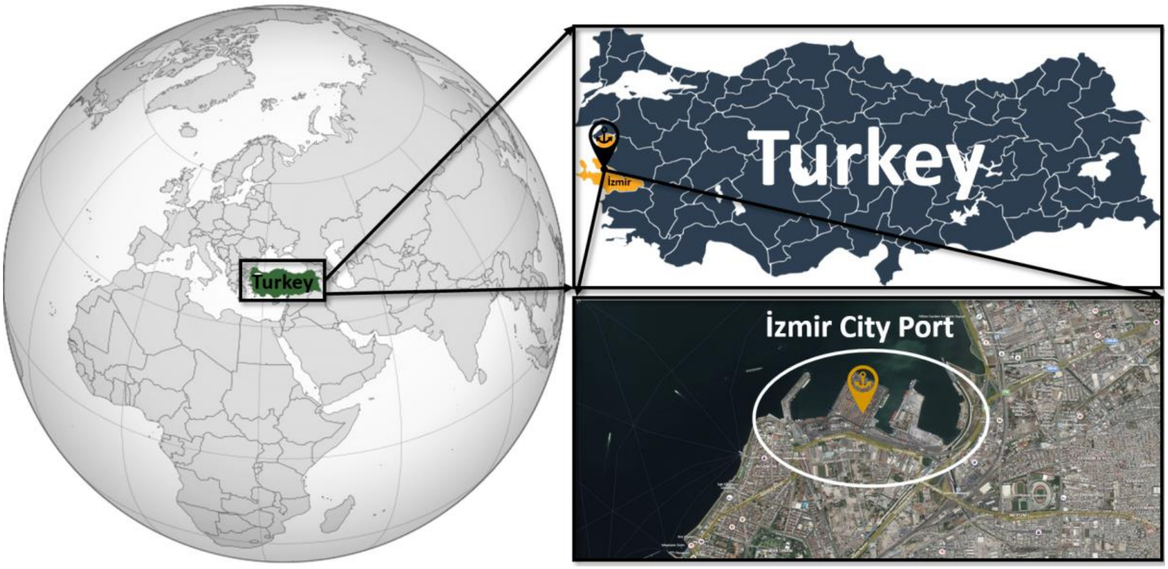


Figure 1. Location of the pilot city port: İzmir Port.

For the last decade, the port induced truck traffic problem was major concern for the local community and decision makers of the İzmir city. Following the decision taken by the İzmir Metropolitan Municipality in 2017, the truck restriction hours inside the city limits were taken between 07:00-10:00 in the morning and 16:00-20:00 in the evening. However, without an integrated truck parking area within the port functional area, the strict restriction hour policy makes no reliable influence on the port induced truck traffic problem. Truck restriction practice further increases the traffic congestion and truck pooling at the port and port connected viaduct as shown in Figure 2. For eliminating this problem, a truck parking area with a sufficient capacity is required adjacent to the port area and its capacity should be determined carefully.

Figure 2. (a-b) Truck parking problem at the entrance gate of the port, (c) Truck pooling problem at the viaduct resulting from the truck entrance restriction.

Methodology and analysis

Parking area design

In a typical port, terminal provides the interface between the sea and hinterland. Specifically, for the containerized cargo, trucks arrive to the port entrance gate where the official documents are processed. If gantry cranes are used, trucks are directly sent to the container blocks otherwise, trucks are served at the loading/unloading bays or parking areas. For the latter case, reach stackers, container forklifts or straddle carriers are used for horizontal transportation between the yard and trucks. Apart from the loading/unloading bays, truck parking areas show similarities with the car parking area with additional design limitations. Parking slots inside the truck parking area are designed with the characteristics of the single or articulated trucks. Compared with the conventional car parking area, the parking slots require wider service roads, a marshalling area where trucks assemble prior to moving into the parking position, and a maneuvering area. For carrying out the functional design, a design vehicle is used as a full articulated type truck with a total length of 14 meters with cab and trailer. The minimum clearance dimension for maneuvering is suggested as 20 meters and the preferable depth is 25 meters. The preferable parking slot width is 5 meters (United Nations Conference on Trade and Development [UNCTAD], 1985) and the typical layout of the truck parking area is shown in Figure 3.

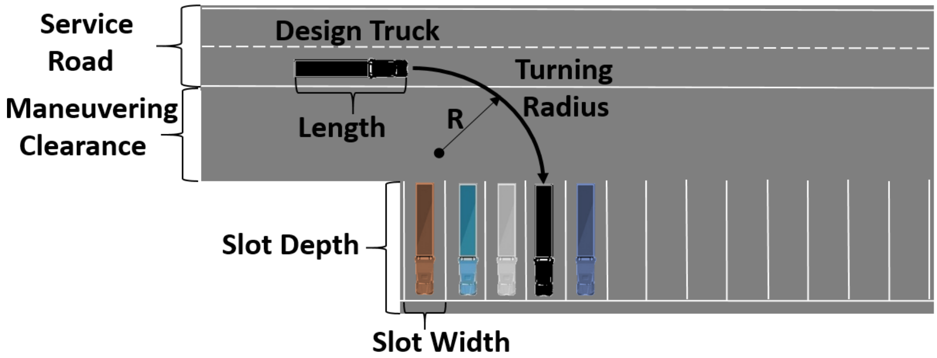


Figure 3. Typical truck parking area layout.

The required area for each parking slot can be determined with Equation 1. and it is a modified form of a basic slot calculation for the car parking area (Wright & Ashford, 1989).

$$A_s = L_{sw} \times (L_{sd} + L_{cd} + L_{lw}) \times c_t \quad (1)$$

Where; A_s is the total area for the slot, L_{sw} is the width of the slot (m), L_{sd} is the depth of the slot (m), L_{cd} is the depth of the clearance (m), L_{lw} is lane width of the service road(m) and c_t is the multiplication factor for including the unoccupied space in the parking geometry. The multiplication factor is not used if the detailed design of the parking area is provided. Total parking area (A_{st}) is then calculated as a function of number of slots (N_s) and total area for each slot (A_s) as given in Equation 2.

$$A_{st} = N_s \times A_s \quad (2)$$

The total truck parking area doesn't include the occupied area of the service gates, toll boxes, administrative buildings and other facilities.

Simulation modelling practice

In this study, Multimethod Simulation Modelling (MSM) is used with coupling the DES and ABS methodologies. ABS is an important branch of distributed artificial intelligence which is used to solve the large and complex problems. In ABS, the multi-agent system is a set of multiple agents whose goal is to decompose the large and complex system into small, communicated and coordinated sub-systems to manage the complexity (Borshchev, 2015). In the ABS framework, agent is an entity that can run independently inside an environment which is influenced by its own living environment. It can continuously obtain information from the environment to improve its own ability. ABS can practice more complex microsimulation capability compared to the DES with intelligent and programmable agents living inside the simulation environment. Among the various framework for project development, AnyLogic software is used as the framework for developing the DSS which supports the use of higher-level programming language of Java and Object-Oriented Modelling approaches.

The agents in the DSS are defined as the main agent, loading truck agent, unloading truck agent and operation bay agent. The main agent, in which the truck agents freely move, is a 2-dimensional space domain of the truck parking area supported in the AnyLogic framework. The parking area layout is designed with 10 parking areas vertically separated with the two-lane and one-directional service roads. Horizontal service roads are connected with the vertical two-lane service roads which direct the truck traffic to the gate or operation bay agent. The parking slots are represented with resources object which are seized and released by the truck agents. The truck agents are generated with the source block at the entrance gate and gate operation delays are considered outside of the simulation scope. The capacity of the parking area can be adjusted with a length variable inside the main agent so the total width of the parking area can be changed with constant number of parking areas. The 2D plan view of the main agent and parking area is shown in Figure 4 with the discrete event simulation blocks.

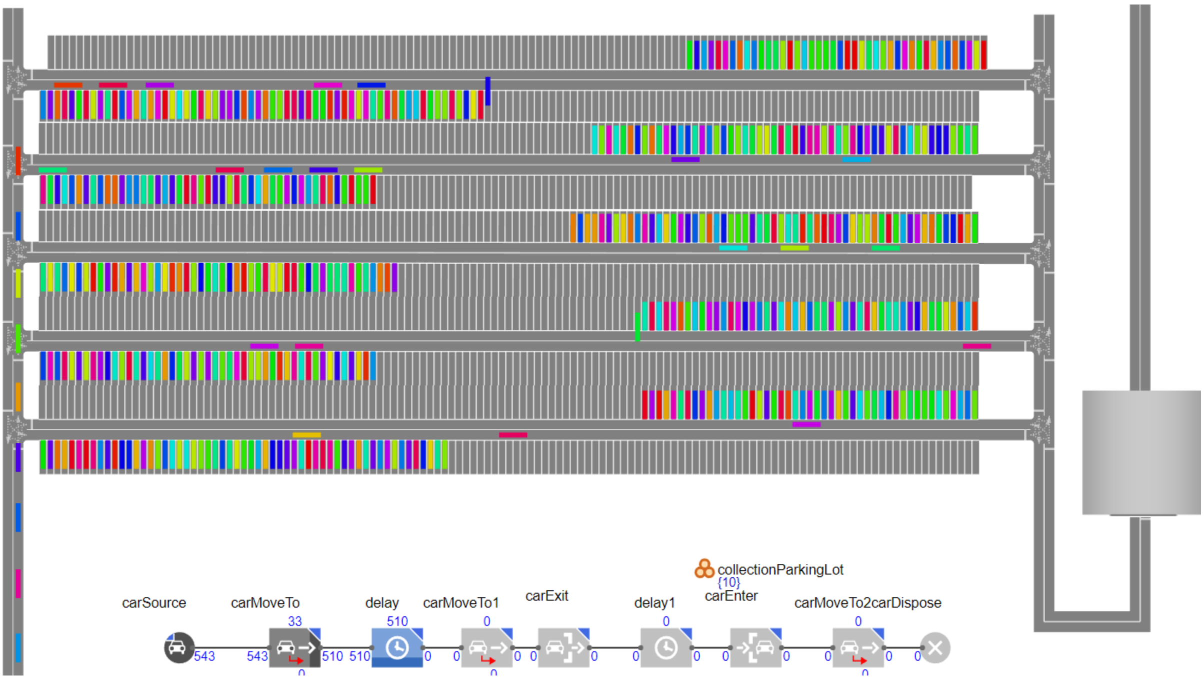


Figure 4. 2D view of the main agent in simulation framework.

The loading and unloading truck agents are generated with arrival rate (truck/hour) inside the main agent. Each generated truck is assigned with the type of unloading or loading trucks and a specific parking area dwell time. The simulation model also has micro-simulation capabilities with implementing the car following theory for the cruising trucks inside the parking area. The maximum speed of the truck is defined as the maximum cruise speed achieved inside the service roads. The acceleration and deceleration of the loaded and unloaded trucks are assumed as realistic values. In the analysis, the maximum speed assumed as 40 km h^{-1} and entering speed is assumed 30 km/h. Acceleration and deceleration of each truck is assumed as 1.8 m s^{-2} and 10 m s^{-2} based on the investigation of the trucks inside the port functional areas (Proctor, Grimes, Fournier, Rigol, & Sunseri, 1995). The ABS logic for the loading and unloading trucks are given in Figure 5.

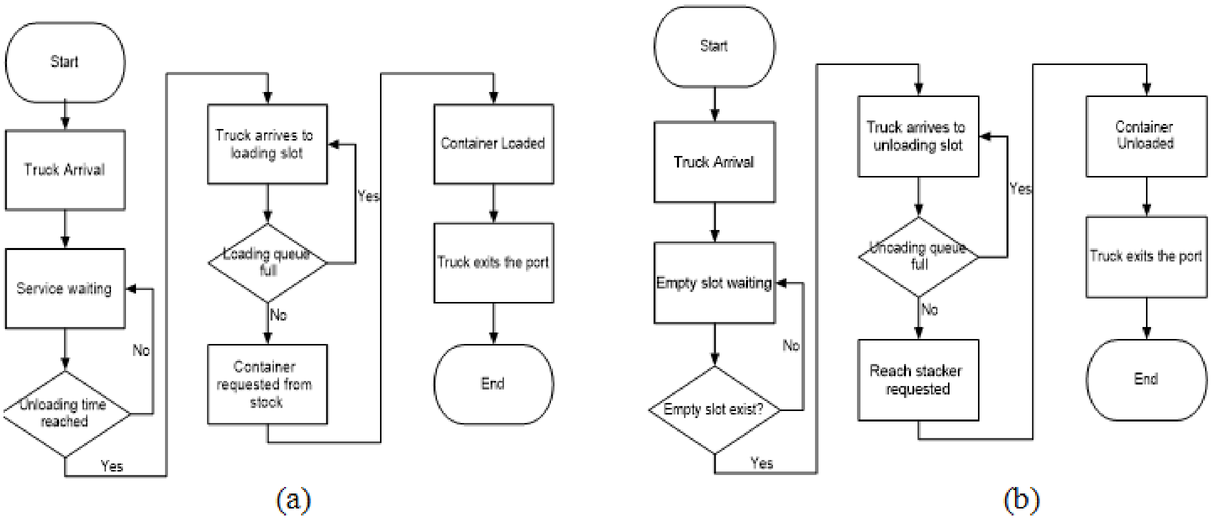
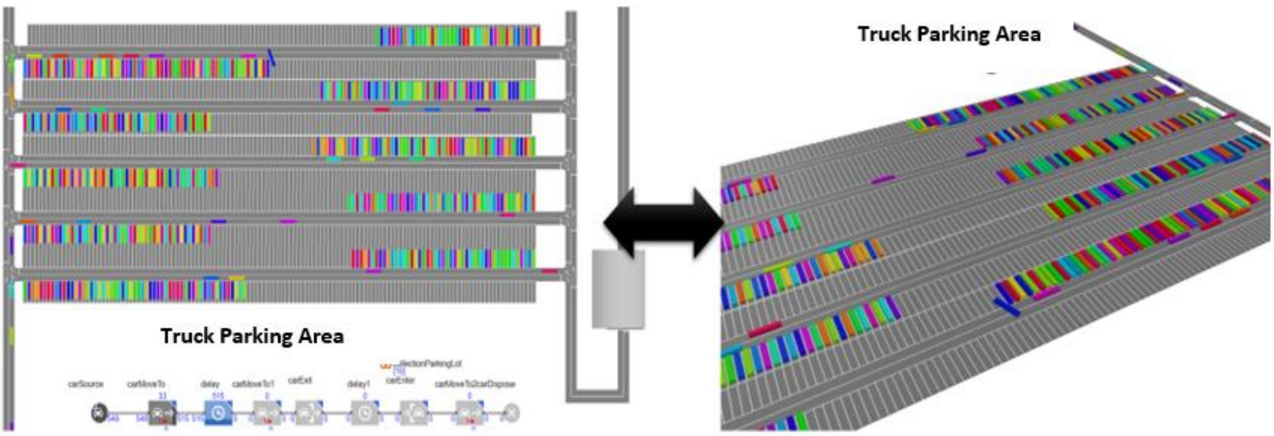


Figure 5. ABS logic for (a) loading and (b) unloading trucks.

The truck loading and unloading operations are complex and unique for the port management strategy. In İzmir port, the unloading trucks are taken to the port storage area and handled with rail mounted gantry cranes. The arriving unloading trucks are first taken to the truck parking area. The arrival schedule of the unloading trucks is stochastic and they arrive before the exact timing of the unloading. The delay between the arrival time and the process time is represented with a truck dwell delay in hours. The unloading process is simulated with an unloading delay of each truck. The hourly unloading capacity of the port is a function of the available equipment and status of the port congestion level. After the unloading operation finishes, if no truck restriction is in practice, truck slot is released and unloading truck leaves the port. If the truck restriction is available, truck returns the same parking slot and waits for the unrestricted time interval for leaving.

The loading trucks also arrives with a stochastic arrival. Each loading truck seizes a parking slot and wait until a determined delay time. The dwell time for loading truck is the summation of the delay caused by the uncertainty of the truck arrival time and total transport delay inside the truck parking area caused by the traffic congestion and waiting delay in the loading queue. Loading trucks are operated inside the container storage yard and the operation delay is represented in the simulation model. During the loading process, an empty slot is reserved for the truck. After the loading is finished, truck uses the same dispatching logic with the unloading truck and waits in the parking area until the time restriction is finished. If no time restriction rule is applied, the truck is dispatched. The truck operation is simulated as a singular agent in which the trucks enters and delays until the loading process is completed. The unloading and loading capacity of the port is determined with the port site investigations and assumptions. As a simplification effort, the delays caused from the port storage area and berth activities are neglected. In Figure 6, the truck activities of truck following and manoeuvring are shown at the microscopic level with 2D and 3D modelling capabilities.



(a) (b)

Figure 6. (a) 2D view of parking and waiting trucks at the parking area and (b) 3D view of the simulation framework.

Cost modelling

In order to implement a cost optimization model, the simulation model generates the output of the total numbers of the unserved trucks. The unserved trucks are considered as the truck deviated from the other parking areas if the port parking area is full. In practice, entrance queue is defined as the parking area. Number of the trucks in the queue is above a predefined limit value and a penalty cost is calculated if a truck is dismissed from the model. Another expense for the model is the construction and operation cost of the parking area. The annual construction cost of the parking area is calculated with the total land cost, construction cost and operation cost of the parking area. The principal aim of the optimization study is to minimize the total annual cost of the truck parking area. The land cost is equal to the annual rental cost if it is now owned by the port authority or the opportunity cost of the land if it is owned by the port. Total annual cost of the parking area can express with the annual cost of land and parking area development costs as given below:

$$C_T = C_L \times A_{st} \times r + C_P \times A_{st} \times (r + r_y + m_a) \quad (3)$$

where; C_L is the cost of land (\$ m^{-2}), r is the interest rate, r_y is the annual amortization factor for the construction cost of parking area and m_a is the annual maintenance cost for the parking area (\$ m^2 slot^{-1}). r_y is determined with the expression as given below:

$$r_y = \frac{r}{1-(1+r)^{-n}} \quad (4)$$

The cost optimization study implements the minimization of the total annual profit cost function as given in Equation 5.

$$C_{TB} = C_T - \sum_{i=i}^{g} c_p \quad (5)$$

where; C_{TB} is the total annual profit cost (\$ m^2 year^{-1}), C_T is the construction cost (\$ m^{-2}), and c_P is the penalty cost for an unserved truck (\$ truck hour^{-1}) and g is the total number of unserved trucks.

Modeling applications and results

Model execution scenario

One of the principal parameters of the simulation model is the truck arrival schedules. The exact arriving schedule of unloading and loading trucks are determined for the existing operation status of the port without any truck restriction. The interarrival data of the loading and unloading trucks are sampled with the sample size of 3000. The arrival time of the trucks are determined by subtracting the dwell time of trucks from the exact interarrival times of the containers. The arrival times of the trucks are sorted and the interarrival times are calculated. The interarrival times are used for fitting a suitable probability distribution for the truck arrivals. The interarrival times of the loading and unloading trucks are shown in Figure 7.

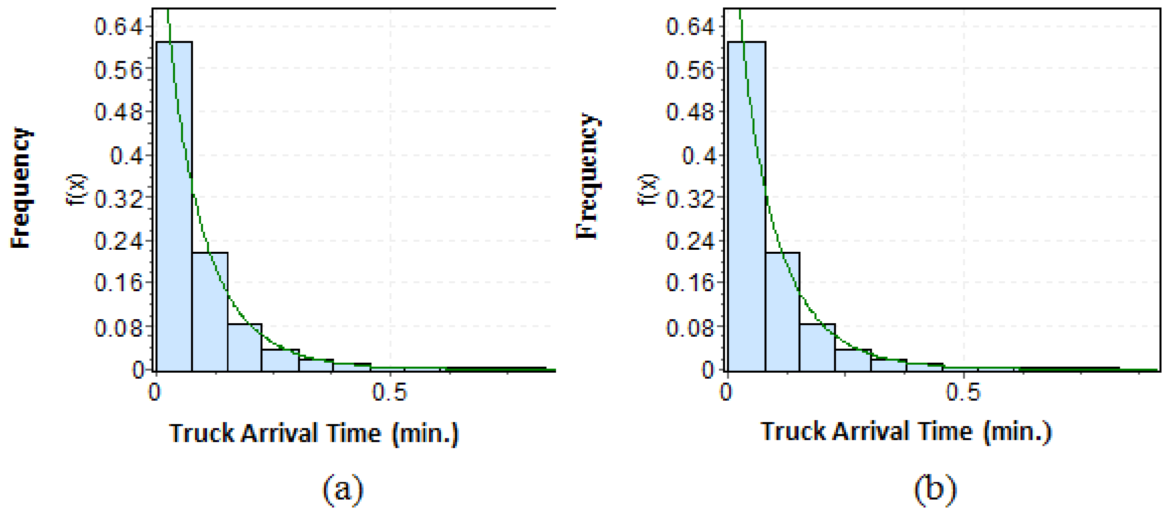


Figure 7. Interarrival times of the (a) loading and (b) unloading trucks.

The average interarrival time of loading trucks are calculated as 3.21 minutes. The dwell times for the unloading trucks are represented with triangular distributions. The distribution parameters for scenarios are determined as (1-3-5) for Scenario 1, (3-5-7) for Scenario 2. The probability distribution plots for the truck waiting times of the scenarios are shown in Figure 8.

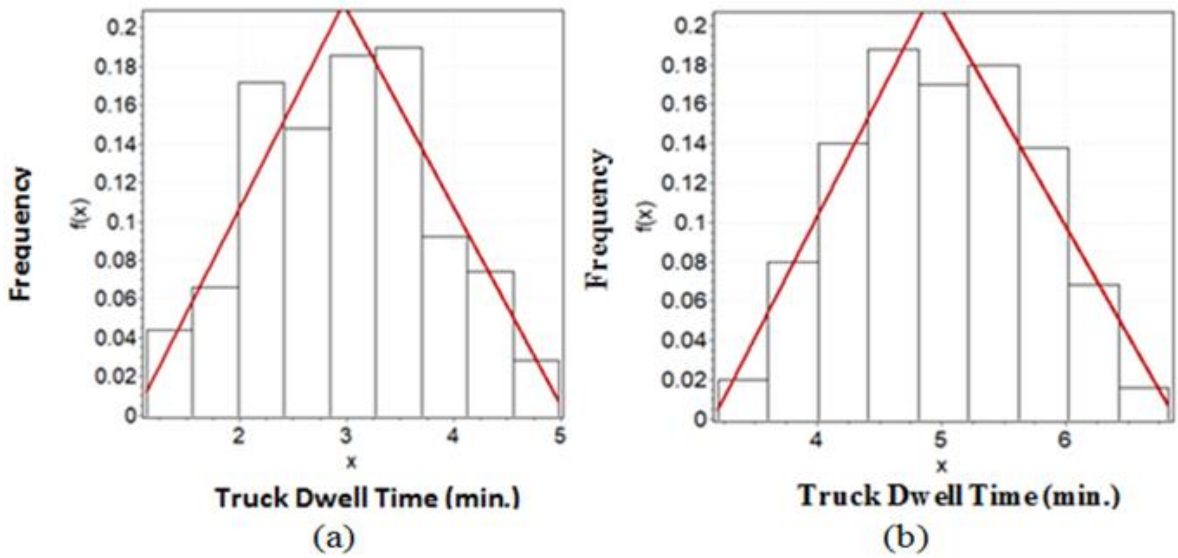


Figure 8. Distributions for the truck waiting times for (a) Scenario 1, (b) Scenario 2.

The parking lot is simulated for 24 hours a day and total of 365 days. The model is executed for unrestricted and restricted operational scenarios. For each of the scenarios, different parking area capacities are examined for the restricted and unrestricted truck arrival scenarios. Figure 9(a) shows the variation of truck numbers in parking area considering the restricted scenario for parking area capacities of 500, 400 and 300 trucks with time window of 700 hours and Figure 9(b) shows the variation of truck numbers in parking area considering the unrestricted scenario for parking area capacities of 300, 250 and 200 trucks.

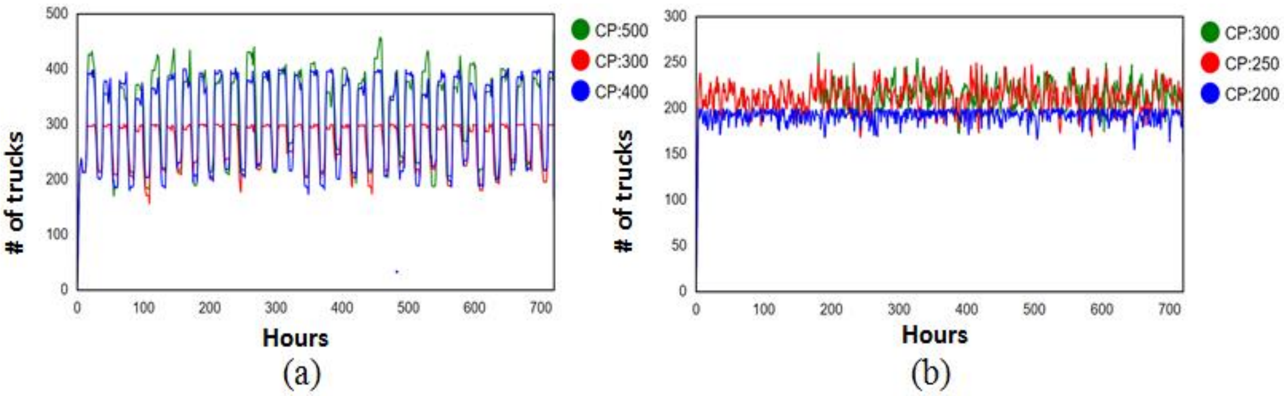


Figure 9. Truck numbers in parking area: (a) restricted (b) unrestricted scenarios (700 hr. time window).

The results show that implementation of the truck restriction scenario yields excessive fluctuations of the truck numbers in the parking area obviously as the result of the instantaneous arrival of the restricted trucks. Additionally, prior to the end of the restriction hour, the dispatched trucks also cause the extreme fluctuation of the total number of trucks in the parking area. The performance metrics of the simulation models for the restricted and unrestricted operational scenarios are given in Table 1.

Application of the cost model

The optimum parking area capacity is determined with a parameter variation study coupled with a cost model. The variable parameter is the parking area capacity and the performance measures are the number of rejected trucks to the parking area because of the insufficient capacity. The model includes dwell cost of the trucks for calculating the parking fee income. The rejected trucks are pooled at another queue outside of the port and accepted to port after the dwell time has passed. Penalty cost is paid to the rejected trucks because trucks require to search and park in another parking area outside of the port area and there would be associated transportation and congestion costs. Used parking area characteristics in the cost model calculations are given in Table 2.

Table 1. Performance metrics for the operation scenarios for average truck waiting time of 3 hours.

Performance Metrics	S1-R	S2-R	S3-R	S4-UR	S5-UR	S6-UR
Capacity (Truck)	200	250	300	400	450	500
Total truck throughput (Annual)	601.123 ±385.7*	604.695 ±397.1	605.035 ±352.1	604.744 ±558.4	605.030 ±376.5	604.398 ±421.6
Unserviceable trucks (Truck year^{-1})	58.275 ±372.8	950 ±51.4	0.0 ±0.0	14.352 ±616.1	463 ±94.6	1 ±2.3
Average number of trucks in parking area	192 ± 0.1	203 ±0.1	213 ±0.2	311 ±0.3	315 ±0.4	348 ±0.4

S1-R: Scenario 1 restricted case, S2-R: Scenario 2 restricted case, S3-R: Scenario 3 restricted case, S4-UR: Scenario 4 unrestricted case, S5-UR: Scenario 5 unrestricted case, S6-UR: Scenario 6 unrestricted case. *:90% confidence interval.

Table 2. Parking area scenario values (UNCTAD, 1985; Antalya Serbest Bölgesi [ASBAS], 2018).

Parking area characteristics	Scenario Values
Slot width	5 m
Slot depth	15 m
Maneuvering clearance depth	20 m
Service road lane width	4 m
Multiplication factor (c)	1.08

The annual operation cost for parameter variation study is calculated with unit area cost, construction and maintenance costs of the parking area. The unit land cost of the port is determined as 200 $ m^{-2} with investigation of the current land value from the website of a real estate agency. However, it was planned that the available land of the port can also be used, and the existing insufficient truck parking area can be extended. For this case, an approximate cost value is considered as $50 m^{-2} for the case study. The construction cost includes the pavement and pavement surface painting costs. The maintenance cost includes the annual maintenance cost and taken as $5 year slot^{-1}. The unit costs, project life and interest rate for the cost model are also given in Table 3.

Table 3. Unit costs for truck waiting penalty and land acquisition, construction and maintenance (UNCTAD, 1985; ASBAS, 2018).

Cost Name	Cost	Unit
Land cost	50	($ m^{-2})
Construction	50	($ m^{-2})
Total cost	100	($ m^{-2})
Project life	20	Years
Maintenance cost	5	($ year slot^{-1})
Interest rate	5	%
Penalty Cost Name	Cost	Unit
Rejected truck penalty	10	($ truck hour^{-1})
Income per Truck	Cost	Unit
Parking fee	5	($ truck hour^{-1})

The income from a single truck was obtained from the tariffs of the nearby privately owned truck service areas as $5 truck hour^{-1} but excluded in cost analysis for sake of simplicity. For the cost model penalty, it was considered that if an arriving truck cannot be accepted to the parking area as a result of lack of free space, a penalty fee is paid to the truck owner for the truck parking service given at a privately-owner truck parking area. Cost modelling study is implemented for the restricted and unrestricted truck operations scenarios. The averages of the model performance metrics for 50 model replications and 95% confidence interval are shown in Table 4.

From the simulation experiments, it can be concluded that the average waiting time of the loading trucks strongly influences the total cost of the model and the total numbers of delayed trucks. For various truck waiting scenarios, the model was executed and corresponding total costs were defined as shown in Figure 10-11.

Table 4. Tabular output of the parking capacity scenarios and associated total costs and income (for 3 hours average truck waiting time).

PC (Truck)	Area (m^2)	PA *10^6 ($)	APA *10^6 ($/year)	RT (Truck)	NT (Truck)	TC *10^6 ($/year)
200	42.12	6.32	0.465	114.000	603.138	2.75
220	46.33	6.95	0.511	43.000	603.705	1.38
240	50.54	7.58	0.558	7.076	602.816	0.70
260	54.76	8.21	0.605	304	603.344	0.61
280	58.97	8.85	0.651	85	602.794	0.65
300	63.18	9.48	0.698	10	603.691	0.70
320	67.39	10,11	0.744	0	604.217	0.74
340	71.60	10.75	0.790	0	604.490	0.79

PC: Parking capacity, PA: Parking area construction cost, APA: Equivalent annual annuity of the initial cost, NT: Number of generated trucks, RT: Number of rejected Trucks, TC: Total cost.

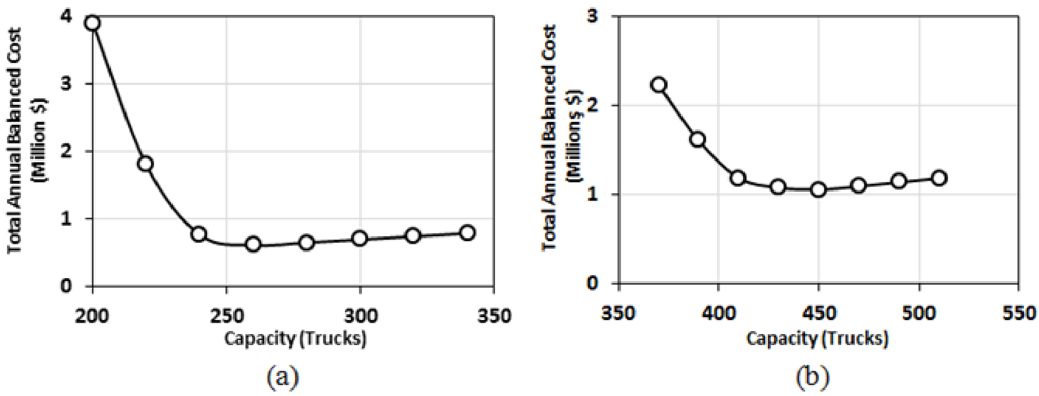


Figure 10. Total cost of the parking area for (a) unrestricted and (b) restricted cases (3 hours dwell time).

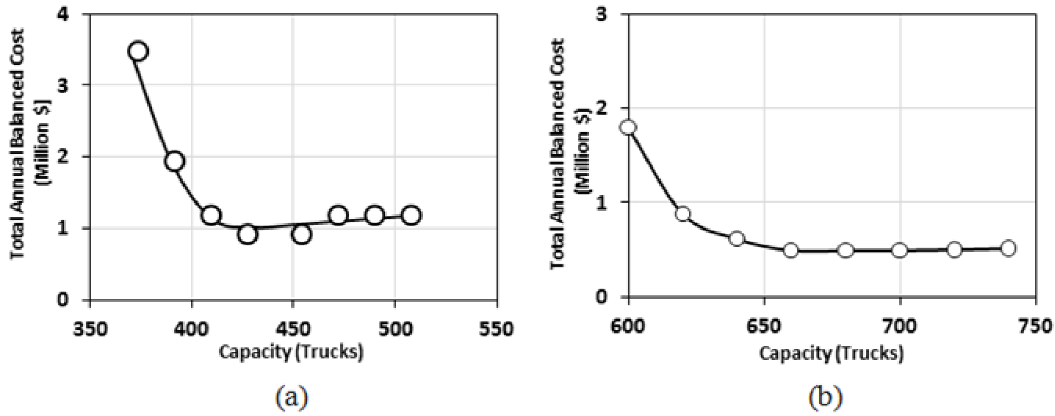


Figure 11. Total cost of the parking area for (a) unrestricted and (b) restricted cases (5 hours dwell time).

According to the cost analysis for different average truck dwell times and truck restriction scenarios, the optimum truck parking area capacities are calculated as 275 trucks for unrestricted and 445 trucks for restricted operation scenarios for the average of 3 hours truck dwell time. The optimum truck parking capacities are calculated as 425 trucks for unrestricted and 657 trucks for restricted operation scenarios for the average of 5 hours truck dwell time.

Profitability analysis with variable land cost

The land cost is the principal contributor for the parking area cost model. Especially without the available land resources, the port authority may also decide to marine fill construction which also will increase the land acquisition cost. In this situation, the variable total cost or the total annual net profit from the model is required to be calculated for the further feasibility and economic analysis. In this part of the study, sensitivity analysis was carried out for considering different land cost values. Especially in the city ports, the land cost value is an important contributor for the total cost of the parking area operation. The analysis was performed with 3 different scenarios with increasing the land cost with successive values of \$150 m^{-2}, \$300 m^{-2} and \$450 m^{-2}. For all scenario, unrestricted truck arrivals are assumed. The annual net profits of the models are shown in the Figure 12.

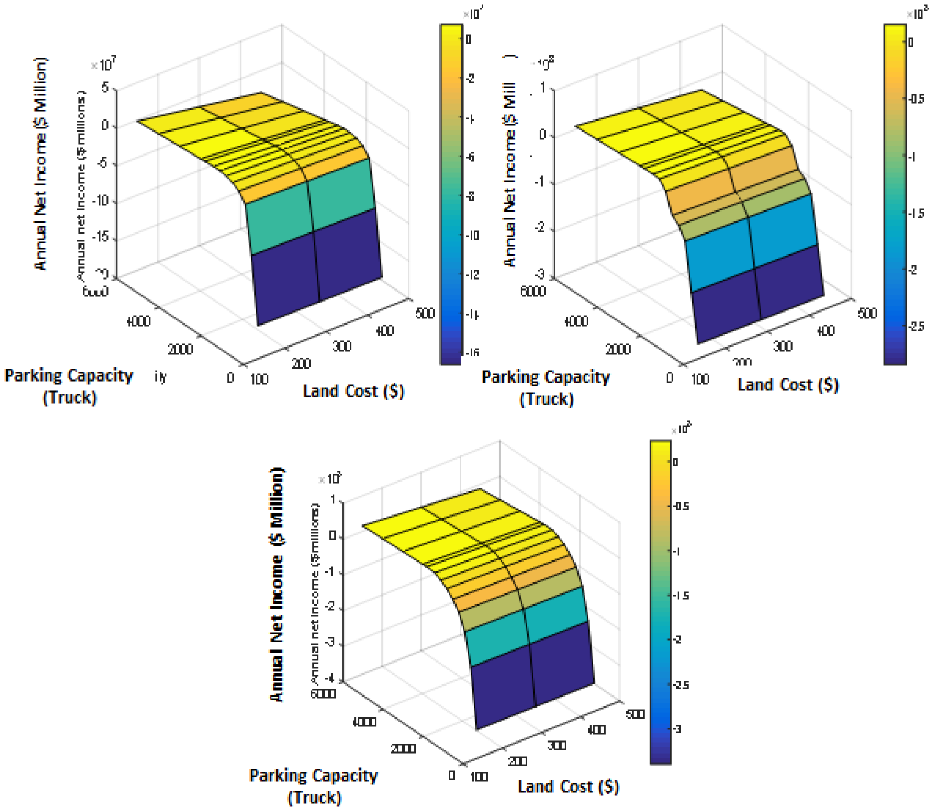


Figure 12. Total net profit from the parking area for average truck waiting times of (a) 3 hours, (b) 5 hours and (c) 7 hours.

The sensitivity analysis for the variable land costs showed that the maximum profit was achieved with 2100 trucks slot capacity for land cost of \$150 m^{-2} for the case of 3 hours average parking time. If the land cost was increased beyond \$320 m^{-2}, the parking project was unfeasible with expenses surpassing the incomes. For the case of 5 hours average truck parking time, the profit significantly decreases with increasing land cost. For this case, the maximum annual profit for the land cost of \$450 m^{-2} is achieved for capacity of 2100 trucks with \$3,883,877. Considering with the lower land cost, a higher truck capacity is required for maximizing the annual profit. For the case of 7 hours average truck parking time, the maximum profit was achieved for 3000 trucks for \$150 m^{-2}, 2800 trucks for \$300 m^{-2} and 2400 trucks for \$450 m^{-2}.

Findings and discussions

Port-generated truck traffic congestion is a major problem in city ports. The literature review and investigation of the İzmir city port case indicate the excessive truck pooling is an inevitable result of the port freight traffic if the port facilities generate a bottleneck. To solve the congestion issue, local authorities apply a truck restriction policy which also generates peak truck pooling at the port entrance with connected roads. To solve this issue, in this study, a Decision Support System (DSS) is developed for implementing the truck parking area for the port and determine the optimum capacity within several operational scenarios. With integrating the discrete event and agent-based simulation approaches, DSS is capable of implementing various truck dwell times and arrival patterns for restriction scenarios. The DSS is calibrated for the case study of the İzmir port with the current freight traffic statistics. The optimized model outputs of İzmir city port show that the optimum truck parking area capacity is increased with 73.1% for 3 hours average truck dwell time and 53.4% for 5 hours average truck dwell time by implementing the truck restriction policy. The cost of free truck parking policy for the port also increases 75.7% for 3 hours average truck dwell time and 55.2% for 5 hours average truck dwell time by implementing the truck restriction policy. In the second part of the study, developed DSS is used for investigating the profitability of the truck parking area under different land cost values. The study results demonstrated that the maximum operational profit is achieved with lower parking area capacity for increasing land costs. The increased cost can be associated with the marine fill jobs and it can be concluded that a detailed cost-benefit analysis should be touched for assessing the feasibility of the truck parking area.

The design and application of truck parking lots is a commonly used in many ports in the world. However, this design and application process is based only on the needs of the trucks. It is possible to prevent the accumulation of trucks at the port gates and decrease the port induced traffic congestion by creating a buffer zone within the port with using the truck parking lots in a holistic manner. As further recommendation, the study can be extended with also considering the mixed cargo handling ports. Moreover, the developed DSS can also be coupled with micro-simulation traffic models for investigating the influences of the port induced truck traffic on the adjacent roads under various truck parking area dispatching strategies.

The study can also be extended considering the environmental issues and the truck operation practices can also be considered using the requirements and suggestions of trucker companies, drivers and port authority. The application of the intelligent transport systems and truck appointment systems can also increase the efficiency and reliability of the truck parking system for the ports.

Conclusion

Study proposed a solution method for truck parking area of the ports by determining the optimum capacity within several scenarios. For this aim, a Decision Support System with using multimethod simulation and cost optimization model for the capacity design of a truck parking area for a city port is developed and preliminary design of the parking area is used to estimate the development cost and outputs of the simulation model. Proposed model results for İzmir city port showed that the optimum truck parking area capacity increased with 73.1% for 3 hours dwell time and 53.4% for 5 hours dwell time by implementing restriction policy. The cost of free truck parking policy may result an increase up to 75.7% for 3 hours dwell time and 55.2% for 5 hours dwell time by implementing a restriction policy. The results of the study indicated that significantly different parking area capacities are required for different truck dwell times for the time restricted and unrestricted truck arrivals.

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