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DOI
10.1061/AJRUA6.0001275

Publication date
2022

Document Version
Final published version

Published in
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering

Citation (APA)
Raju, N., Arkatkar, S., Easa, S., & Joshi, G. (2022). Experimental Design for Measuring Operational Performance of Truck Parking Terminal Using Simulation Technique. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, *8*(4), Article 05022002. https://doi.org/10.1061/AJRUA6.0001275

Experimental Design for Measuring Operational Performance of Truck Parking Terminal Using Simulation Technique

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Abstract: The paper presents the performance analysis of a well-designed truck parking terminal, which is planned for regulating truck traffic over a commercial port. The designed truck parking terminal is modeled using microscopic traffic simulation, which is validated based on the movement of vehicles to the parking bays. After validation, various scenarios were created to evaluate parking terminal performance by varying the parking volumes and number of operational parking bays. The operational efficiency of the parking terminal for design scenarios was evaluated using parking performance measures that included parking load, average parking duration, parking turnover, and load-to-capacity ratio (parking index). For the design peak load of 4,200 vehicles/day with a uniform arrival rate, the operational efficiency was found to be about 73%. Interestingly, it was observed that with an increase in the number of operational parking bays, the parking efficiency decreased for the given volume level. Considering this phenomenon, a methodology was developed to identify the optimum number of parking bays under varying demand-supply scenarios. The developed methodology can help identify the optimum number of parking bays for existing and future (expansion) conditions. Furthermore, this study highlights the importance of using simulation in evaluating operational and design aspects of transportation facilities, where the need for repeated empirical observations is eliminated. As such, this study should be of interest to traffic engineers and practitioners interested in the efficient operation of parking terminals. **DOI: 10.1061/AJRUA6.0001275.**

Author keywords: Terminal; Simulation; Trucks; Performance measures; Parking bays; Optimization.

Background

With the ever-growing traffic flows and road infrastructure, handling the subsequent parking activities is one of the significant challenges in transportation. Further parking systems act as the core of urban transportation systems. The impacts of lack of parking systems and poor parking management are becoming increasingly visible in transportation systems. In considering the risk of failure along with space constraints in the present transport network, parking operations are one of the critical aspects in the transportation domain. They were further marking parking management as vital in handling the parking demand. However, unlike the other transportation components, the research advancements in parking operations are limited in nature.

In commercial ports, ongoing activities such as imports and exports of goods result in a vast amount of trucking activity over the port. Managing truck movements would be essential to reduce traffic congestion over the road network. Banning parking activities around the port premises will increase delays for port operations while permitting parking over port premises will increase congestion inside the port. To address this problem, a centralized parking terminal would be essential. Further, with real estate restraint over the port premises, the parking terminal must be planned effectively, focusing on port trucking activity. In this respect, the parking terminal functionality must be evaluated for various supply-demand scenarios so that the operational performance of the terminal can be best quantified.

After a thorough literature review, it was found that, compared to other transportation components, parking studies are limited, and most of them are confined to empirical observations. Hence, the studies have focused mainly on parking characteristics, when various design guidelines have been developed (Dávid and Krész 2018; Litman 2016; Liu et al. 2015; Paidi et al. 2018; Young 1988). Besides, operational measures such as parking indices have been developed by García and Marin (Chen et al. 2016; García and Marín 2002; Lei and Ouyang 2017; Pierce et al. 2015). The implementation of intelligent transportation systems technologies in newly-constructed parking terminals has boosted parking studies and generated different smart parking policies that have aided their performance (Carrese et al. 2014; Dill 2008; Hensher and King 2000; Horni et al. 2013; Rowe et al. 2011; Wang and He 2011), modeling logistics (Davidsson et al. 2005; Firdausiyah et al. 2019; Perboli et al. 2018), optimal parking supply (Duan et al. 2019; Ji et al. 2015; Wang et al. 2019), urban freight parking (de Abreu e Silva and Alho 2017), electric vehicle parking (Aggoune-Mtalaa et al. 2015; Kang and Recker 2009; Latinopoulos et al. 2017; Li et al. 2010), and modeling parking near railway stations (Debrezion et al. 2008). Wang et al. (2012) proposed an adaptive longitudinal driving assistance system based on driver characteristics, with a pioneering contribution of a self-learning component for

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Note. This manuscript was submitted on May 3, 2022; approved on July 31, 2022; published online on October 8, 2022. Discussion period open until March 8, 2023; separate discussions must be submitted for individual papers. This paper is part of the ***ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering***, © ASCE, ISSN 2376-7642.

self-improvement. Ma et al. (2010) tested the coordinated and conditional bus priority traffic signal algorithms over coordinated, signalized intersection groups.

The previous parking studies were mainly limited to the analysis of supply-demand relations. To fully evaluate the parking terminal's functional performance, all system elements should be analyzed, including existing and future demand volumes, the arrival pattern, vehicle characteristics, parking duration, and the number of parking bays. The analysis of such a system is difficult, if not impossible, to perform analytically or through field observations, especially for new planned terminals. Simulation tools can be valuable in simulating and analyzing the performance of such systems.

At the same time, understanding the parking terminal performance over different demand and supply combinations from an empirical perspective is quite tedious and challenging. In this regard, simulation tools provide the opportunity in testing the numerous demand versus supply options. With the technological advances in computations, simulation tools have become valuable in solving traffic-related problems. Using simulation, the performance of transportation systems can be comprehensively evaluated. Examples of simulation studies include evaluating future management strategies of port operation by Easa (1986), analyzing the effect of grade on traffic characteristics by Arkatkar and Arasan (2010) and Bains et al. (2012), analyzing vehicle behavior by Raju et al. (2017), evaluating surrogate safety measures by Gettman and Head (2003), optimizing the traffic signals by Goodall et al. (2013), analyzing pedestrian characteristics by Yang et al. (2005), simulating toll plazas by Bains et al. (2017), and autonomous vehicles (Raju and Farah 2021). However, most simulation studies are related to midblock road sections and intersections.

Interestingly, from the literature, it is observed that researchers used PTV VISSIM (PTV 2016) for modeling various types of traffic conditions; for example, Bie et al. (2016) targeted improving the capacity of signalized roundabouts and solving the constraint of unstable flow patterns. Xu and Zheng (2009) used PTV VISSIM and assessed the impacts of a traffic signal phase scheme and the performance of the bus rapid transit system.

In recent times, Mao et al. (2021) used simulation for investigating the safety effects of work zones and suggested the in-vehicle work zone warning application under the connected vehicle (CV) environment. Coretti Sanchez et al. (2022a) used the simulation in understanding the shared mobility services and demonstrated the application of the simulation model for policy making. Coretti Sanchez et al. (2022b) tested the shared autonomous bicycle systems using simulation tools and assessed the planning strategies. In simulating parking terminals, whereas in the case of parking systems, Waheed et al. (2020) used the numerical simulation approaches in conceptualizing the smart parking systems.

To the authors' knowledge, no comprehensive methodology is available to determine the parking bays' optimum number in the parking system, especially for a truck terminal.

This study presents a comprehensive evaluation of the performance of a proposed truck parking terminal using simulation to improve the commercial operations of the port. Most traffic simulation software is not well-calibrated for parking simulation. However, in this study, a simulation software PTV VISSIM (PTV 2016) that can simulate parking terminals was used. The study involves three phases:

1. Develop and validate a simulation model of the central parking terminal,
2. Simulate various parking supply-demand scenarios, and
3. Analyze the simulation results in-depth to improve parking terminal operations and develop a design tool to help design and manage the parking terminal.

The next section presents the simulation model's development, including the study area, simulation model elements, simulating terminal behavior, and parking performance measures. The following section presents analysis and results, including evaluating simulation scenarios, results of performance measures, and design aid.

Development of Simulation Model

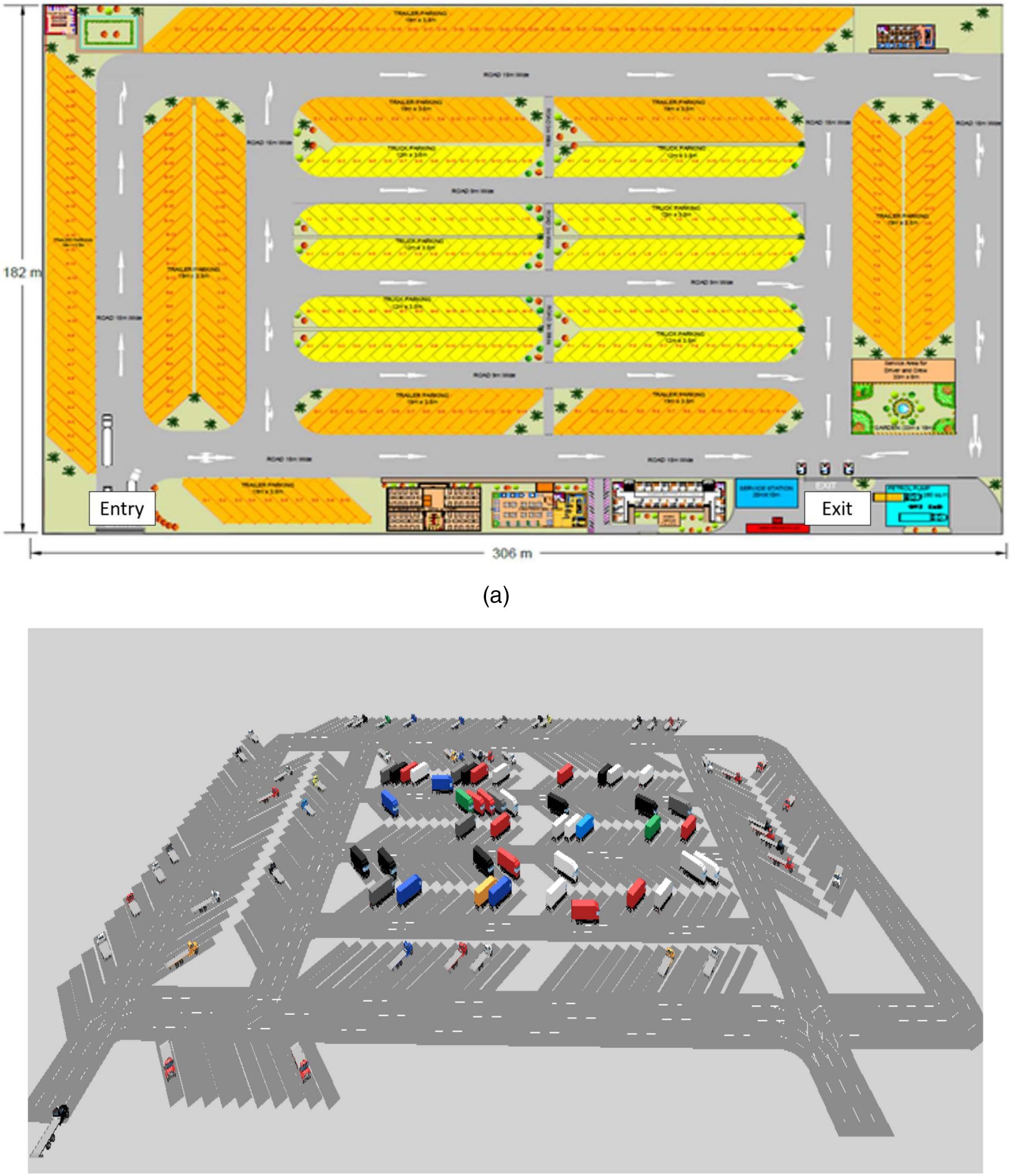
The study area is a truck parking terminal located in the Kandla port, Gujarat, India. The increase in import and export activities of freight movement in this port has caused an enormous trucking activity over and around the port premises and induced a substantial demand for a truck parking facility. Considering current demand along with a future prospective, the port authorities have commenced the design and construction of a centralized truck parking terminal. Various comprehensive traffic surveys were conducted, including traffic volume counts, retention-time analysis of trucks, and in-and-out surveys. After careful comparison with the commodity turnover, the port authorities developed a plan for the proposed parking terminal. The port location is 18 km from port gates on Kandla bypass road, Gandhidham city, Gujarat India. The terminal consisted of 341 parking bays and was designed for a peak volume of 4,200 vehicles per day (60% trailers and 40% containers) for a design period of 10 years. Based on field observations, a uniform arrival rate was assumed. The retention-time analysis estimated that the parking duration of vehicles would be classified into three types (short-term, medium-term, and long-term) with specific vehicle categories, as shown in Table 1. The proposed parking terminal is shown in Fig. 1(a). The interior yellow-colored bays were designated for containers, and the peripheral orange-colored bays were designated for the trailers. The study was conducted to evaluate the performance of the parking terminal design for the forecasted parking loads.

Simulation Model Elements

In line with the study's objective, the parking terminal was simulated using (PTV 2016) by selecting the plan of the parking terminal as a background image. The entire parking terminal is created with the help of links and nodes, followed by parking bays. Other inputs, such as anticipated parking periods (short, medium, and long term), are also assigned to the parking bays with equivalent attraction potential. For the design vehicle characteristics, vehicle dimensions are established in the simulation model according to the design standards for the trailers and containers available in India.

Table 1. Details of the designed truck parking terminal

Type of parking	Parking duration (h)	Average parking duration (h)	Parking turnover per day (vehs)	No. of bays (containers)	No. of bays (trailers)	Total
Short term	< 1	1	24	37	98	135
Medium term	1–3	3	8	96	93	189
Long term	3–5	5	5	—	17	17



(a)

(b)

Fig. 1. Plan and snapshot of the simulated parking terminal: (a) plan of the simulated parking terminal; and (b) snapshot of the simulated parking terminal.

Furthermore, the estimated uniform arrival rate of the vehicles for the daily parking and the generation of vehicle arrivals are prepared for the simulation tool. The uniform random variable of vehicle arrivals is generated as follows:

$$h_i = a + (b - a)R_i \tag{1}$$

where h_i = arrival headway of arrival of vehicle i (h); a, b = lower and upper limits of the uniform distribution of arrival headways (h); and R_i = uniform random number between 0 and 1.

Unlike the simulation of midblock road sections and intersections, the simulation of a parking terminal is entirely different. At the same time, it is quite a challenging task, considering the realistic movement of vehicles. With various variables, it can be noted that simulation can be carried out in the case of midblock and intersections, and the outcomes can be evaluated in 1 to 3 simulation hours. However, applying the same logic in the parking terminal simulation can result in erroneous outcomes. The parking durations may not be precisely in the range of the vehicle arrival rates. With this in mind, taking advantage of the fast-forward option in VISSIM, the simulation was carried out for 24 simulation hours with the given parking times and the designed volume inputs. A snapshot of the simulation process is shown in Fig. 1(b) to visualize the process better.

Simulating Terminal Behavior and Validation

Simulation is conventionally accomplished in four stages as model development, calibration, validation, and analysis/evaluation of specific strategies. The model validation is to match the simulation

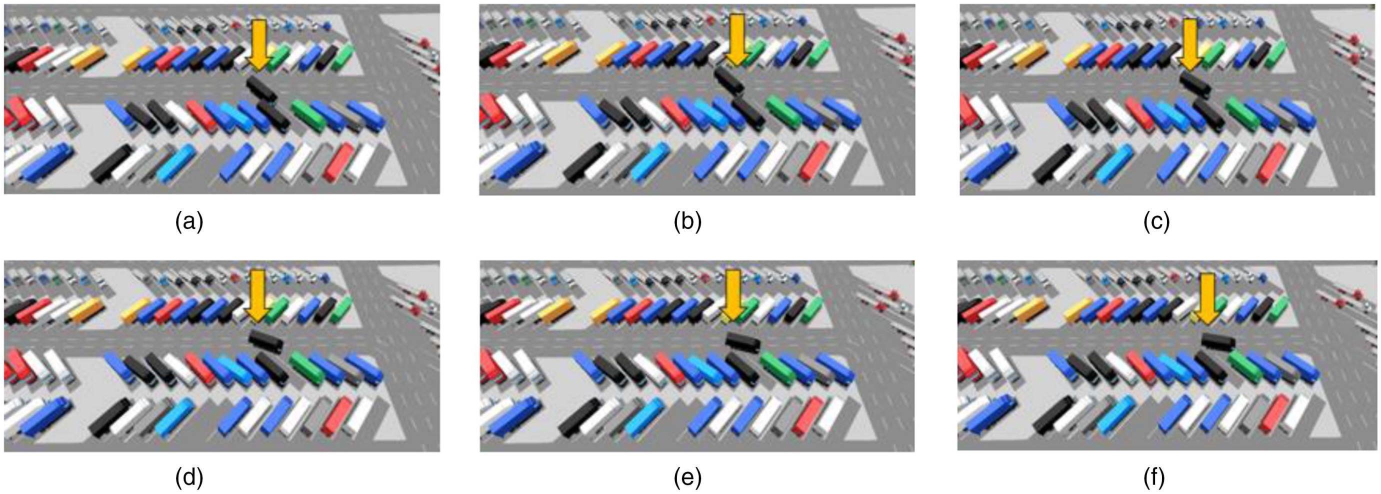

(a) (b) (c) (d) (e) (f)

Fig. 2. Continuous snapshot from simulation illustrating a black truck leaving the parking bay: (a) truck in reverse motion at t1; (b) truck in reverse motion at t2; (c) truck in reverse motion at t3; (d) truck in aisle network at t4; (e) truck moving forward at t5; and (f) fully unparked truck at t6.

results as close as possible to field conditions. In the case of midblocks and intersections segments, the rate of change in flow conditions can have a spillback effect in terms of shockwave effects and impacts the traffic operations. On the other hand, in the case of the present parking terminal, the rate of change in flow will have a marginal effect and more minor spillback impacts. Even in peak demand, vehicle interactions are minimal in the aisle network.

In the present study, since the parking terminal is still not operational, the validation process was performed in a slightly different manner. In the case of midblock road sections and intersections, derived variables such as travel time, stream speed, and traffic volume from simulation can be compared with field observations. However, in the case of a truck parking terminal, the other measures will not be useful in the validation process, considering the fewer vehicle interactions over the driving aisle network of the parking terminal.

In the present study, a different strategy for model validation was adopted. In a parking terminal, generally, a vehicle enters the parking terminal and then parks in the parking bays. After its predefined parking time, the vehicle unparks using backward movements (reverse gear), vacates the parking bay, and then continues its forward movement over the driving aisle network for departure. However, achieving this type of movement is a challenging task in the simulation process. For this, vehicles' movements were used as a validation measure in the parking terminal to match field conditions more accurately. In replicating this behavior in simulation, a reverse link is created. The link took a curved shape by repeatedly adjusting the nodes so that vehicle movements can be more realistic. Once achieved, a parking bay was placed over it. In this way, a single base parking bay is initially created, after which the parking bay is duplicated numerous times and copied over the plan of the parking terminal. Besides, all parking bays are connected to the driving aisle network. Thus, using visual inspection, the entire 341 parking bays were validated with realistic truck movements. To illustrate, Fig. 2 shows a continuous snapshot of the simulation process of a truck (designated with arrows), leaving the parking bay in the reverse direction and continuing its forward movement over the driving aisle network of the parking area. Initially in Fig. 2(a), the truck just initiated its backward movement from the parking bay, and even this movement continued in Figs. 2(b–d); once it acquired the required gap for forwarding movement, the truck has taken forward movement Figs. 2(e and f).

Parking Performance Measures

In evaluating the performance of the parking terminal, three measures of effectiveness that quantify system functionality were used. The measures were based on two variables: parking accumulation and parking load. Parking accumulation represents the occupancy of the parking bays over time. This variable allows the analysis of the demand-supply variation over time. The parking load is based on the number of parking volumes and duration and represents the total vehicle-hours (Veh-hrs) demand of the system. The variable can be calculated as the area under the accumulation curve and is given as

$$parking\,accumulation = (\varphi \times \tau - \rho \times \tau)_T \qquad (2)$$

$$parking\,load = \int_{t1}^{t2} accumulationcurve \times dt \qquad (3)$$

$$parking\,load = \int_{t1}^{t2} (\varphi \times \tau - \rho \times \tau) \times dt \quad \forall\ \varphi \geq \rho \qquad (4)$$

where φ = arrival rate of the truck volume; ρ = departure rate of the truck volume; τ = time step; t = time interval; $t1$ and $t2$ = time instants; and T = time duration.

Based on these two variables, three performance measures were defined: average parking duration, parking turnover, and parking index (load-to-capacity ratio). These performance measures are defined as follows. The average parking duration is defined as the ratio of the parking load to the parking volume. That is

$$parking\,duration = \frac{parking\,load}{parking\,volume} \qquad (5)$$

$$parking\,duration = \frac{\int_{t1}^{t2} (\varphi \times \tau - \rho \times \tau) \times dt}{\varphi} \quad \forall\ \varphi \geq \rho \qquad (6)$$

where φ = arrival rate of the truck volume; ρ = departure rate of the truck volume; τ = time step; t = time interval; and $t1$ and $t2$ = time instants.

The parking turnover measure is defined as the average occupancy of a parking bay by vehicles for a given duration. Generally, it is expressed as the ratio of parking volume to the available parking bays, as follows:

$$Parking\,turnover = \frac{parking\,rate}{number\,of\,parking\,bays\,available} \qquad (7)$$

$$Parking\,turnover = \frac{\varphi}{N-(\varphi-\rho)\times\tau} \qquad (8)$$

where φ = arrival rate of the truck volume; ρ = departure rate of the truck volume; τ = time step; and N = total number of parking bays in the terminal.

The parking index measure reflects the efficiency of the parking terminal for the given parking volume. It is defined as the ratio of load at which it operates to the capacity of the parking terminal, that is

$$parking\,index = \frac{parking\,load}{parking\,capacity} \qquad (9)$$

$$parking\,index = \frac{\int_{t1}^{t2}(\varphi\times\tau-\rho\times\tau)\times dt}{\int_{t1}^{t2} N\times dt} \qquad (10)$$

Note that capacity is evaluated as the product of the number of operational parking bays and the duration of simulation hours.

Analysis and Results

Evaluation of Simulation Scenarios

The developed simulation model was used to test the functional efficiency of the terminal under different scenarios. It was perceived that even though the parking terminal is designed for a peak volume of 4,200 vehicles/day (vpd) with a uniform arrival rate, there can be unexpected variations in demand due to the intense port operation. Hence, the vehicular volume was varied in the simulation to test its effect on terminal performance. Therefore, an experiment was designed, in which the volume at the parking terminal was varied from 600 vpd to 6,000 vpd, with an increment of 900 vpd. The truck arrival pattern to the parking bays was assumed to be uniform, and the anticipated parking durations were short-, medium-, and long-term according to the design.

The simulation was carried out, and the accumulation diagram (plot of the number of parking bays occupied over the duration) was prepared for each scenario, as shown in Fig. 3(a). As noted, initially, when the vehicles arrive and park in their respective parking bays, a steeper slope in the accumulation diagram is observed for a specific duration. At some time later, the system reaches a steady state at which the number of vehicles arriving at the terminal equals those departing the terminal, with some continual parking occupancy. For example, in the 1,500 vpd, the equilibrium is found to be around 100 parking bays. It can be inferred that for the 1,500 vpd demand scenario, the parking operator must reserve a minimum of 100 parking bays to be operational to avoid breakdown of the parking system.

Furthermore, the number of operational parking bays varied from 341 (as the base case) to 325, 300, 275, 250, and 200 bays. Then, the entire simulation process was repeated for the previous parking volumes. To illustrate, the accumulation diagrams for the three cases are presented in Fig. 3(a). To check operational efficiency, queuing analysis in terms of the average queue length per hour is obtained from the simulation model, as shown in Fig. 3(b). As noted, significant queuing starts from a volume of 3,300 vpd, and as the parking volume increased, the queuing length increased. Hence, it may be inferred that as parking volume (demand) increases, the variation in queue length among the different number of parking bays is reduced.

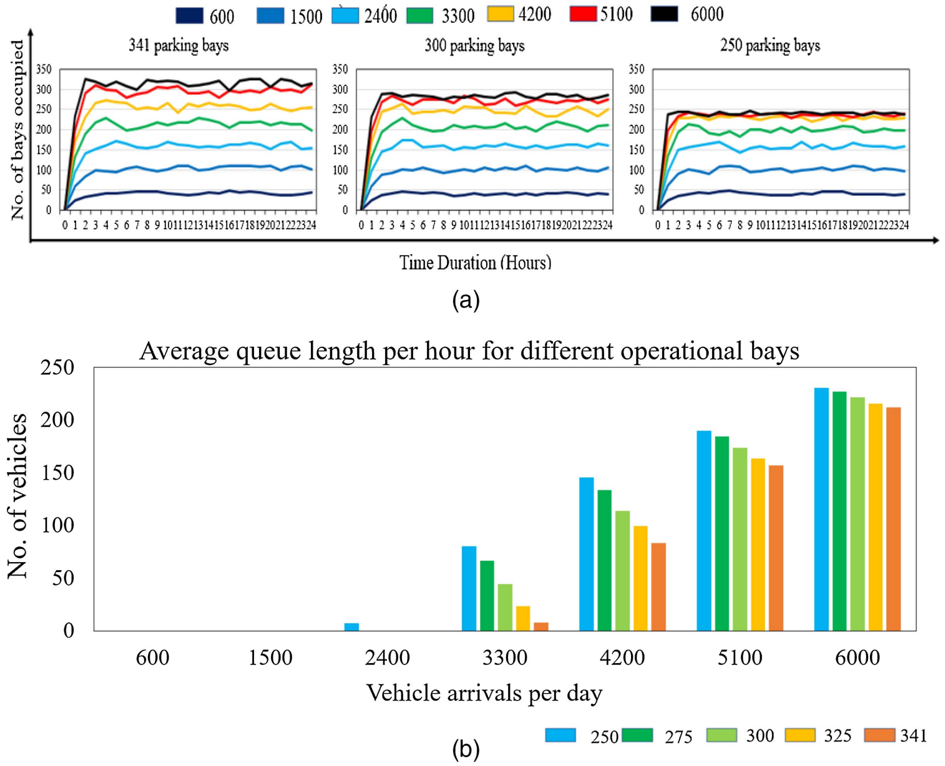


Fig. 3. Accumulation diagram for the parking system for different numbers of bays and average queue lengths of vehicles for different volume levels: (a) accumulation diagram; and (b) average queue length.

Results of Performance Measures

The parking performance measures were assessed for each combination of parking volume and number of operational bays, as shown in Fig. 4. For the parking load, it was found that with an increase in parking volume, the parking load increased up to a certain point with a steep rise in slope. After that, it became parallel to the x-axis, and as the number of operational bays changes, the peak parking load changes, which is a pattern observed in all permutations. From this, it can be interpreted that after a specific parking load, the variation becomes flat, and no more load can be taken by the system, indicating system saturation. In the present case, the peak parking load resembles a road section's capacity under prevailing traffic flow characteristics. From the operator's point of view, the parking index can indicate to the operator to load each parking bay in the terminal to its maximum potential. From the average parking analysis, in the present scenarios, vehicles' parking retention time has not deviated from the input time durations. Based on field observations, it is anticipated that the average parking duration will remain constant.

Moreover, it should be noted that the duration computations are inclusive of the delay due to queuing vehicles in the parking terminal. Therefore, variations in the average parking duration were observed. It was also observed that whenever there was no queue in the system, the parking duration remained constant until a parking volume of 3,000 vpd, beyond which the duration varied as the queue length increased. As a result, the average parking duration parameter is varied with parking volume, which should theoretically be constant. Parking turnover is simply the average occupancy of the parking bay for a given duration and represents the throughput of the parking system. From the operator's point of view, the parking turnover can be an influential parameter in analyzing the parking terminal's fiscal feasibility. The operator covets high parking turnover for making profits, but in design, the supply should accommodate the demand with a reasonable level of queuing to provide a better quality of service.

Finally, the parking index is evaluated for different scenarios. In general, a more extensive parking index indicates more excellent use of the parking terminal, but from the functional point of view, it would not be prudent to run the parking terminal at 100% efficiency. At such a level of efficiency, a slight change in parking load can cause a breakdown of the system. It was observed that for the design peak load of 4,200 vpd at present, the parking index was around 73%, indicating that the design is functionally feasible, where 27% reserved capacity remained (a safety factor). However, currently, no standards are available to grade the parking terminal, and related research has been limited.

Design Aid

It can be perceived that with a change in the number of operational bays for the same parking volume, the parking index would change. A larger number of bays would result in a smaller parking index, as

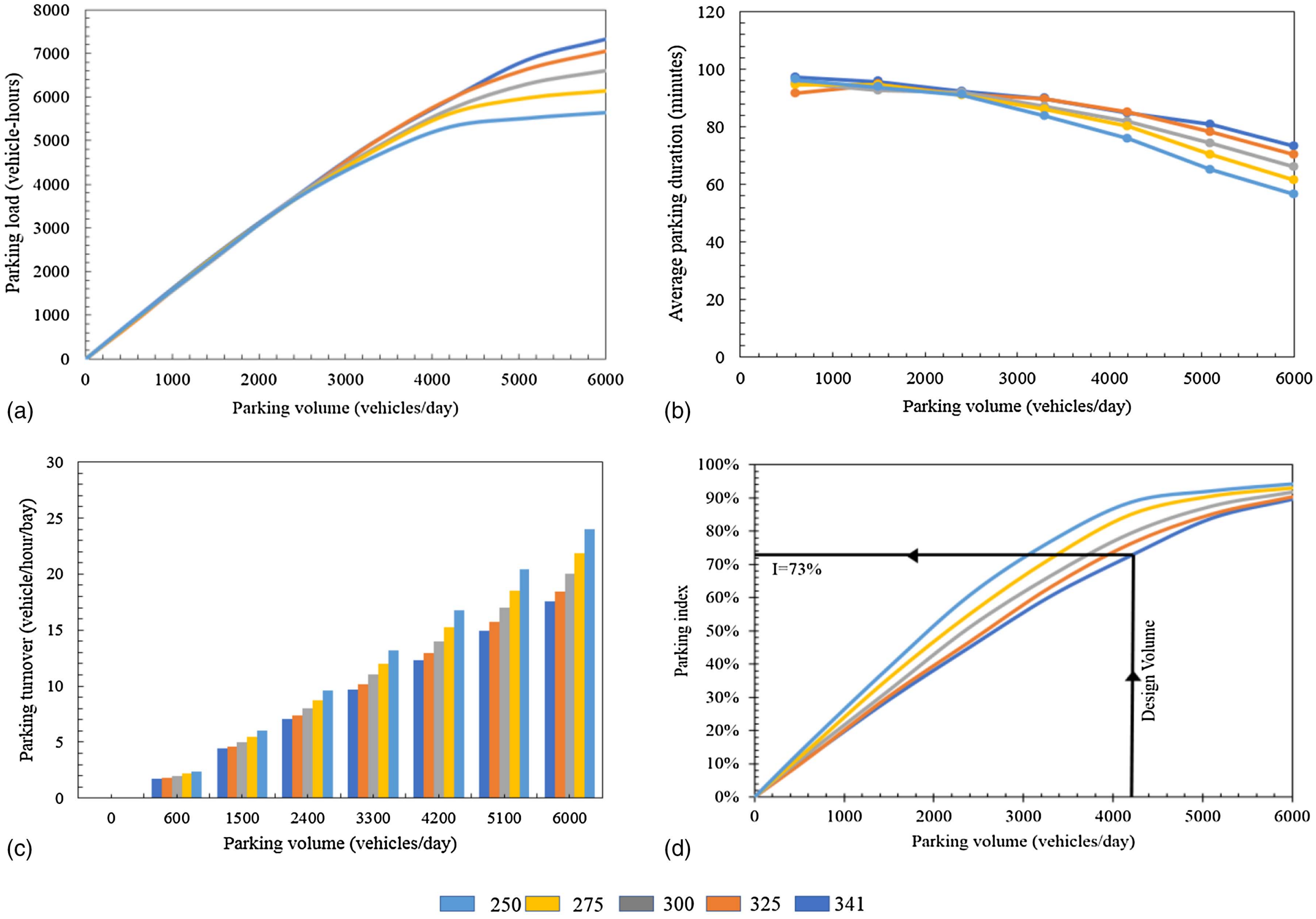


Fig. 4. Parking performance measures from the simulation model: (a) parking load; (b) average parking duration; (c) parking turnover; and (d) parking index.

shown in Fig. 5. This indicates that with an increase in the number of parking bays, the parking volume can be well-served. However, from an operator's point of view, reserving a larger number of parking bays may not be financially viable. Further, computing the optimal number of parking bays for a given parking volume creates an intricate problem. The parking index analysis noted that the slope of the data lines varies with a change in the number of operational bays. For example, in the case of 250 operational parking bays, the line's slope is much steeper than 341 parking bays. It is professed that the derived concept can help supervise the parking terminal operations for identifying the optimal number of operational bays. For the design load of 4,200 vpd, the parking terminal's efficiency varies from 73 to 87% for different operational bays, as shown in Fig. 5.

Furthermore, two curves corresponding to the future expansion of the number of bays were added in Fig. 5 (N = 380 and 400) to illustrate the concept. At a given parking volume, the parking index increases as the number of operational bays decreases. In the case of operations such as the expansion of the parking terminal or maintenance, those can be well planned to use the developed design chart. Moreover, the use of information and communication technologies (ICT) for planning and managing the parking terminal can be customized in the best possible way. The methodology adopted in this study can help evaluate the parking design and act as a guideline for future operations. To illustrate the design chart's implementation, two examples are presented next that reflect the operator's point of view.

Application Examples

Example 1: Consider a situation in which, after four years of the construction of the parking terminal, due to continuous substantial trucking activity, the utilities of the parking bays are damaged. As a result, the operator wants to plan a maintenance activity without affecting the truck parking operation. It was noted that 341 parking bays are operational, the existing parking volume is 3,800 vpd, and it was stipulated that the parking index should not exceed 80% to avoid a breakdown in the system. To address this issue, for $V = 3{,}800$ vpd and $I = 80\%$, the number of required operational parking bays is determined as 275, as shown in Fig. 5. It indicates that the operator must maintain a minimum of 275 parking bays operational for this parking volume and can carry out the maintenance work for the rest of the bays.

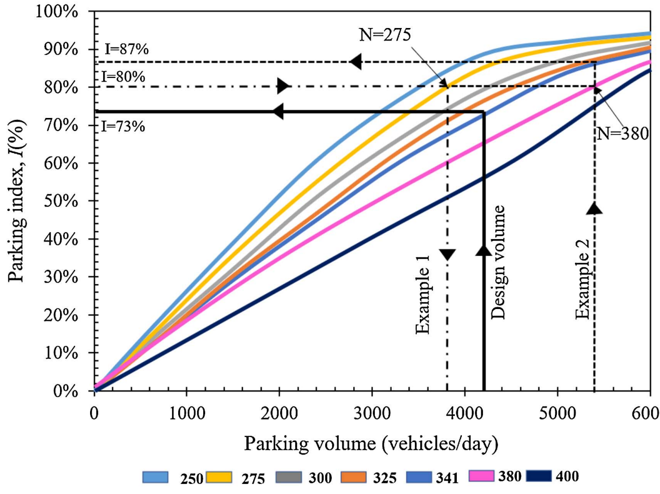


Fig. 5. Relation of parking index and parking volume.

Example 2: Due to the increase in imports and exports over the port activities, the terminal's parking volume has increased from 3,800 vpd to 5,400 vpd. The operator wants to know the exact operational efficiency of the parking terminal to plan the future expansion of the parking terminal, so the operator interpolates the parking index for a volume of 5,400 vpd at 341 operational parking bays as $I = 87\%$, as shown in Fig. 5. To bring the system back to its stipulated efficiency to 80%, from the design chart, for $V = 5{,}400$ vpd and $I = 80\%$, the required number of parking bays is 380. Therefore, the operator will need to add 40 parking bays to accommodate the parking demand of 5,400 vpd.

Conclusions

The rapid expansion of the Indian economy, coupled with the ever-growing international trade of various types of goods, has resulted in the expansion of the road network and the associated development of road infrastructure. The major movement of goods in the hinterland of ports is handled by road transport due to ease of movement and reliability. However, handling the demand for parking the variety of trucks has become one of the major challenges in the vicinity of ports. In the case of a commercial port, the ongoing activities such as imports and exports of goods result in a large amount of trucking activity around the port area. On these lines, faring the truck movement can be a sensible measure in reducing the traffic congestion over the port network. At the same time, banning parking activities around the port premises will increase the delay of the port operations. Similarly, permitting parking within the port premises will increase the congestion inside that may adversely affect port operations. To address this problem, a centralized parking terminal can help regulate the inflow and cater to the parking problem of the trucks. Furthermore, with real estate restraint over the port premises, the parking terminal must be planned effectively with full assistance to port trucking activity. Along these lines, the present work initiates with an approach of testing a centralized truck parking terminal and designing the parking terminal demands for different levels of traffic data in sensing the traffic flow patterns over in and around the port considering the uncertainties for the risk of failure. Based on the collected traffic data from the traffic surveys, data were analyzed in terms of truck parking demand.

In this direction, the study has presented a simulation model for a truck parking terminal using VISSIM software. The model is validated and used to analyze various supply-demand scenarios and to evaluate parking terminal efficiency. The parking terminal efficiency is found to be about 73%. In addition, the study presented a novel design chart that can be used to identify the optimum number of parking bays to maintain a specific desired efficiency. Also, the design chart is a valuable decision-making tool for port operators in maintenance planning. The present study can be considered a decent attempt to simulate parking operations for better management of truck parking terminals. The methodology adopted in the present study highlighted the power of simulation in elevating future transportation systems. Based on this study, the following comments are offered:

- The results show that for the designed peak load of 4,200 vpd and the planned 341 parking bays, the parking terminal efficiency is found to be 73%, providing a reserve capacity of 27% when the parking terminal reaches the end of the 10-year design period. The present study has provided valuable guidelines for the design of this system.
- The developed design chart would be very useful in planning the expansion and maintenance of the proposed parking terminal in

two ways. First, for a given parking volume and parking index (efficiency), the required number of parking bays can be determined. Second, for a given parking volume and number of parking bays, the parking index can be determined, which is useful for maintenance management.

- The presented framework can be used in testing other transportation components so that their functionality can be evaluated at the planning and design stages. Even any new ICT-based techniques for operational improvements can be tested with the presented framework using simulation models. Further, from the analysis of the scenario combinations, it is observed that there is a specific capacity of the parking terminal that varies with the number of operational parking bays. This finding can be beneficial in evaluating terminal capacity.
- The operation of parking terminals at ports is so complex that it cannot be analyzed analytically or using empirical observations, especially if the terminal is new or has not been constructed. Therefore, the proposed parking terminal can only be analyzed using simulation. Such simulation is so powerful that the outcomes of this study may be considered an attempt to realize the need for developing standards for truck terminals at ports to ensure effective planning and management. These results can also be used for deriving phase-wise development of the truck parking terminal.

Data Availability Statement

Some data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request:

- Simulation model.
- Data generated from simulation runs.

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