


Assessing urban curbside parking for commercial vehicles: simulation and policy insights

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ABSTRACT

As e-commerce and urban deliveries spike, there is an increasing demand for curbside loading/unloading space. However, commercial vehicle drivers face numerous challenges while navigating dense urban road networks. These challenges can lead to conflicts with other road users, congestion, illegal parking, and parking time violations. While existing research often highlights pedestrian and bicyclist safety in urban environments, far less attention has been given to the experience and perspective of the truck drivers themselves, who are central to urban goods movement. Moreover, previous research on how commercial vehicle drivers make choices about when and where to park is limited. Available data often comes from field studies where only limited situations can be observed, with no experimental controls and a lack of known drivers' characteristics. To address this gap, this study used the Oregon State University heavy vehicle driving simulator to examine the behavior of commercial vehicle drivers in various parking and delivery situations while accounting for key variables. A fully counterbalanced, partially randomized, factorial design was chosen to explore four independent variables: number of lanes (2-lane and 4-lane roads), with/without bike lane, available/unavailable passenger vehicle parking, and commercial vehicle loading zone (none, occupied, and unoccupied CVLZ). Driver speed, eye tracking, and parking behavior were used as performance measures. Data from 33 commercial driver's license (CDL) holders yielded 792 observations across 24 scenarios. The findings from speed, eye movement, and parking behavior support more effective curb management strategies that improve delivery efficiency while recognizing the operational problems faced by truck drivers.

Background

Millions of people who live and work in cities purchase more than half of their goods online (Laura Stevens, xxxx). As e-commerce and urban deliveries spike, there is an increasing demand for curbside loading/unloading space. Simultaneously, cities grapple with managing urban freight more actively, and to be able to do so, city planners and policymakers need to better understand commercial vehicle driver behaviors and factors they take into consideration when choosing a place to park for deliveries.

Freight movement in urban areas is a heterogeneous phenomenon. Commercial vehicle drivers face numerous challenges and have to adopt different travel and parking behaviors to navigate the complex urban network and perform deliveries and pick-ups efficiently. However, they are often perceived by other road users, and sometimes even by city planners, as significant contributors to urban congestion, being blamed for illegal parking, double parking, and overstaying their parking time limit. Still, the perspective of truck drivers themselves is often overlooked, even though they are the ones navigating these challenges daily.

Previous studies have found that curb use and demand by

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commercial vehicles are not met with adequate curb allocation. Scenarios illustrating this discrepancy include the parking of commercial vehicles on sidewalks, bike lanes, and turn lanes; the extension of loading ramps and liftgates that impede crosswalks and sidewalks; and the staging of freight vehicles in locations that interfere with pedestrian and bicycle traffic (Dalla Chiara and Goodchild, 2020). Additionally, a 2019 UFL study in Seattle, WA, also found that more than half of vehicles parked in commercial vehicle loading zones (CVLZs) were passenger vehicles, while delivery vehicles only constitute about a quarter of vehicles parked in passenger load zones (PLZs) (Gao et al., 2019). UFL researchers also identified three main criteria commercial vehicle drivers use when choosing a parking location: (a) avoiding unsafe maneuvers, (b) minimizing conflicts with other road users (e.g., passenger or ride-hailing cars, bikes, and buses), and (c) competition with other commercial vehicle drivers (Chiara et al., 2021). It was also found that in response to the lack of available parking, drivers take one of the following actions: unauthorized parking, cruising for parking, queuing, and re-routing.

Building on these observations, sometimes the availability of designated CVLZs does not promise sufficient space for parking operations. McCormack et al. studied that some vehicles require more space for their operations due to their large size, which can compromise adjacent spaces, such as sidewalks and bike lanes. There should be enough envelopes around the vehicle for safe operations (McCormack et al., 2019). Jashami et al. studied the interaction between commercial motor vehicles and bicyclists in the absence of designated CVLZ. It was a condition where drivers might use the entire bicycle lane for their operations, forcing bicyclists to change lanes entirely. Two-thirds of bicyclists preferred to use the travel lane for passing commercial vehicles, while some even used the sidewalk. Therefore, it is necessary to reduce the frequency of commercial motor vehicles parking in bicycle lanes to mitigate safety issues raised by unauthorized parking (Jashami et al., Oct. 2020). Mukherjee and Mitra concluded that the pedestrian-to-vehicle volume ratio, vehicle overtaking, reduction in line of sight, sidewalk encroachment, and pedestrian crossings are critical factors that affect pedestrian safety (Mukherjee and Mitra, 2020).

Despite these ongoing issues, the unique needs of delivery trucks and commercial vehicles are not acknowledged in current design practices. For example, design guidelines published by the National Association of City Transportation Officials (NACTO) (National Association of City Transportation Officials, xxxx; 'Curbside Management Strategies for Improving Transit Reliability.', 2017; Institute of Transportation Engineers, 2018) do not include solutions to address freight infrastructure insufficiencies in urban spaces, or recent curb management guidelines by NACTO, Institute of Transportation Engineers (ITE) and International Transport Forum (ITF) (Mukherjee and Mitra, 2020) do not provide an optimal length CVLZs or discuss where on the block is a desirable location for placing CVLZs. These findings highlight the necessity of a deep understanding of the fundamental decision-making process and parking behaviors of commercial vehicle drivers. However, the literature on this topic is scarce, and the data for such studies usually come from empirical field studies, such as video data, GPS data, microscopic traffic simulations, and theoretical analysis are a few of them (Dalla Chiara and Goodchild, 2020; Chiara et al., 2021; Allen et al., 2012; Lopez et al., 2019; Gopalakrishnan et al., 2020; Yao et al., 2019; Yang et al., 2019; Raddaoui and Ahmed, 2020; Low et al., 2020; Nevland et al., 2020; Aljohani and Thompson, 2016; Yang et al., 2020; Gillberg et al., 1996). Previous studies have used truck simulators for training (Hirsch et al., 2017) and examining improvements in human performance (Allen and Tarr, 2005) but have not evaluated truck driver parking behavior. While there are only limited situations that can be observed in existing situations, even with those, driver characteristics remain mostly unknown. Previous research (Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area, 2238) has highlighted off-peak delivery programs as an effective strategy to alleviate curbside congestion. These programs encourage freight operators

to shift deliveries to nighttime hours to reduce peak-hour curb demand. While this approach has been successfully implemented in cities like New York, it may not be feasible for all businesses, particularly those serving perishable goods or time-sensitive deliveries. Therefore, CVLZ expansion should be considered in tandem with off-peak delivery incentives to create a balanced curbside management strategy.

Previous research has examined speed, total fixed duration (TFD) on pavement markings in the context of a bike simulator (Jashami, 2023). However, these variables have not been studied in truck simulator environments, particularly in relation to truck parking behavior. This study aims to fill these gaps and serve as a valuable resource for policymakers, transportation engineers, and urban planners. Examples of how street and curb designs might be improved to better accommodate the needs of commercial vehicles include improving curb use, such as moving CVLZs closer to intersections to give drivers more space to maneuver, and placing passenger and commercial vehicle load zones next to each other. To that end, the experimental variables and performance measures selected in the present study were designed using a heavy vehicle driving simulator to best address the study objectives. This includes the evaluation of commercial vehicle drivers' parking behaviors in an urban environment setup using data on drivers' parking-choice behaviors, speed, and eye movements needed to resolve existing research questions.

Methodology

In previous studies, researchers argued that direct driver surveys could provide a similar insight to driver behavior. However, surveys often suffer from recall bias, as respondents may inaccurately report past decisions. Additionally, surveys cannot capture real-time behavioral responses to unexpected conditions (e.g., an occupied CVLZ or last-minute parking decisions). To fill these gaps, the present study evaluated in-the-moment driver decisions within a driving simulator environment paired with survey responses to fully understand driver behavior and limit the impact of biases such as recall or inaccurate reporting. The following section outlines the equipment, study formulation, and factorial design used.

To establish a more robust understanding of the abilities and limitations of commercial drivers and the ability to influence these characteristics through infrastructure design and operations, this study contributes new empirical evidence by incorporating eye-tracking analysis and real-time driver decision-making in simulated urban setups. Unlike traditional observational studies that rely on indirect inference, this methodology captures how CMV drivers visually process parking decisions, providing a more granular understanding of driver behavior. Additionally, the factorial design allowed for isolation of key variables influencing parking choices, which is difficult to obtain in uncontrolled field studies or survey data alone. Performance measures included speed, eye tracking, and parking behavior evaluation. Oregon State University's (OSU) Heavy Vehicle Simulator was used to observe these parameters in a simulated driving environment, and the Tobii Pro Glasses 3 was used to measure the eye movement of participants.

Heavy vehicle simulator

The OSU Heavy Vehicle Driving Simulator seats the driver within a quarter-cab steering and operation station and presents the opportunity to operate the heavy truck within the simulated environment. This piece of equipment also features an adjustable seat that faces three 60-inch high-definition screens to provide an expansive 210° field of view. Additionally, side mirrors are embedded in the screens to provide accurate visualizations of the vehicle and road geometry. The dashboard configuration is representative of a heavy truck on the roadway. This entire setup is shown in Fig. 1-right.

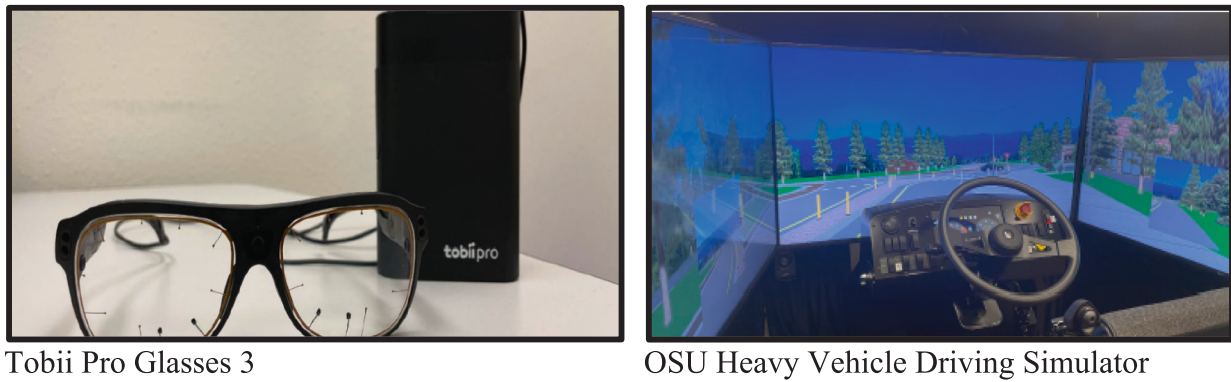


Fig. 1. Study Equipment.

Tobii pro glasses 3

These glasses feature four cameras seamlessly implemented into the lenses, side-by-side 16 illuminators, along with a front-facing scene camera to capture a 106° field-of-view. The inclusion of prescription lenses was available on-site, which could attach to the device and permitted those who typically wear prescription glasses to participate in the study without having to limit their visual acuity. Fig. 1-left shows the Tobii Pro device and the associated data collection unit that connects via Wi-Fi to an external laptop used to calibrate and collect data. The eye-tracking device was calibrated prior to each data collection session. The system was integrated to be synced with this external platform, iMotions, the software that allowed data to be collected and assessed in real time.

After collecting participants' eye-movement data, fixation and dwell time data were analyzed by area of interest (AOI) polygons with the iMotions software suite. Dwell time is defined as average of how long the respondents gazed at the AOI. Only data with an accuracy above 75% was used for analysis. Overall accuracy was 80.7%. The AOI that was explored in this experiment was pavement markings (No CVLZ, Occupied CVLZ, available CVLZ). Researchers drew AOI polygons on individual video frames in a sequence separated by intervals of approximately 5–10 frames. Once the data reduction was completed, iMotions provided total fixation duration (TFD) on each of the AOIs separately. An example of the AOI polygons and corresponding eye-gaze movements is shown in Fig. 2. These polygons were drawn for each video frame, and the driver's gaze is represented by a red circle. When the driver's gaze falls within an AOI, the corresponding gaze duration is recorded. The truck driver's eye-tracking data started from approximately 300 ft before parking maneuver.

Experimental design

A factorial design (2x2x2x3 = 24 scenarios) was used to allow for the observation of four independent variables separately. The independent

variables included in the experiment were i) the number of lanes (2 and 4), ii) bike lane presence (with and without), iii) passenger car parking space availability (yes and no), iv) commercial vehicle loading zone (CVLZ) presence (available, unavailable, and occupied) as shown in Fig. 3.

Twenty-four scenarios were included in the factorial design, all of which were presented to participants. Scenarios followed current guidelines by NACTO and ODOT for urban settings with a mix of residential and commercial buildings. The commercial vehicle loading zone was 40 feet long. Each road was 700 feet long, with a lane width of 12 feet and a speed limit of 25 mph. Some scenarios included pedestrians on the sidewalk, bicyclists in the bike lane, and moving cars and trucks to simulate real-world conditions. Fig. 4 shows four examples of the 24 scenarios. Scenarios were presented to participants in a random order to control carryover effects and practice.

Participant recruitment

Thirty-four individuals were recruited who met the pre-established

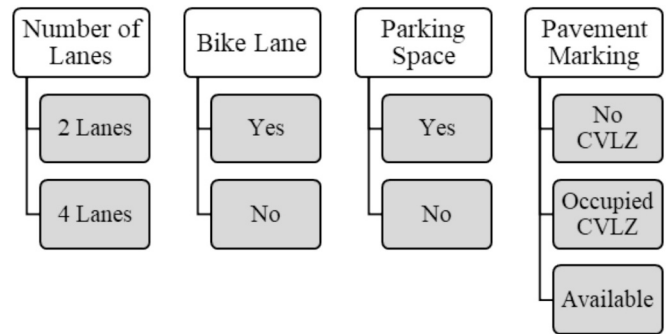


Fig. 3. Variables and Levels.



Fig. 2. Example of a truck driver fixation pattern on pavement marking area of interest (AOI) and how AOIs were drawn and identified.

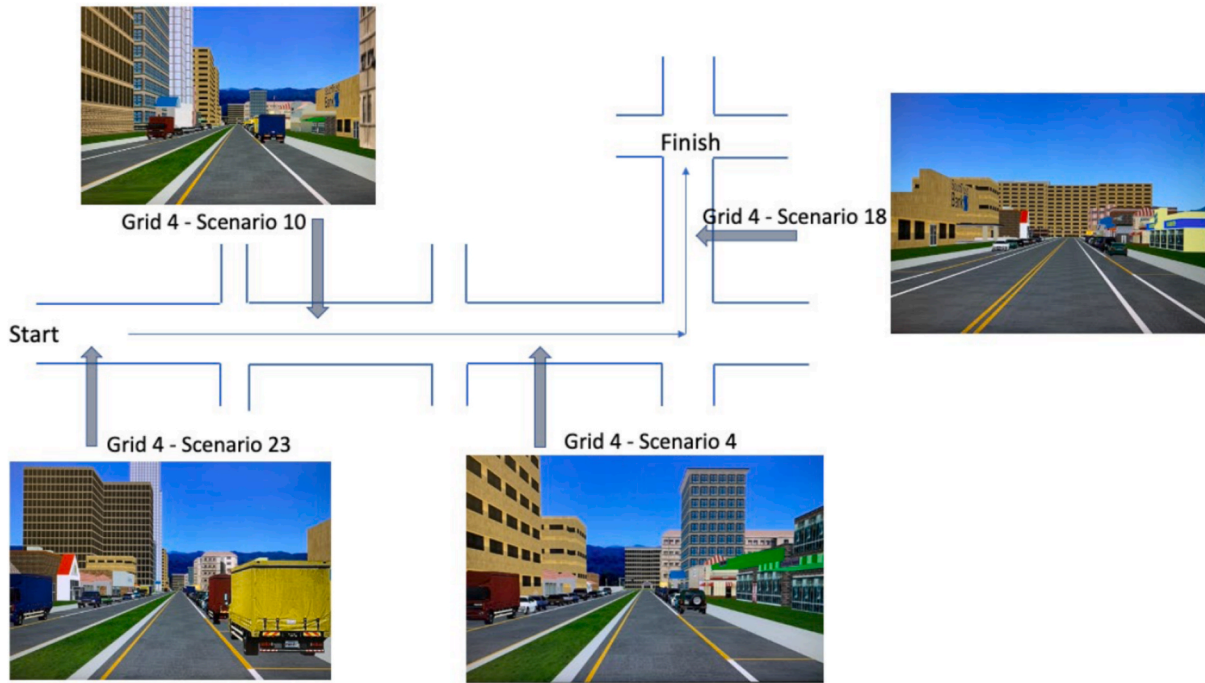


Fig. 4. Example drive: (scenario 10) Two lanes, no bike lane, no parking space, CVLZ occupied; (scenario 18) Four lanes, bike lane, parking space, CVLZ available; (scenario 23) Two lanes, no bike lane, no parking space, CVLZ occupied (scenario 4) Two lanes, no bike lane, parking space, CVLZ available.

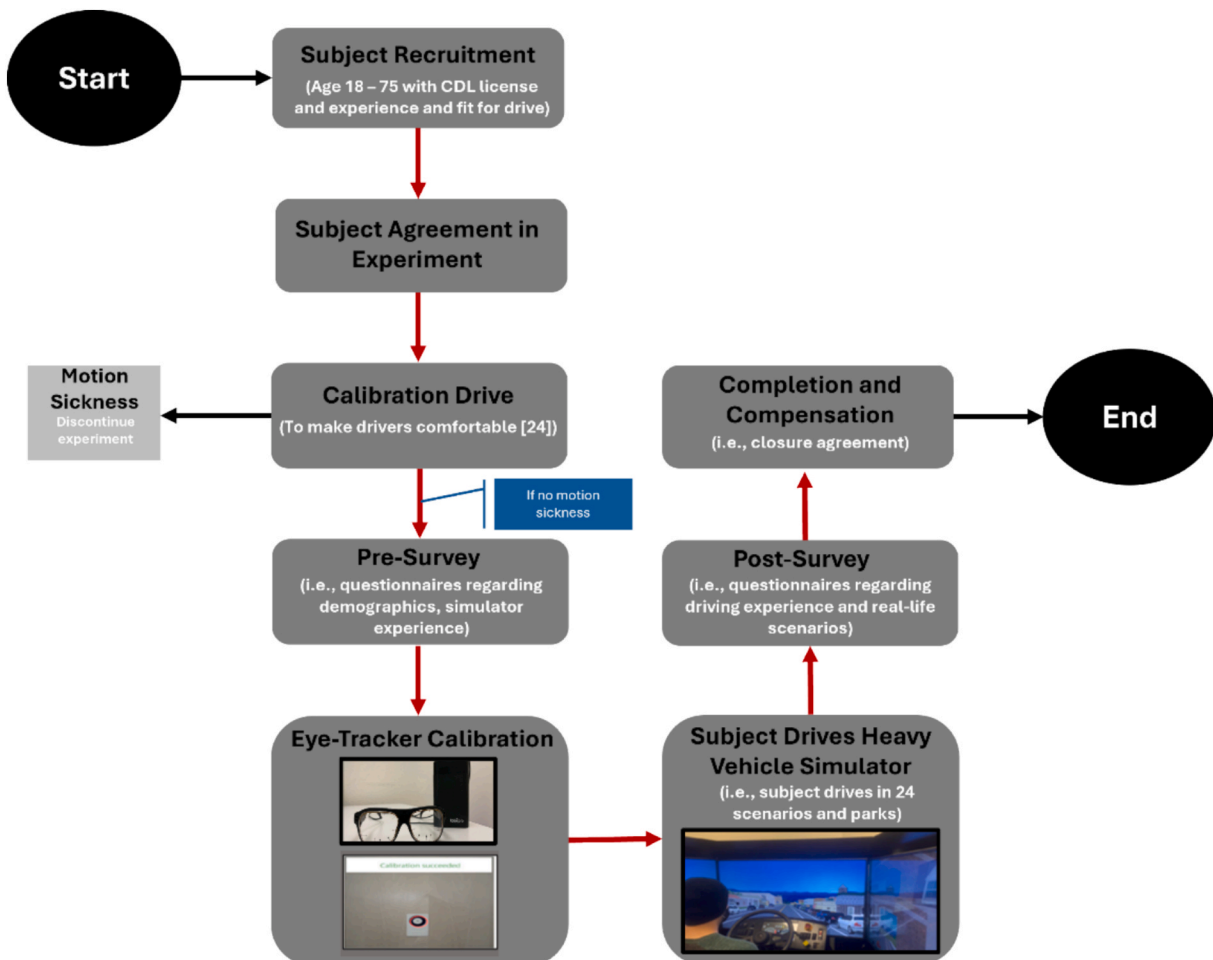


Fig. 5. Experimental Process.

requirements for participation in this heavy truck study. These requirements were strictly followed, with the commercial driver’s license (CDL) of all participants being checked prior to beginning the experiment. The recruiting process for this study utilized all resources available to generate the sample size obtained. Printed flyers were posted at various trucking organizations, common rest stops, and bulletin boards along the I-5 corridor spanning from Portland to Corvallis, OR. Social media posts on Facebook, LinkedIn, and various OSU campus listservs were leveraged to spread information about the study. Lastly, many agencies provided information about the study to those within their network to generate a larger sample of drivers.

Upon arrival, participants were asked to read and acknowledge the informed consent documentation outlining the potential risks associated with participation in this study (IRB Study Number: IRB-2021–1008). This document does not provide any specific details of the study to avoid bias in driver response to the scenarios of interest, but offers information pertaining to the reason, overview, and objectives of the study.

Experimental drive

Prior to beginning the experimental drive, participants were provided with a diagram of a box truck that was modeled and calibrated for the simulated environment and were instructed to operate the vehicle the same as if they were driving it in the as-built environment. This diagram provided the length of the vehicle to help participants visualize their vehicle before beginning the simulated drive. Before beginning the experimental drive, participants were exposed to a generic grid or “calibration drive” that featured no experimental variables (Helena et al., xxxx). This provided them with the opportunity to grow accustomed to operating the vehicle in a virtual world. The experiment process can be seen in Fig. 5, with steps shown in red arrows.

Results

CMV drivers’ parking behavior was evaluated using three performance measures: speed, total fixation duration on pavement markings, and parking-decision behavior while navigating through various scenarios.

Speed results

Prior to data collection, proximity sensors were coded into the simulated environment to consistently segment the data and isolate a 500 ft roadway segment associated with each scenario. Participant speed was evaluated over a span of 500 feet along the roadway. A 100-foot section at the beginning and end of the 700-foot segment was excluded to account for any variations influenced by proximity to the intersections. Following this assessment, statistical analyses were carried out. A linear mixed-effects model (LMM) was constructed to further understand speed variations across the roadway segments of interest.

Prior to that, descriptive statistics were assessed to understand the distribution of the data while accounting for the independent variables (number of lanes, the presence of bike lane, passenger vehicle parking space availability, as well as CVLZ availability). Descriptive statistics (mean and standard deviation) at these points are described in Table 1 to understand how speed varied across different scenarios.

It was found that, in the two-lane scenarios, mean speeds varied between 12.4 mph and 17.6 mph when there was no designated commercial vehicle loading zone. The presence of passenger car (PC) parking spaces and bike lanes had an impact on drivers’ speed. In the absence of designated loading zones, drivers tended to reduce their speeds when passenger car parking spaces were available along bike lanes. When CVLZs were occupied, average speed ranged from 13.3 mph to 20.0 mph. Drivers showed higher speeds when bike lanes were present, and passenger car parking spaces were occupied. Conversely, when loading zones were available, average speeds were reduced, ranging from 8.0

Table 1
Descriptive Statistics of Speed (mph).

Speed Statistics					
Description	Two Lanes				
		Bike Lane / Space	Bike Lane / No Space	No Bike Lane / Space	No Bike Lane / No Space
No CVLZ	Mean	12.4	16.5	16.1	17.6
	SD	2.7	4.8	6.4	6.9
Occupied CVLZs	Mean	16.5	15.9	13.3	20.0
	SD	5.4	5.9	4.1	7.8
CVLZs	Mean	15.2	13.8	8.0	16.8
	SD	6.1	3.8	2.7	7.5
Four Lanes					
No CVLZ	Mean	15.8	12.8	11.7	17.3
	SD	6.0	5.4	4.4	7.6
Occupied CVLZs	Mean	19.0	17.6	17.1	16.4
	SD	8.4	6.4	6.3	6.4
CVLZs	Mean	16.4	14.1	7.7	15.5
	SD	6.5	5.4	2.4	6.5

mph to 16.8 mph, which demonstrates the least speed range for the three scenarios conducted.

In a four-lane urban setting, when there was no designated CVLZ, average speeds ranged from 11.7 mph to 17.3 mph. Drivers had minimum speeds (11.7 mph) when there was no bike lane in the presence of passenger car parking spaces. When CVLZs were occupied, the average speed was between 16.4 mph and 19.0 mph. Drivers showed lower speeds when there was no bike lane provided, with no PC parking space. Likewise, CVLZ availability resulted in mean speeds ranging from 7.7 mph to 15.5 mph, which is the minimum among all other road settings described.

Also, prior to statistical modeling, speed variability among different settings was graphically presented in Fig. 6. Overall, lower speeds were observed when there was either available CVLZ parking or PC parking space. However, drivers had higher speed variations in the presence of PC parking spaces while there was an unavailable or occupied CVLZ.

A statistical model was developed to evaluate the speed data as a dependent variable. The LMM analytical technique was selected given its ability to handle repeated sampling of subjects to best account for fixed/random effects and minimize Type I error rates (Jashami et al., Oct. 2020). The sample size for this measurement was 31 subjects, which is greater than the minimum required (20 subjects) for an LMM analysis (Jashami et al., Oct. 2020). Data was collected and analyzed over a span of 500 feet along the roadway. A 100-foot section at the beginning and end of the 700-foot segment was excluded to account for any variations influenced by proximity to the intersections. The independent variables of the number of lanes, the presence of bike lanes, PC parking space availability, as well as CVLZ availability were considered in the estimate of the dependent variable of speed along each segment. Lastly, the participant number was considered as a random effect, and all statistical analyses were performed at a 95% confidence level using Python. The output from the first model is described in Table 2.

Results of the LMM showed that all the variables were statistically significant (p-value < 0.05), except for the number of lanes. The random effect was significant (Wald Z = 2.19, p < 0.05). For the fixed effect variables, it was found that the absence of a designated commercial vehicle loading zone (CVLZ) increased participants’ speed by 1.5 mph, and this treatment was statistically significant (p < 0.01). Additionally, when the CVLZ was occupied, a statistically significant effect was also found, with speeds increasing by 3.5 mph compared to the baseline condition (p < 0.001). The absence of passenger car parking spaces revealed a statistically significant increase of 2.2 mph compared to when parking was available (p < 0.05). In contrast, the absence of a bike lane was statistically significant in reducing participants’ speeds by 0.9 mph when compared to the environment with bike lanes (p < 0.05). In general, participants tended to decrease their speed when encountering

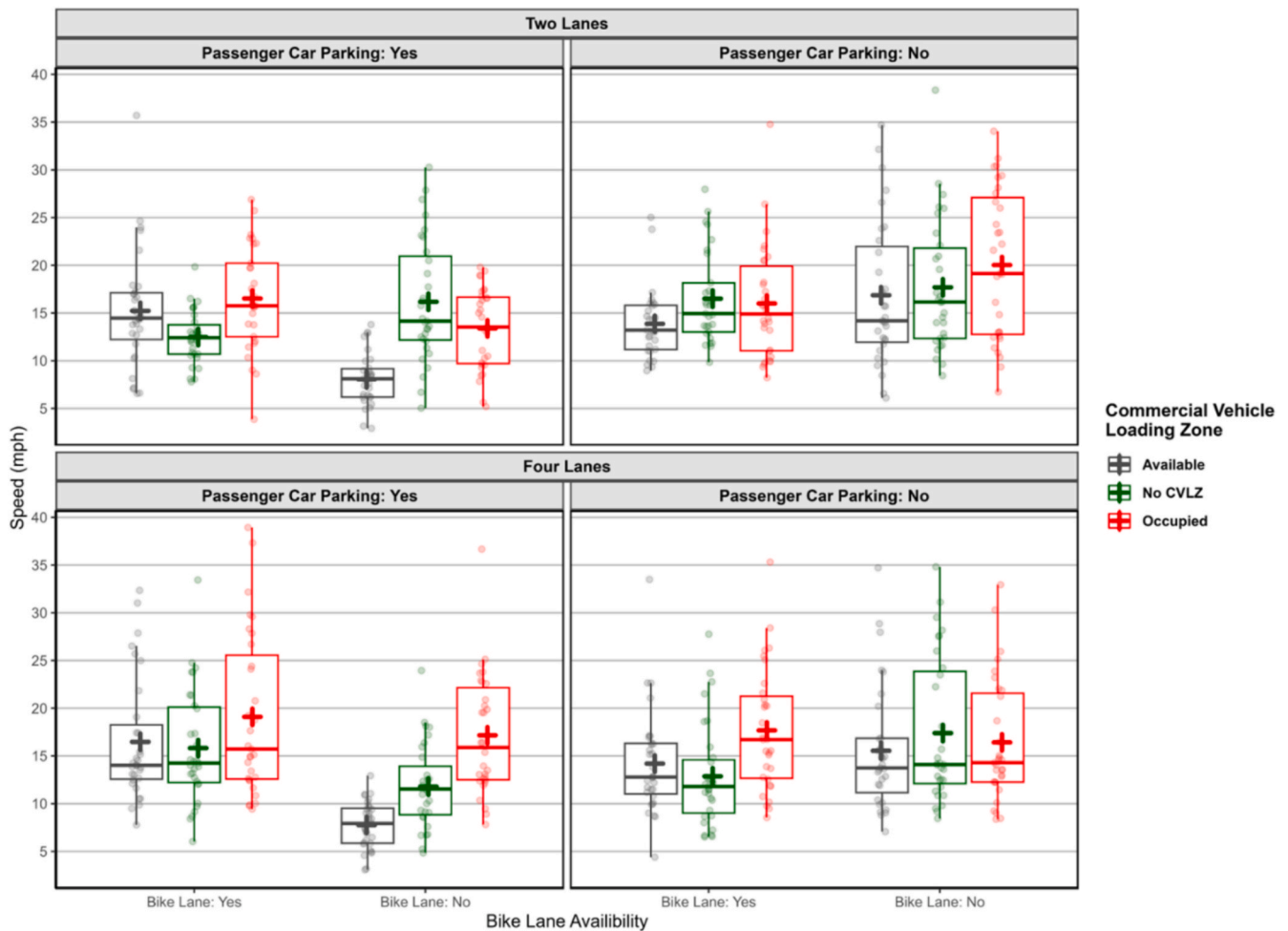


Fig. 6. Speed Distribution Among All Scenarios.

Table 2
Results of LMM on Speed (mph).

Variable	Estimate	Std. Error	P-value
Participant random effect (Var)	14.49	4.05	<0.001*
Constant	13.12	0.83	<0.001*
<i>CVLZ Availability</i>			
CVLZ Available	Baseline		
No CVLZ	1.51	0.47	0.001*
CVLZ Occupied	3.53	0.47	<0.001*
<i>Passenger Car parking space Availability</i>			
Available	Baseline		
Unavailable	2.16	0.38	<0.001*
<i>Number of Lanes</i>			
2	Baseline		
4	-0.26	0.38	0.499
<i>Presence of Bike Lane</i>			
Yes	Baseline		
No	-0.89	0.38	0.020*
<i>Summary Statistics</i>			
R Squared	41.07%		
-2Log likelihood	4556.06		
AIC	4560.08		

* Statistically significant parameter estimates at 95% confidence level.

unoccupied CVLZ or passenger car parking spaces, which suggests they found a parking spot and were about to park. To that end, the statistical results derived from the model align with the visualizations described in Fig. 5, indicating that the model is performing correctly and accurately predicting fluctuations in speed.

Visual attention

While drivers were searching for parking spots, the frequency and duration of participants' fixations on AOI (loading zone pavement markings) were recorded. Fixation duration is one dimension of visual attention. Visual attention is the primary perceptual input that facilitates the driving task, i.e., control, guidance, and navigation. Longer fixation durations mean that participants spend more time processing the information at a particular location indicating increased interest (Pannasch et al., 2011), greater difficulty, or increased cognitive load (Ozcelik et al., 2009). Generally, the total fixation duration represents the total length of time participants spent looking at a particular AOI during length of exposure. More specifically, it is quantified by classifying fixations that are located within the boundaries of a particular AOI and summing their durations in seconds. A total fixation duration (TFD) of 0 s indicated that the participant did not look at the target.

The Average Total Fixation Duration (ATFD) was calculated by averaging all participants' total fixations on each AOI of interest. Longer fixation durations on CVLZ suggest increased visual attention on the part of the participant at that particular element of the built-environment. This suggests that they are thinking about those spaces more while trying to decide if they can park their vehicle there or not.

Total fixation duration on pavement markings

For the loading zone pavement markings' AOI, mean and standard deviation (SD) values for TFD for each treatment variable level are reported in Table 3. When there was no CVLZ, the average TFD was 0.8 s to 1.3 s in the two-lane settings and 0.7 s to 1 s in the four-lane settings.

Table 3
Total Fixation Duration Pavement Marking.

Total Fixation Duration Pavement Marking					
Description	Two Lanes				
		Bike Lane / Space	Bike Lane / No Space	No Bike Lane / Space	No Bike Lane / No Space
No CVLZ	Mean	1.3	0.9	1.3	0.8
	SD	1.6	1.1	1.7	1.2
Occupied CVLZs	Mean	4.8	3.8	4.3	3.7
	SD	7.9	4.0	3.6	3.6
CVLZs	Mean	1.0	3.4	2.0	1.2
	SD	1.1	4.5	2.0	1.5
Four Lanes					
No CVLZ	Mean	1.0	0.8	1.4	0.7
	SD	1.3	2.0	1.7	1.2
Occupied CVLZs	Mean	3.9	3.5	3.8	4.3
	SD	3.4	3.7	4.4	3.5
CVLZs	Mean	1.9	1.5	2.1	1.1
	SD	2.0	1.7	1.9	1.0

There was no significant difference in TFDs between the two urban settings, as drivers, upon realizing the absence of a designated spot, began to scan other information. In contrast, in both the two and four-lane scenarios where CVLZs were occupied, drivers exhibited maximum TFDs ranging from 3.8 s to 4.8 s and 3.5 s to 4.3 s, respectively. This suggests that drivers located the designated zone, but contrary to their expectations, it was already occupied, hoping to find others

that were not occupied. In addition, when CVLZs were available, in both settings, drivers showed TFD of 1.0 s to 2.0 s and 1.9 s to 2.1 s, respectively (Table 3). In two-lane scenarios, drivers experienced the maximum TFD when a bike lane was present, and passenger car parking space was absent.

As shown in Fig. 7, drivers generally experienced high TFDs when CVLZs were occupied and low TFDs when these were available, which aligns and complements the speed results.

Parking behavior

Each video of the driving test was recorded in 4 k cameras using SimObserver and processed in the Data Distillery software. Following the completion of the experiment, each video was reviewed to quantify the frequency of different parking behaviors exhibited by drivers. A total of 672 scenarios were recorded and observed. The results in Table 4 indicate that illegal parking occurrences were highest in the absence of

Table 4
Parking Choice Information.

	CVLZ Available		CVLZ Occupied		CVLZ Not Available	
	PC	No PC	PC	No PC	PC	No PC
Illegal Parking	31	29	90	24	105	101
Legal Parking	81	77	0	0	0	0
No Parking	14	19	39	11	21	30

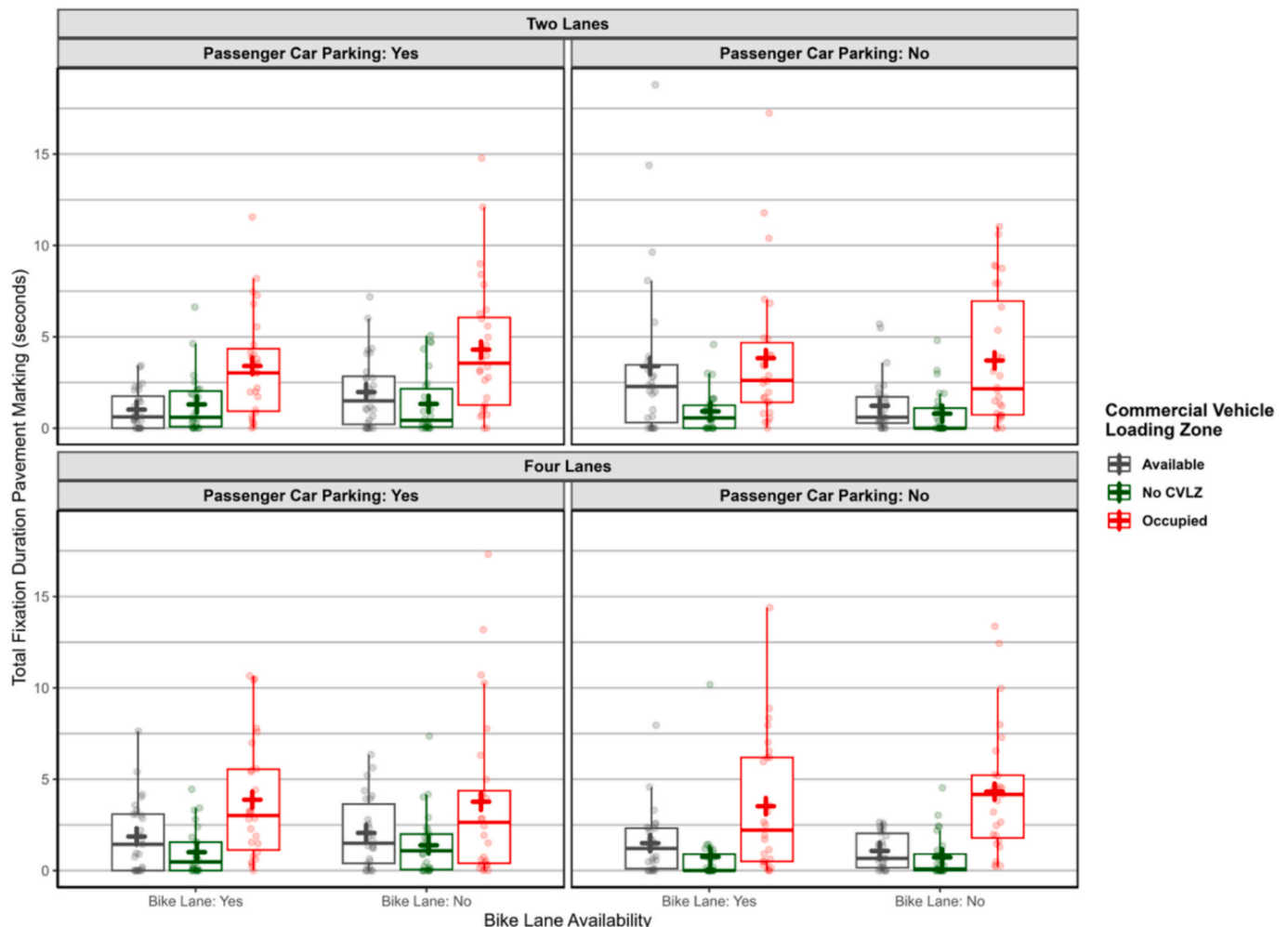


Fig. 7. Total Fixation Duration for Pavement Markings.

designated Commercial Vehicle Loading Zones (CVLZs), regardless of the availability of passenger car parking spaces. Furthermore, when CVLZs were occupied, drivers frequently chose to park illegally using the available passenger car spaces, posing potential hazards to stationary vehicles and other non-motorized road users. Moreover, in about 50% of the instances, drivers parked illegally when there were either no CVLZs or when they were occupied by other trucks, regardless of passenger car parking space. It was also observed that in only 20% of the instances, drivers did not park at all while searching for a parking space.

Post-survey results

To reinforce the findings of the simulator experience, participants were asked to subjectively evaluate the different curbside parking scenarios to understand self-reported stress and behavioral responses. This step allowed for verification that the responses observed in the simulated environment were intentional and reflective of the driver's internal thought processes (i.e., increased stress, time restrictions, etc.) Approximately 38% of drivers reported feeling uncomfortable while looking for designated CVLZ, leading them to park illegally in either the travel or bike lane. Additionally, around 35% of drivers admitted to parking in either the bike lane or the travel lane. In real-life situations, more than 30% of drivers indicated they park in no-parking zones, followed by 16% in bike lanes. This underscores how the safety of non-motorized users is compromised under current guidelines. Furthermore, 84% of drivers advocated for exclusive truck parking at the curbside. Additionally, drivers indicated the effect of parking maneuvers on roadway traffic and authorized parking space as the top two factors while considering prospective locations to park. These responses were also validated by studying their behavior in the later part of the study. Overall, drivers' responses, in combination with the experimental part, strengthen the hypothesis that agencies should provide exclusive guidance on curbside parking.

Discussion

This paper examined how commercial vehicle drivers respond to varying driving conditions for curbside parking. These simulated environments were intended to be as close to real-life scenarios according to ODOT and MUTCD guidelines ([Oregon Department of Transportation Traffic Management Section Traffic Engineering Services Unit Safety Comparison of Angle and Parallel Parking File Code: TRA 07-01-05', 2001](#); [U.S. Department of Transportation and Federal Highway Administration, 2023](#)). This research aimed to provide evidence that would allow policymakers, transportation engineers, and urban planners to better understand commercial vehicle drivers' curbside parking behaviors and safety in relation to CMV drivers and other road users. Many urban locations provide no to minimal commercial vehicle loading zones, which results in commercial vehicles parking in unauthorized spots, such as bicycle lanes, double parking in travel lanes, and passenger car parking spaces, causing congestion. This behavior is a safety risk for other road users and commercial vehicle operators because sometimes drivers exit the vehicle facing the travel lane, resulting in unexpected conflict.

By understanding drivers' behavior, this study aims to inform better urban planning and policy decisions to enhance safety and operational efficiency. Results showed that the number of lanes had minimal impact on drivers' speed due to the posted speed limit of 25 mph. However, drivers showed higher speeds when the bike lane was present, and passenger car parking spaces were occupied in two-lane settings. This suggests that truck drivers likely anticipated the unavailability of parking spots and, therefore, accelerated, recognizing the ineffectiveness of searching for one. On the other hand, in two and four-lanes scenarios, provided with a bike lane and passenger car parking space, there was a noticeable variation in average speeds, indicating that some of the drivers decided to use the PC spaces to park. Moreover, using

those spaces would require drivers to navigate through narrow spaces, causing drivers to reduce their speed ([Sabek et al., 2024](#)). Additionally, when CVLZs were occupied, drivers' speeds were high, indicating their intent to quickly move on and search for alternative parking spaces.

When drivers navigate for parking, their attention is divided between driving and looking for authorized parking. Given the urban settings provided in this experiment, drivers showed high TFDs when CVLZs were occupied, indicating that they were constantly looking for designated parking zones. Truck drivers frequently multitask while driving, aiming to improve travel efficiency and alertness. However, research indicates that engaging in secondary tasks impacts their attention levels, which is crucial for road safety ([McManus et al., 2017](#)). Furthermore, drivers had lower TFDs where no CVLZ was provided, suggesting that drivers kept moving around the block to find a parking space. Research indicates that dividing attention is linked with fatigue and crashes ([Trick et al., 2004](#)). Additionally, the post-drive questionnaire results revealed that 75% of drivers looked for available space prior to parking and performing parking operations, indicating the importance of having proper parking spaces.

Drivers showed a high frequency of illegal parking in the absence of designated CVLZs, regardless of the availability of passenger car parking spaces. It suggests the inadequacy of current design guidelines. Furthermore, drivers parked illegally in passenger car parking spaces when CVLZs were occupied, which could lead to safety concerns, particularly for pedestrians and bicyclists, as larger vehicles parked in spaces meant for smaller cars may obstruct the sight distance ([Chiara et al., 2020](#)). Researchers found that bicyclists were less comfortable while riding when commercial vehicles were parked, prompting them to utilize the travel lane, posing a potential risk ([Sabek et al., 2024](#)). These findings highlight the practical need for urban planners and policymakers to increase the number of designated CVLZs. By providing adequate CVLZs, cities can reduce the frequency of illegal parking and congestion, thereby improving safety for bicyclists and other road users. That said, only twenty percent of the time, drivers navigated around the block to find a legal space to park.

While this study demonstrates the benefits of adding CVLZs in reducing illegal parking and improving traffic safety, the economic feasibility of such an initiative must be carefully evaluated. Research suggests that increasing CMV parking can decrease congestion-related costs, reduce enforcement burdens, and improve delivery efficiency; however, the financial burden of allocating urban curb space remains a challenge. Studies indicate that cities like New York and San Francisco generate substantial revenue from commercial vehicle fines, making enforcement a more immediate source of revenue than infrastructure expansion ([Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area, 2238](#)). However, offsetting these fines with improved logistics, efficiency, and safety benefits could yield long-term economic gains. Future research should quantify these trade-offs to help policymakers make cost-effective curb management decisions.

Additionally, previous studies have noted that large freight carriers, such as UPS and FedEx, often treat parking fines as an operational expense rather than a deterrent ([Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area, 2238](#)). This practice reduces the effectiveness of penalty-based enforcement in modifying parking behavior for large firms. However, independent truck operators and small businesses may not have the financial flexibility to absorb such fines, making curbside parking availability a more pressing concern. In 2012, commercial vehicles (CVs) incurred over \$27 million in parking fines in Toronto. These fines were a major contributor to the high costs associated with the last mile of the supply chain and are passed on to consumers in the form of higher prices for final goods and services ([Wenneman et al., 2014](#)). This discrepancy suggests that a differentiated policy approach may be needed, where stricter enforcement applies to large logistics firms while infrastructure improvements are prioritized for small operators leading to reductions in the transportation costs of goods. In practice, such differential enforcement may

be challenging.

Overall, this study emphasizes the importance of providing adequate CVLZs and buffer zones to ensure the safety of bicyclists, parked vehicles, and other road users. Moreover, the results indicate that while drivers generally prefer to park legally, space and time constraints often lead to illegal parking, compromising traffic safety and operations. Additionally, the study highlights the importance of providing adequate parking spaces to mitigate stress levels and improve driving and parking operations, ultimately promoting road safety in urban environments.

Conclusions

The study was designed to examine the behavior of commercial vehicle drivers in various urban settings and how the lack of commercial vehicle loading zones (CVLZs) contributes to traffic congestion and safety issues. Two behavioral measures, speed and fixation durations, were evaluated using Oregon State University's (OSU) heavy vehicle simulator. Precise measurements were recorded to better understand truck drivers' behavior in a simulated urban environment, which is very tough to study in real life. Participants also responded to questions in a post-ride survey, where they showed their concerns about designated parking availability and other road features.

Several factors must come together to make accurate recommendations for improving CVLZ parking in urban settings. Results showed that urban settings impacted the vehicles' speed. In comparison to four-lane settings, drivers exhibited variation in speeds when bike lanes and passenger car parking spaces were present in two-lane scenarios. When CVLZs were occupied, drivers showed higher speeds, posing a hazard to other road users because they were looking for a place to park. Furthermore, commercial motor drivers' attention is divided when they drive. They constantly look for parking along the roadway. Drivers showed high TFDs when CVLZs were occupied, indicating the importance of proper allocation of space along the curbside. Additionally, in those urban settings where CVLZs were present but occupied, drivers' line of sight was obstructed by already parked commercial vehicles, increasing crash risk. Furthermore, around 60% of drivers parked illegally regardless of the urban settings. While 20% of drivers moved around the blocks looking for designated CVLZs. It shows a lack of designated CVLZs, promoting unpleasant delays and safety risks. These findings were also validated by a post-drive questionnaire, indicating that more than 80% of drivers advocated for exclusive truck parking. Results also showed that some of the drivers were involved in a crash while performing parking maneuvers, which clearly indicates insufficient planning regarding curbside parking. Overall, researchers should provide exclusive guidelines for better curbside management. Understanding commercial vehicle drivers' behavior in different urban settings will help cities to enhance logistics operations and management of curbside freight parking, mitigate illegal parking, and ultimately reduce traffic congestion. The results could be used to provide various recommended remedies for curbside parking on urban roadways. These suggestions may help improve CVLZ curbside parking and roadway design standards, enabling the urban street system to function more effectively, reliably, and safely for all users.

With that in mind, several recommendations may be considered, such as: 1) CVLZs signs: in areas where commercial vehicles are present, CVLZs signs could be put up to deter illegal parking for both road users; 2) Scheduling delivery times: Space limitations necessitate commercial vehicle parking in a bike lane or passenger vehicle parking spaces in the absence of CVLZs. If particular times of day can be set aside explicitly for commercial vehicle deliveries in a few spots on a curb face, this may contribute to mitigating the challenges; 3) Buffered bike lane: If there are no CVLZs for commercial vehicles, drivers may choose to use the bike lanes instead, which contributes to increased conflicts between cyclists and passenger cars; 4) Hand Truck: Drivers should always have access to a hand truck that enables them to go further and make many deliveries rapidly from a single parked space because long-term parking

reduced the number of options for illegal parking; and 5) Educational campaigns: For city planners, this project can help improve urban curbside parking management also increase the curbside parking spaces (CVLZs); for commercial vehicle drivers, it would be helpful to provide education flyers/posters to instruct them where are legal CVLZs when they deliver goods; for the researchers, the outcome could enhance their understanding about commercial vehicle parking behavior and safety between a commercial vehicle and other road users.

This study provided valuable insights, but it also has a few limitations that should be addressed in further studies. This simulated environment does not fully capture real-life scenarios, such as the seriousness of delivery or the type of commercial vehicle. Drivers in real-world scenarios must contend with ticket fines, enforcement presence, pedestrian risks, and physical stressors that could influence their decision-making. While simulators allow for controlled experimental conditions and data collection on eye tracking and speed variations, field studies incorporating enforcement penalties and real-world constraints should be incorporated in future research. Furthermore, while simulator studies provide insights, it was recognized that local governments may require more direct empirical evidence before implementing curbside policy changes. The study findings should be supplemented with pilot programs that test CVLZ expansion in real urban areas, incorporating feedback from commercial operators, policymakers, and enforcement agencies. Moreover, while the CDL drivers recruited for this study share similarities with urban truck drivers across the United States, such as having the same license requirements, urban driving environment, and the same truck type, the sample was limited to 33 drivers in Oregon. That said, regional differences in roadway infrastructure, traffic density, freight patterns, and driver demographics may limit the extent to which these findings can be generalized to broader urban truck driver populations and highlight the need for further research.

This study focused on general urban environments but did not incorporate bus lanes, right-turn only lanes, counter traffic flow lanes, or one-way streets. These elements could influence CMV driver decisions, particularly in constrained urban settings. Future research should integrate these additional variables to provide a more comprehensive understanding of why urban road configurations impact commercial vehicle parking behavior. Furthermore, future studies should explore the impact of vehicle size on parking choices, conducting on-street observational studies in different urban settings to validate simulator findings, and collaborating with local municipalities to evaluate policy interventions, such as timed loading zones and dedicated freight corridors.

Author contributions

The authors confirm contributions to the paper as follows: study conception and design, YL, SBUH, LSD, HJ, DH AR, AG, EM Author; data collection: YL, SBHN; analysis and interpretation of results, SBUH, HJ, LSD, DH; draft manuscript preparation: SBHN, LSD, YL, HJ, DH all authors reviewed the results and approved the final version of the manuscript.

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Yujun Liu: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Syed Baqir Ul Husnain:** Visualization, Methodology, Investigation, Data curation. **Logan Scott-Deeter:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision. **Hisham Jashami:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation. **David Hurwitz:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Andisheh Ranjbari:** Writing – review & editing, Supervision, Resources, Project

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

- Laura Stevens, 'Survey Shows Rapid Growth in Online Shopping'.
 Dalla Chiara, G., Goodchild, A., 2020. Do commercial vehicles cruise for parking? Empirical evidence from seattle. *Transp Policy (oxf)* 97, 26–36. <https://doi.org/10.1016/j.tranpol.2020.06.013>.
- Gao, J., Ranjbari, A., MacKenzie, D., 2019. Would being driven by others affect the value of travel time? Ridehailing as an analogy for automated vehicles. *Transportation (amst)* 46 (6), 2103–2116. <https://doi.org/10.1007/s11116-019-10031-9>.
- Chiara, G.D., Krutein, K.F., Ranjbari, A., Goodchild, A., 2021. 'Understanding urban commercial vehicle driver behaviors and decision making'. In: *Transportation Research Record*. SAGE Publications Ltd, pp. 608–619. <https://doi.org/10.1177/03611981211003575>.
- McCormack, E., Goodchild, A., Sheth, M., Hurwitz, D., 2019. Developing design guidelines for commercial vehicle envelopes on urban streets. *International Journal of Transport Development and Integration* 3 (2), 132–143. <https://doi.org/10.2495/TDI-V3-N2-132-143>.
- Jashami, H., Cobb, D., Hurwitz, D.S., McCormack, E., Goodchild, A., Sheth, M., Oct. 2020. The impact of commercial parking utilization on cyclist behavior in urban environments. *Transp Res Part F Traffic Psychol Behav* 74, 67–80. <https://doi.org/10.1016/j.trf.2020.07.014>.
- Mukherjee, D., Mitra, S., 2020. A comprehensive study on identification of risk factors for fatal pedestrian crashes at urban intersections in a developing country. *Asian Transport Stud.* 6, 100003. <https://doi.org/10.1016/j.eastsj.2020.100003>.
- 'National Association of City Transportation Officials'.
 'Curbside Management Strategies for Improving Transit Reliability.', 2017. Institute of Transportation Engineers, 'Curbside Management Practitioner's Guide', 2018.
- Allen, J., Browne, M., Cherrett, T., 2012. Survey techniques in urban freight transport studies. *Transp. Res.* 32 (3), 287–311. <https://doi.org/10.1080/01441647.2012.665949>.
- Lopez, C., Zhao, C.L., Magniol, S., Chiabaut, N., Leclercq, L., 2019. Microscopic simulation of cruising for parking of trucks as a measure to manage Freight Loading Zone. *Sustainability (switzerland)* vol. 11 (5). <https://doi.org/10.3390/su11051276>.
- Gopalakrishnan, R., Alho, A.R., Sakai, T., Hara, Y., Cheah, L., Ben-Akiva, M., 2020. Assessing overnight parking infrastructure policies for commercial vehicles in cities using agent-based simulation. *Sustainability (switzerland)* vol. 12 (7). <https://doi.org/10.3390/su12072673>.
- Yao, Y., Zhao, X., Ma, J., Liu, C., Rong, J., 2019. Driving simulator study: eco-driving training system based on individual characteristics. *Transp. Res. Rec.* 2673 (8), 463–476. <https://doi.org/10.1177/0361198119843260>.
- Yang, G., Ahmed, M.M., Gaweesh, S., 2019. Impact of variable speed limit in a connected vehicle environment on truck driver behavior under adverse weather conditions: driving simulator study. *Transp. Res. Rec.* 2673 (7), 132–142. <https://doi.org/10.1177/0361198119842111>.
- Raddaoui, O., Ahmed, M.M., 2020. Evaluating the effects of connected vehicle weather and work zone warnings on truck drivers. *Workload and Distraction Using Eye Glance Behavior*, *Transp Res Rec* 2674 (3), 293–304. <https://doi.org/10.1177/0361198120910743>.
- Low, R., Tekler, Z.D., Cheah, L., 2020. Predicting commercial vehicle parking duration using generative adversarial multiple imputation networks. *Transp. Res. Rec.* 2674 (9), 820–831. <https://doi.org/10.1177/0361198120932166>.
- Nevland, E.A., Gingerich, K., Park, P.Y., 2020. A data-driven systematic approach for identifying and classifying long-haul truck parking locations. *Transp Policy (oxf)* 96, 48–59. <https://doi.org/10.1016/j.tranpol.2020.04.003>.
- K. Aljohani and R. G. Thompson, 'Impacts of logistics sprawl on the urban environment and logistics: Taxonomy and review of literature', Dec. 01, 2016, *Elsevier Ltd*. doi: 10.1016/j.jtrangeo.2016.08.009.
- Yang, G., Ahmed, M.M., Subedi, B., 2020. Distraction of connected vehicle human-machine interface for truck drivers. *Transp. Res. Rec.* 2674 (9), 438–449. <https://doi.org/10.1177/0361198120929692>.
- Gillberg, M., Kecklund, G., Åkerstedt, T., 1996. Sleepiness and performance of professional drivers in a truck simulator - Comparisons between day and night driving. *J. Sleep Res.* 5 (1), 12–15. <https://doi.org/10.1046/j.1365-2869.1996.00013.x>.
- B. Helena, ; H David, and H Salvador, 'Preliminary Investigation of Heavy Vehicle Parking Design in Oregon Rest Areas'.
 'Oregon Department of Transportation Traffic Management Section Traffic Engineering Services Unit Safety Comparison of Angle and Parallel Parking File Code: TRA 07-01-05', 2001.
- U.S. Department of Transportation and Federal Highway Administration, *Manual on Uniform Traffic Control Devices for Streets and Highways*, 11th ed. 2023.
- Jashami, H., et al., 2023. Evaluation of bicyclist physiological response and visual attention in commercial vehicle loading zones. *J. Saf. Res.* <https://doi.org/10.1016/j.jsr.2023.11.018>.
- Sabek, B., Srour, F.J., El Mendelek, M., El Khoury-Malhame, M., Khoury, J., 2024. Are you in the mood to pass? a study on the interplay of psychological traits and traffic on young drivers' overtaking behavior on two-lane, two-way highways. *Transp Res Part F Traffic Psychol Behav* 101, 59–77. <https://doi.org/10.1016/j.trf.2023.12.022>.
- McManus, B., Heaton, K., Stavrinou, D., 2017. Commercial motor vehicle driving performance: an examination of attentional resources and control using a driving simulator. *J. Exp. Psychol. Appl.* 23 (2), 191–203. <https://doi.org/10.1037/xap0000120>.
- Trick *, L.M., Enns, J.T., Mills, J., Vavrik, J., 2004. Paying attention behind the wheel: a framework for studying the role of attention in driving. *Theor. Issues Ergon. Sci.* vol. 5 (5), 385–424. <https://doi.org/10.1080/14639220412331298938>.
- Chiara, G.D., Cheah, L., Azevedo, C.L., Ben-Akiva, M.E., 2020. A policy-sensitive model of parking choice for commercial vehicles in urban areas. *Transp. Sci.* 54 (3), 606–630. <https://doi.org/10.1287/trsc.2019.0970>.
- Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area," *Transportation Research Record*, v. 2238, n. 1.
- T. Allen, and R. Tarr. 'Driving simulators for commercial truck drivers-humans in the loop.' *Driving Assessment Conference*. vol. 3. no. 2005. University of Iowa, 2005.
- Hirsch, P., Choukou, M.A., Bellavance, F., 2017. Transfer of training in basic control skills from truck simulator to real truck. *Transp. Res. Rec.* 2637 (1), 67–73.
- Pannasch, S., Schulz, J., Velichkovsky, B.M., 2011. May). on the control of visual fixation durations in free viewing of complex images. *Atten. Percept. Psychophys.* 73 (4), 1120–1132. <https://doi.org/10.3758/s13414-011-0090-1>.
- Ozcelik, E., Karakus, T., Kursun, E., Cagiltay, K., 2009. September 1). an eye-tracking study of how color coding affects multimedia learning. *Comput. Educ.* 53 (2), 445–453. <https://doi.org/10.1016/j.compedu.2009.03.002>.
- Wenneman, A., Roorda, M., Habib, K., 2014. Illegal commercial vehicle parking, parking demand, and the built environment. In *Canadian Transportation Research Forum*.