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The Impact of Commercial Parking Utilization on Cyclist Behavior in Urban Environments

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ABSTRACT

With growing freight operations within the United States, there continues to be a push for urban streets to accommodate trucks during loading and unloading operations. Currently, many urban locations do not provide loading and unloading zones, which results in trucks parking in places that can obstruct roadway infrastructure designated to vulnerable road users (e.g., pedestrians and cyclists). In an effort to understand the implications of these truck operations, a bicycle simulation experiment was designed to evaluate the impact of commercial vehicle loading and unloading activities on safe and efficient bicycle operations in a shared urban roadway environment. A counter-balanced, factorial design was chosen to explore three independent variables: commercial vehicle loading zone (CVLZ) sizes with three levels (no CVLZ, Min CVLZ, and Max CVLZ), courier position with also three levels (No courier, behind the truck, beside the truck), and loading accessories (Acc) with two levels (no Acc, and with Acc). Cyclist's velocity and lateral position were used as performance measures. Data were obtained from 48 participants (24 women) resulting in 864 observations in 18 experimental scenarios. Linear Mixed-Effects Models (LMM) were developed to examine the effect of each independent variable level on bicyclist performance.

Results from LMM model suggest that loading zone size had the greatest effect on cyclist's divergence. Additionally, when the courier was walking beside the truck, cyclist's velocity significantly dropped to almost one m/sec in compared when the courier located behind the truck. The presence of accessories had the lowest influence on both velocity and lateral positions of cyclists. In the no CVLZ scenarios, the delivery vehicle was parked at the bike lane, therefore; cyclists had to choose between using the travel lane or the sidewalk. About one-third of participants decided to use the sidewalk. These findings could support better roadway and CVLZ design guidelines, which will allow our urban street system to operate more efficiently, safely, and reliably for all users.

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1. Introduction

There is continued pressure for multiple modes to share urban streets and compete for curb space as urban populations and freight activities grow. Cities are recognizing curb space as valuable public real estate that must be better understood, managed, and designed to improve the quality of life for residents and the transportation systems of cities.

Cities are responsible for strategizing how best to manage, regulate, and design curb space for different transportation modes and activities, including commercial vehicle parking and urban deliveries. These strategies are complex because they include a wide range of stakeholders and are further compounded by well-accepted urban planning policies (such as Smart Growth and Complete Streets) that support compact development, a mixture of land uses, and a range of feasible transportation options that promote and facilitate modes of travel other than the automobile – e.g., transit, bicycles, and walking (NACTO, 2019; Smart Growth America, 2019). Complete streets "are designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists, and transit riders of all ages and abilities. By adopting a Complete Streets policy, communities direct their transportation planners and engineers to routinely design and operate the entire right of way to enable safe access for all users, regardless of age, ability, or mode of transportation" (Smart Growth American, 2019). Although these policies are well intended, current application standards have significant gaps that do not fully support the unique infrastructure and design needs of freight activity and urban goods deliveries.

Previous studies and observations by the research team found that curb use by commercial vehicles is not aligned with designated curb allocation, and current allocation is not spatially allocated according to demand (SCTL, 2019; Goodchild, Ivanov, McCormack, Moudon, Scully, Leon, & Giron Valderrama, 2018; Wygonik, Bassok, Goodchild, McCormack, & Carlson, 2015). Common actions that reflect the limitations of curb space design for deliveries include commercial vehicles parking on sidewalks and in bike lanes and turn lanes, loading ramps and lift gates blocking crosswalks and sidewalks, and the staging of freight in locations that impede bike and pedestrian movements. These issues are more notable in certain corridors with a high demand for deliveries, but this is not reflected in the street design or design of the loading spaces for commercial vehicles in these corridors. These problems occur because commercial vehicles using designated loading zones are not allocated an envelope, or space adjacent to the vehicle, to accommodate loading and unloading activities.

When performing delivery activities, couriers (i.e., delivery vehicle drivers and helpers) are required to walk around the vehicle, extend ramps and handling equipment, and maneuver goods; all these activities require space around the vehicle beyond the dimensions of the vehicle itself. A parallel can be drawn with parking for disabled drivers, which allocates an extra buffer next to a disabled parking space allow a wheelchair to exit/enter the vehicle. However, unlike disabled parking, trucks are typically not allocated this buffer space, and as a result of these design insufficiencies, couriers undertake high-risk behaviors by walking in roadway and bike lanes.

While North American data are unavailable, studies in the United Kingdom found that "every year, about 70 people are killed and 2000 seriously injured in accidents involving vehicles in and around workplaces. A significant number of these occur during deliveries and collections" (Health and Safety Executive, 2019).

Due to these design limitations, drivers of commercial vehicles and couriers are observed using and obstructing pedestrian pathways and bicycle infrastructure to complete deliveries. These actions create uncertainty and disrupt the predictable flow of traffic. As a result, it puts the driver and other road users in direct conflict and ultimately, in harm's way. Currently, there are no explicit commercial vehicle load zone (CVLZ) design standards in the United States that incorporates the functional design elements a commercial vehicle would need to load and unload.

2. Literature Review and Field Observations

There is little oversight or regulations about design considerations for CVLZs, and discussions about well-designed CVLZs with sufficient operating envelopes lack clear policies, procedures, and methods for standardized CVLZ design guidelines.

2.1. Commercial Vehicle Load Zones Design Standards/Guidelines – Current Practices

Cities across the United States have different rules and regulations for these zones but can be generalized to include a paid permit and signage to indicate the constraints within the loading zone. Figure 2.1 is an example of a type of CVLZ sign in Seattle, Washington. (To give a sense of the scale required for this system, the City of Seattle has approximately 460 commercial vehicle load zones (CVLZ), 150 of which are located in Downtown Seattle (City of Seattle, 2016)). In addition, there is no national standard for curb paint. Different cities have different policies regarding curb paint as well, but in some cities such as Seattle and San Francisco, yellow curb paint indicate activities that include but are not limited to freight loading/unloading activity (SDOT, 2018; SMFTA, 2019)

There is minimal information about CVLZ design and envelope requirements in the major geometric, traffic control, and street design guidebooks used by planners and engineers. The Manual on Uniform Traffic Control Devices (MUTDC, 2009), a commonly used resource with national standards for roadways in the United States, includes detailed information about appropriate signage and grades for commercial vehicles but does not include clear standards for the design and dimensions of a CVLZ.

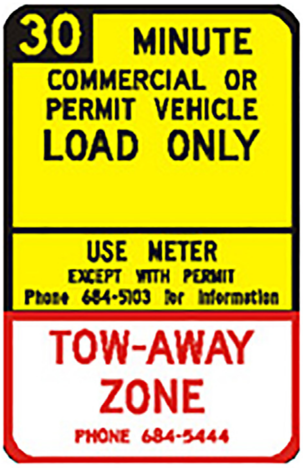

Fig. 2.1. Commercial vehicle loading zones signage (SDOT, 2015)

In the American Association of State Highway and Transportation Officials (AASHTO, 2011) "A Policy on Geometric Design of Highways and Streets," guidelines are suggested for urban parking lanes. These include a width sufficient to accommodate delivery vehicles and serve as a bicycle route, allowing a bicyclist to maneuver around a vehicle's open door. The length of curb space allocated to each parking spot is not included.

The National Association of City Transportation Officials (NACTO, 2019) is a non-profit association of major North American cities that publishes design guidelines for various urban planning elements and modes such as bikes, transit, and freight. NACTO acknowledges that the operational envelope required for comfortable and safe movements is different for all modes, and that freight requires additional space for hand and cart movement (NACTO, 2016a). One of the freight delineations is for commercial vehicles and light trucks, which are defined as "trucks generally used for carrying goods from ex-urbanized logistic centers to the city." They are bigger in scale compared to motorized personal vehicles but do not require wider corner radii or bigger lanes. NACTO identifies the general dimensions of commercial vehicles and light trucks as 7 – 10 m (23 - 33 ft) long and 2 m (6.5 ft) wide (Figure 2.2). NACTO also recommends that box trucks with a width of 2.4 m (8 ft) have a parking spot 3.4 m (11 ft) wide to incorporate the buffer space required for the door zone (NACTO, 2016b). Although NACTO recognizes that additional space is required for freight parking to support freight loading/unloading activities, there is no additional information about the length of a commercial vehicle parking spot.

A study that used focus groups to learn from truck drivers about urban deliveries found that an impediment to urban freight activity was loading areas with insufficient space. The drivers recommended that curb space be at least 30 ft (9 m) long (Pivo, Carlson, Kitchen, & Billen, 2002).

One of the few reports to explore truck access and parking, "Truck Movement and Access in Urban Areas," noted that if traffic engineers considered the unique needs of urban freight in their practice, then the transportation ecosystem at large would improve (Ogden, 1991). A section on load zones addressed the problems of on-street load zones, which included being inconveniently located, not being sufficiently in number, and poor design and layout (e.g., with the potential for collisions between vehicles and roadside objects such as poles, verandas, street lights). Although this article did not identify ideal on-street commercial vehicle parking dimensions, it included recommended minimum dimensions for a loading bay, which may be used as a proxy for on-street commercial vehicle load zone dimensions:

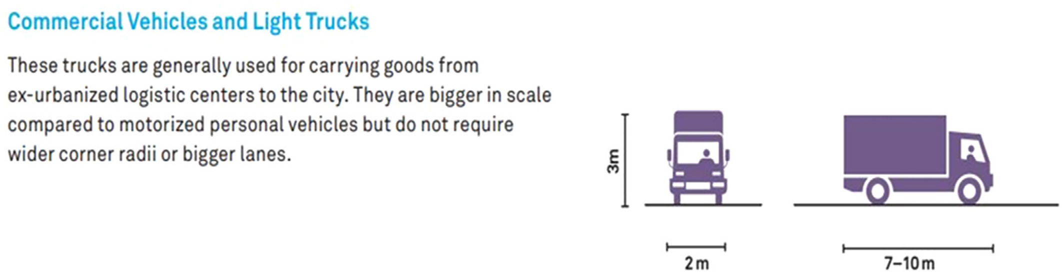

Figure 2.2. Urban Freight Vehicle Defined and Dimensions (NACTO, 2016a)

- Light rigid two-axle truck: length 21' 8" in, width 6' 10" in, and wheelbase 12' 1" in.
- Heavy rigid three-axle truck: length 36' 0"in, width 7' 3" in, wheelbase (to midpoint of rear axles) 18' 1" in.
- Articulated truck with three-axle tractor: overall length 55' 9" in, width 8' 2" in. tractor wheelbase 12' 2" in., kingpin to midpoint of trailer axles 28' 3" in.

2.2. Bicycle Behavior with Commercial Vehicles

In both urban and suburban environments, commercial vehicles are often provided limited to no space for loading and unloading operations. As a result, commercial vehicles are often staged in locations that block vehicular traffic and obstruct infrastructure (e.g., sidewalks, bicycle lanes, etc.) that are used by pedestrians and cyclists. Specifically, when no commercial vehicles loading and unloading zone is provided, trucks frequently utilize bike lanes, thus obstructing the bike lane for cyclist's riding path. As a result, cyclists are required to deviate from the bike lane into the adjacent travel lane, consequently exposing themselves to vehicles in the adjacent travel. Due to the dangers that arise for cyclists during commercial vehicle loading and unloading, researchers have just begun to investigate and understand this event using field observations of conflict points, historical crash data, and state-preference surveys evaluating cyclists' levels of comfort.

In 2013, a study was done New York City that investigated the conflicts between commercial vehicles and bicycles. Conway, Thuillier, Dornhelm, and Lownes (2013) observed measured conflicts (e.g., cyclists deviate from the lane, cyclists use the adjacent lane to navigate, cyclists stop to avoid conflict) between commercial vehicles and bicycles on several blocks based on three (3) types of bike lane configurations (e.g., buffered bike lane next to curb, bike lane to the right of on-street parking, bike lane to left of on-street parking), neighborhood types, and retail densities. The study found that when buffered bike lanes were provided, there was a higher incidence of conflicts (Conway et al., 2013).

The City of Seattle conducted a study that looked at crash data involving cyclists and trucks between 2004 and 2014 to determine the rate of fatalities and serious injuries. Butrina, Goodchild, McCormack, and Drescher (2016) found that the during this period the rate of fatalities (4.0%) and serious injuries (13.0%) for bicycle-truck crashes was higher than the city average rate of fatalities (0.4%) and serious injuries (7.6%) (Butrina et al., 2016).

Researchers have also looked at how truck interactions and loading zones play influence into cyclists perceived level of comfort while riding (Winters, Davidson, Kao, & Teschke, 2011; Abadi, Fleskes, Jashami, & Hurwitz, 2018). Winters et al. (2011) conducted a survey in Vancouver to determine how 73 variables played an influence into cyclist's comfort levels. Winters et al. (2011) found that truck traffic played a significant role in a bicyclist's perception of comfort while riding. In 2018, Abadi et al. (2018) investigated people's preferences when riding in urban areas using an online survey and found that individuals riding alongside both truck traffic and interacting with commercial vehicle loading zones could potentially decrease level of comfort by 42% (Abadi et al., 2018).

Understanding this bicycle-truck conflict within loading and unloading zones is important as the implications of this event play a much larger influence into the design and operations of the roadway paradigm.

2.3. Field Observations of activities and movements around commercial loading zones

In 2019, the research team conducted field observation of 25 deliveries in Seattle, collecting 15 critical aspects (e.g., commercial vehicle characteristics, vehicle classification, driver and passenger entry/exit door type, exiting/entering commercial vehicle behavior, etc.) regarding delivery characteristics (Mccormack, Goodchild, Sheth, & Hurwitz, 2019). Based on the evaluation, the following was found:

- Majority (i.e., 18 of 25) of the vehicles were classified as Class 5 (i.e., two-axle, six-tire, single-unit trucks),
- 20 of 25 deliveries conducted were done by a single person who served as both driver and courier
- 18 of 25 trucks had the driver and passenger door operated as swing out doors
- 13 of 25 deliveries used hand trucks for the delivery

Based on these observations, since a majority of deliveries were conducted by one person, at a minimum, adequate door opening space would need to be provided on the driver's side of the vehicle for safe and comfortable ingress and egress and less concern may be given for the passenger's side. Furthermore, as most vehicles operated with a swing out door, a commercial vehicle operating envelope should include additional space for the opening door radius. Overall, the observations indicate a need for adequate space for drivers to safely navigate the truck during deliveries.

2.4. Summary

Overall, there is no direct acknowledgment that urban freight activities require envelopes around trucks to support urban load and unload activities. The standard design sources and manuals to support planners and engineers responsible for installing transportation infrastructure address the space required for parking trucks but did not account for the envelope needed around that parked truck necessary for the safe and effective loading and unloading of goods. Therefore, more research is needed to understand and provide the minimum operating space required during urban loading/unloading activities around a commercial vehicle and the impact of commercial vehicle loading and unloading activities on pedestrian and bicycle operations in a shared urban roadway environment.

3. Methodology

A bicycle simulation experiment was designed to evaluate the impact of commercial vehicle loading and unloading activities on safe and efficient bicycle operations in a shared urban roadway environment. This study was approved by the Oregon State University (OSU) Institutional Review Board (Study #8506).

3.1. OSU Bicycle Simulator

The OSU bicycling simulator consists of an instrumented urban bicycle placed on top of an adjustable stationary platform. A 10.5 ft × 8.3 ft (3.20 m × 2.54 m) screen provides the forward view with a visual angle of 109° (horizontally) × 89° (vertically) and image resolution of 1024 × 768 pixels. Researchers construct the virtual environment and observe the performance of subject bicyclists from within the operator workstation shown in Figure 3.1, which is out of view from participants in the bicycle simulator experiment.

The update rate for the projected graphics is 60 Hz. Ambient sounds around the bicycle are modeled with a surround sound system. The computer system consists of a quad-core host running Realtime Technologies SimCreator Software with an update rate for the graphics of 60 Hz (Hurwitz, Horne, Jashami, & Abadi, 2019). The simulator software is capable of capturing and outputting highly accurate values for performance measures such as speed, position, brake, and acceleration. Figure 3.2 shows views of the simulated environment created for this experiment from the participant's view (left) and outside view (right).

The virtual environment was developed using simulator software packages, including Internet Scene Assembler (ISA), Simcreator, AutoCAD, Blender, and Google Sketchup. The simulated test track was developed in ISA using JavaScript-based sensors on the test tracks to display dynamic objects, such as a commercial vehicle driver walking alongside the truck.

3.2. Simulator Environment

The environment was designed to replicate a typical urban roadway with varying commercial loading and unloading zones. The experiment consisted of the following three (3) roadway cross-sections:

- Two (2) 3.65 m travel lanes, two (2) 1.84 m bicycle lanes, with no parking lane (i.e., truck uses bicycle lane for loading and unloading operations) (shown in left Figure 3.3)
- Two (2) 3.65 m travel lanes, two (2) 1.84 m bicycle lanes, and one (1) 3.50 m small loading zone (i.e., truck uses parking lane for loading and unloading operations) (shown in middle Figure 3.3)
- Two (2) 3.65 m travel lanes, two (2) 1.84 m bicycle lanes, and one (1) 4.50 m large loading zone (shown in right Figure 3.3)

Ambient traffic in the environment was coded manually, to ensure that each participant encountered the same number of vehicles and to limit the number of interactions or conflicts that each participant encountered. The ambient traffic was designed in the experiment to simulate normal traffic conditions, which includes vehicles passing cyclists every 10 seconds (i.e., 360 vehicles/hour); however, to ensure that the experiment was controlled, the ambient traffic did not pass cyclists while they were interacting with the commercial vehicle loading zone. Before beginning the experimental drive, bicyclists performed a one- to two-minute calibration ride to acclimate to the operational characteristics of the bicycling simulator, and to determine if they are prone to simulator sickness and as such should be removed from the experiment to mitigate discomfort (Hurwitz, Jashami, Buker, Monsere, Kothuri, & Kading, 2018). Participants were instructed to ride and follow all traffic laws that they normally would. The test ride was conducted on a generic city environment track similar to this experiment so that participants can become accustomed to both the bicycle's mechanics and the virtual reality of the

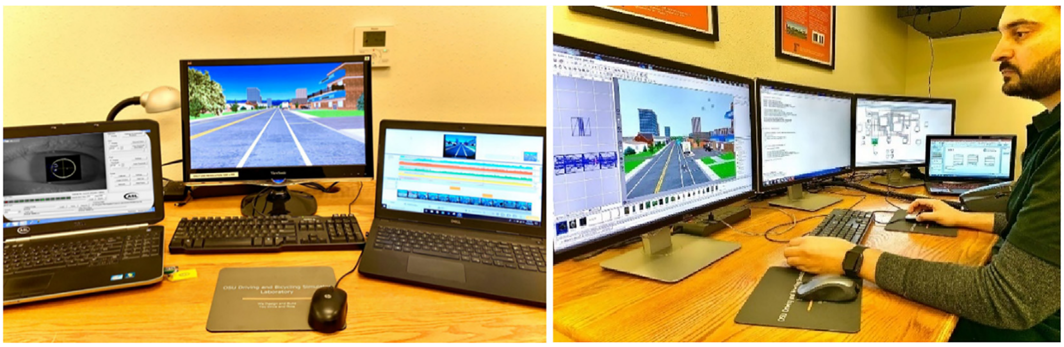

Figure 3.1. Operator workstation for the bicycling simulator. *Left*: Real-time monitoring of the simulated environment. *Right*: A researcher designing an experiment in SimCreator.

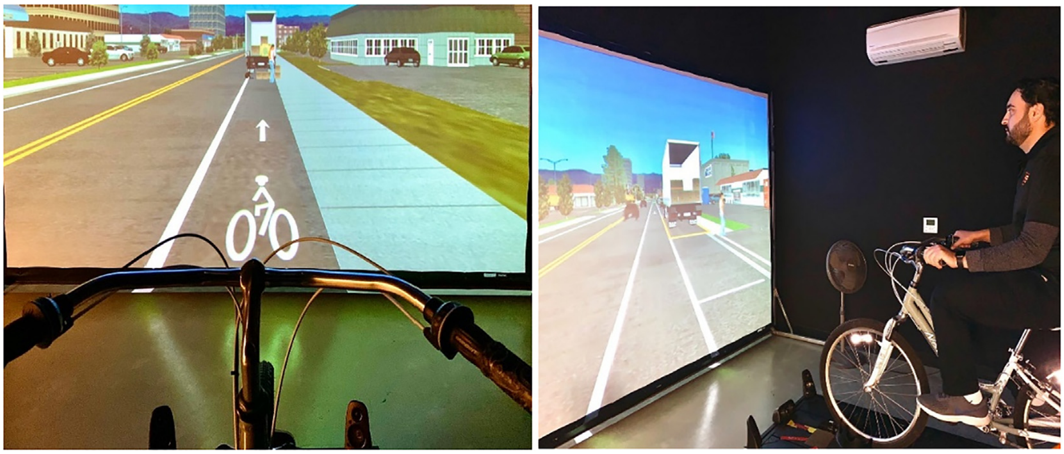

Figure 3.2. Simulated environment in the OSU bicycle simulator. *Left*: Participant's perspective. *Right*: A researcher testing the environment.

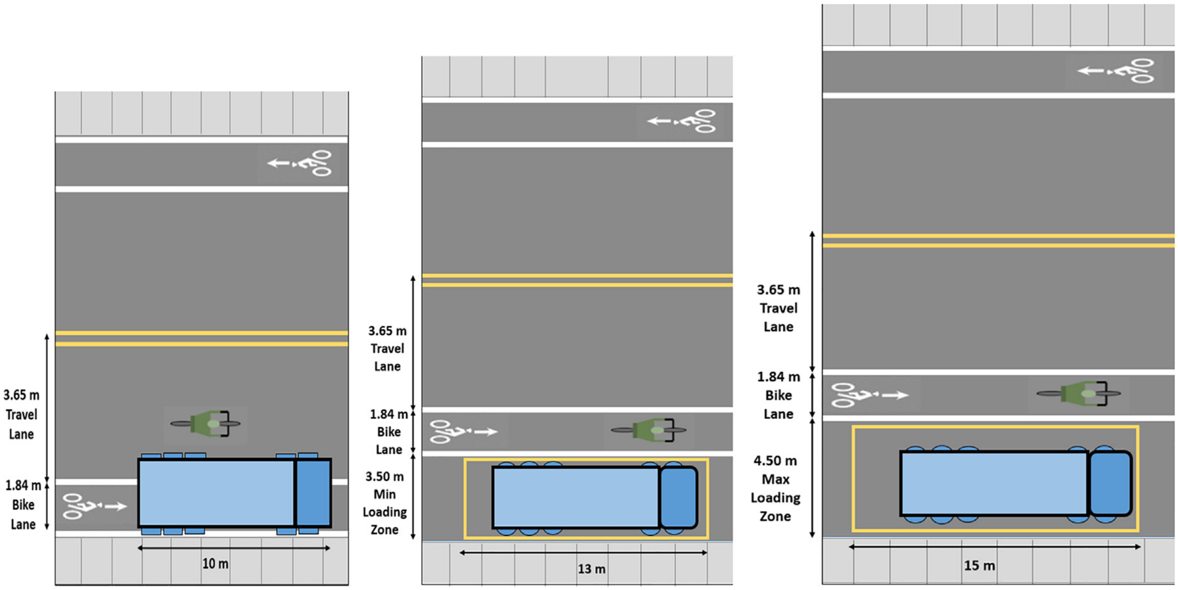

Figure 3.3. Roadway cross-section. *Left:* roadway with no parking lane. *Middle:* roadway with minimum loading zone. *Right:* roadway with maximum loading zone.

simulator. In the case that a participant reported simulator sickness during or after the calibration ride, they were excluded from the experimental rides.

3.3. Independent Variables

A factorial design was chosen for this experiment to enable the exploration of all three independent variables separately. Table 3.1 summarizes the independent variables and their associated levels in the factorial design. The experiment included three independent variables: pavement marking, courier position, and accessory (Table 3.1).

The factorial design resulted in the inclusion of 18 scenarios, which were presented within participants. Four examples of these scenarios are presented in Figure 3.4. To control for practice or carryover effects, the scenario order was partially counterbalanced by utilizing five different tracks, each ranging in length from approximately 2 to 4 minutes, depending on the participant's cycling speed and track length. The grid sequences were randomized for each participant (Jashami, Hurwitz, Monsere, & Kothuri, 2020).

Table 3.1
Experimental variables and levels

VARIABLE	Level	LEVEL DESCRIPTION
Pavement Marking	0	No CVLZ – Truck in Bike Lane
	1	Min CVLZ – Size of the vehicle only
	2	Max CVLZ – Size of the vehicle plus desired operational footprint (total width = 4.50 m)
Courier Position	0	No Courier
	1	Courier Behind Vehicle
	2	Courier on Driver's Side
Accessory	0	No Accessory
	1	Hand Truck

Figure 3.4. Examples of the experimental design scenarios: (a) A scenario with accessories, and without CVLZ and courier; (b) A scenario with minimum CVLZ and accessories, and without courier; (c) A scenario with maximum CLZ and accessories, and without courier; (d) A scenario with maximum CLZ and courier on driver's side, and without accessories

3.4. Dependent Variables

Two dependent variables were measured and evaluated through this work. These dependent variables were lateral position data from the truck and bicyclist and the cyclist's velocity.

3.5. Experimental Protocol

Participants were recruited through flyers posted around Corvallis, Oregon, and through emails sent to different campus organizations and email listservs. At the start of the experiment, participants were asked to provide informed consent and answer a prescreening survey to ensure that they were physically and mentally able to ride a bicycle, had good vision, and were not prone to simulator sickness. The prescreening survey also included demographic questions (i.e., age, gender, ethnicity, cycling experience, highest level of education, and prior experience with simulators). After completing the prescreening survey, participants were introduced to the bicycling simulator controls. The displays were explained. Participants then completed an approximately 2-minute calibration ride. After the experimental rides, which took approximately 30 minutes to complete, participants answered a post-ride survey, which included questions on their experience and their attitude towards automation after the experimental ride.

3.6. Participant Demographics

A total of 50 participants (26 women, 24 men) participated in the simulator study. Two women were excluded from the experiment. One was due a simulator sickness, and the other due to an eye tracker calibration issue. Although it was expected that many participants would be OSU students, an effort was made to incorporate participants of all ages within the specified range of 18 to 75 years. The age of participants ranged from 18 to 74 years with 24 women (M_{age} = 29.84, SD_{age} = 7.48) and 24 men (M_{age} = 36.45, SD_{age} = 15.57). Additionally, the pre-survey that was provided to all participants found that participants most frequently bicycled weekly 1-5 miles (22.0%) and 5-10 miles (22.0%), while individuals most often bicycled for recreational purposes (34.7%) and for exercise (33.7%).

3.7. Statistical Modeling

A Linear Mixed Effects Model (LMM) model was chosen for the analysis because 1) of its ability to handle the errors generated from repeated subject variables as the participants are exposed to all scenarios, 2) it can handle fixed or random effects, 3) categorical and continuous variables can easily be accommodated, and 4) the probability of Type I error occurring is low (Jashami, Hurwitz, Monsere, & Kothuri, 2019 ; Kothuri, Monsere, Jashami, & Hurwitz, 2020; Jashami, Abadi, & Hurwitz, 2017). A potential limitation of LMM is that more distributional assumptions need to be addressed (Maruyama, 2008). The sample size for this study was 48 participants, which is greater than the minimum required for a LMM analysis (Barlow, Jashami, Sova, Hurwitz, & Olsen, 2019). Therefore, the LMM was chosen to model the data. The model was developed using the statistical software Minitab for Windows (version 19.2) to consider the independent variables of loading zone size, courier position, and accessories. These variables were included in the model as fixed effects. While the participant variable was also included in the model as a random effect.

4. Results

Two measures of cyclist performance were evaluated: lateral position and cyclist's velocity. The lateral position was the distance between the cyclist and the truck, while the cyclists navigating the commercial loading and unloading zones. The cyclist's velocity was the instantaneous speed calculated throughout the ride but specifically investigated in and around the interaction of the cyclists and commercial loading and unloading zone.

4.1. Bicycle Performance Results

4.1.1. Lateral Position Results

Mean (μ) and standard deviation (SD) values for lateral position for each independent variable level are reported in Table 4.1. Center of the bike lane was defined as 0 m making the left edge -0.92 m (travel lane side). Bicyclists encountering a truck in the bike lane (no loading zone), a courier was walking beside the truck, and a hand truck with some boxes were present behind the truck had the most divergence ($\mu_{Lateral}$ = -1.88 m, $SD_{Lateral}$ = 0.51 m) from the center of bike lane toward the travel lane. On the other hand, bicyclists had the least divergence ($\mu_{Lateral}$ = -0.15 m, $SD_{Lateral}$ = 0.15 m) when a truck was parked in the largest loading zone, no courier was present, and accessories existed behind the truck.

A LMM was used to estimate the relationship between the independent variables and participant's mean lateral position, which is appropriate given the repeated measures nature of the experimental design, where each participant experienced each scenario (Jashami, Hurwitz, Abdel-Rahim, Bham, & Boyle, 2017). Both fixed and random effects needed to be included in the model. In the case of statistically significant effects, custom post hoc contrasts were performed for multiple comparisons using Fisher's Least Significant Difference (LSD). All statistical analyses were performed at a 95% confidence level. Restricted Maximum Likelihood estimates were used in development of this model.

The results of the model are shown in Table 4.2. The random effect was significant (Wald Z=4.37, $p<0.001$), which suggests that it was necessary to treat the participant as a random factor in the model.

All three independent variable characteristics were found to have a significant impact on the lateral position of the bicyclists. Regardless of the courier position and accessories, a bicyclist, encountered with a parked truck in the maximum load-

Table 4.1
Mean and Standard Deviation of Lateral Position (m) at Independent Variable Level

Commercial Vehicle Loading Zone (CVLZ)	Descriptive Statistics	No Accessories No Courier	Behind	Beside	Hand Truck No Courier	Behind	Beside
No CVLZ	μ	-1.47	-1.65	-1.58	-1.61	-1.75	-1.88
	(SD)	(0.50)	(0.52)	(0.61)	(0.47)	(0.51)	(0.51)
Min CVLZ	μ	-0.25	-0.31	-0.51	-0.28	-0.38	-0.53
	(SD)	(0.15)	(0.14)	(0.33)	(0.21)	(0.19)	(0.40)
Max CVLZ	μ	-0.17	-0.23	-0.20	-0.15	-0.18	-0.26
	(SD)	(0.14)	(0.17)	(0.20)	(0.15)	(0.19)	(0.16)

Table 4.2
Mean and Standard Deviation of Lateral Position (m) at Independent Variable Level

Variable	Levels	Estimate	DF	P
Participant random effect (SD)	-	(0.20)	-	<0.001*
Constant	-	-0.74	47	<0.001*
Loading Zone Size	Max CVLZ	0.37	799	<0.001*
	Min CVLZ	0.55	799	<0.001*
	No CVLZ	Base	-	-
Courier Position	Beside	-0.08	799	<0.001*
	Behind	-0.007	799	0.616
	No Courier	Base	-	-
Accessories	Acc	-0.04	799	<0.001*
	No Acc	Base	-	-
CVLZ x CP	Max CVLZ x Beside	0.05	799	0.006*
	Min CVLZ x Beside	Base	-	-
CVLZ x Acc	No CVLZ x Acc	-0.06	799	<0.001*
	No CVLZ x No	Base	-	-
Summary Statistics				
Adjusted R^2	86%	Observations		864
-2Log Likelihood	500.93	Participants		48
AIC	504.95	Observations/Participant		18

* Significant at the 95% confidence level

ing zone, diverged the least compared to minimum loading zone or no loading zone ($p < 0.001$). The second significant variable was courier position. When bicyclists rode in a scenario that had a courier on the side of truck, the participants diverged about 0.2 m more than the no courier condition ($p < 0.001$). However, when the courier was behind the truck, it was not statistically different from the no courier scenario. Finally, the accessories variable found that the average bicyclist's divergence was 0.08 m higher when there was a hand truck and boxes than without ($p < 0.001$).

Moreover, LMM revealed two statistically meaningful two-way interactions between loading zone size, and both courier position ($p = 0.006$) and accessories ($p = 0.049$), as shown in Figure 4.1.a and Figure 4.1.b, respectively. However, the interaction term between courier position and accessories was not significant (Figure 4.1.c). In Figure 4.1, the y-axis shows mean

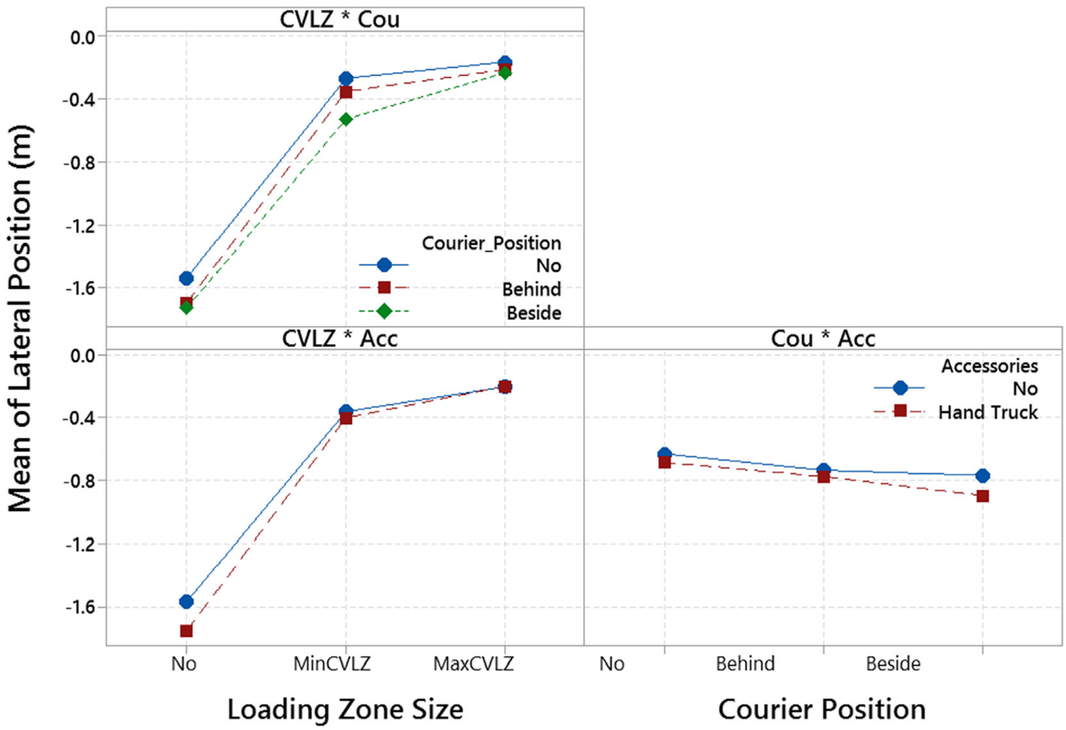

Figure 4.1. Two-way interactions of treatment variables on mean lateral position: a) two-way interactions plot between loading zone size and courier position, b) two-way interactions plot between loading zone size and accessories, and c) two-way interactions plot between courier position and accessories

lateral position. The x-axis in plots 4.1.a and 4.1.b shows the three levels of loading zone size treatment, and the x-axis in 4.1.c shows the two levels of accessories treatment. For example, Figure 4.1.a plots the interaction between the levels of loading zone size and courier position. Regardless of accessories, on average, participants diverged more towards the travel lane at minimum loading zone compared to maximum loading zone when the courier was walking alongside the truck. Meanwhile, while holding the courier position constant, bicyclists diverged less at the no loading zone in the no accessories scenario as compared with accessories. Additionally, the three-way interaction between the three treatment variables was not significant ($p > 0.05$). All treatment factors were inspected by pairwise comparison.

Figure 4.2 plots lateral position distribution (m) on the y-axis, aggregated at each 1 meter at different loading zone size (truck was parked at the bike lane, truck was parked at on-street parking zone, and truck was parked at the desired loading zone) without accessories and courier was alongside the truck to further explore the influence of the most impactful treatments on the bicyclist's divergence. The x-axis shows traveled distance along the bike lane. The dots indicate the data point of each bicyclist (for all 48 participants). As shown in this figure, loading zone size has an increasing effect on mean lateral position, with a parked truck on the bike lane having the highest divergence from the center of the bike lane toward the travel lane. It is worth pointing out that 18 bicyclists out of 48 decided to take the sidewalk instead of the travel lane but this

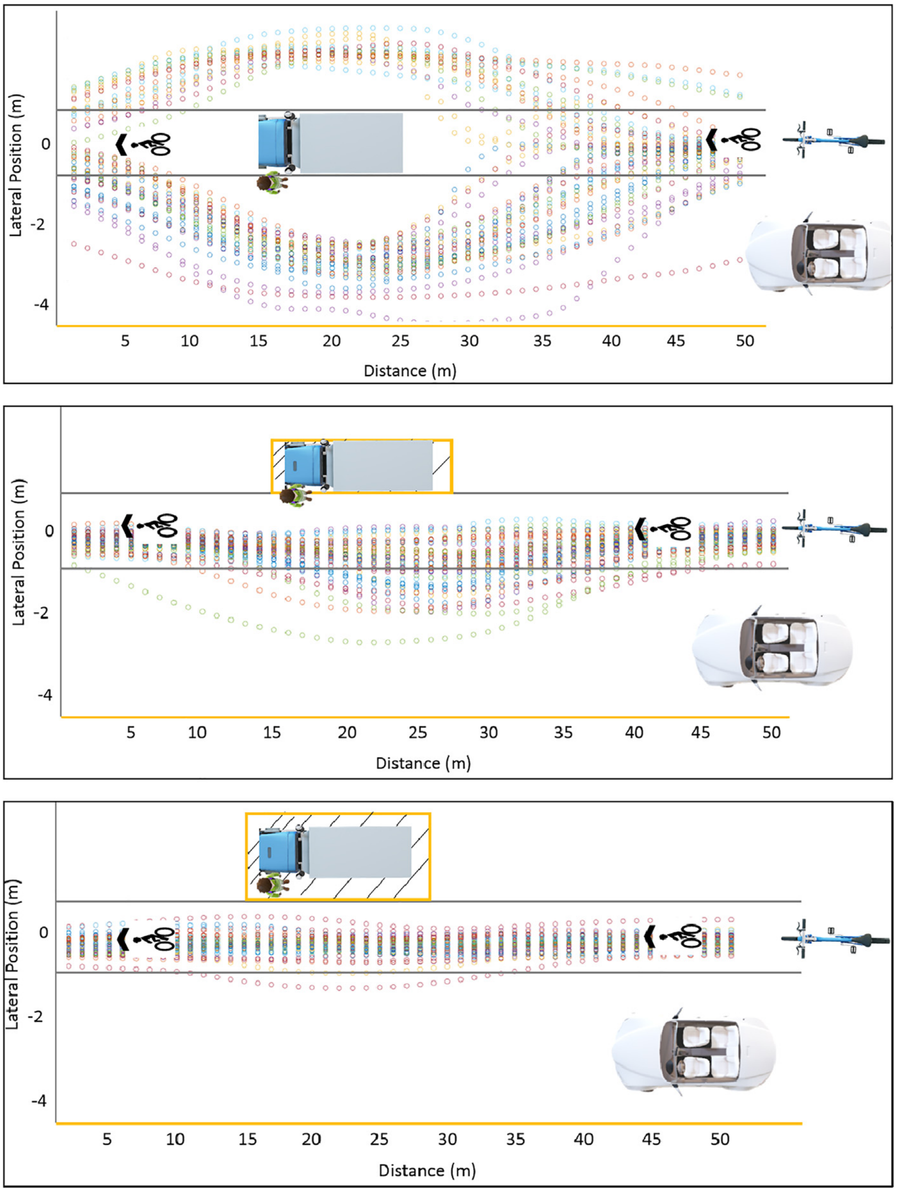

Figure 4.2. Bicyclists' lateral position at different loading zone sizes and courier on side

scenario did not happen when the truck was parked at the on-street parking (Min CVLZ). For the minimum loading zone, several participants diverged from the bike lane and this due to the courier position, so they tried to avoid them.

4.1.2. Speed Results

For each scenario, the average speed (m/sec) of bicyclists from 25 meters before the parked truck to 15 meters after was recorded. Table 4.3 shows the mean (μ) and standard deviation (SD) values for speed for each level of every independent variable. As shown in the table, the highest mean speed occurred with the desired loading zone, and when no couriers and accessories were present (μ = 6.32, SD = 0.96 m/sec). The lowest mean speed occurred with the no loading zone and accessories scenario while the courier was on the side of the truck (μ = 5.23, SD =1.35 m/sec).

A modeling approach similar to the one that was followed for the lateral position was used to examine differences in mean speed. The results of the model are shown in Table 4.4. The LMEM for commercial vehicle loading zone found that all treatment factors (loading zone size, courier position, and accessories) were statistically significant and thus having influence on bicyclists' speed at the 95% confidence level.

Regardless of the courier position and accessories, bicyclists tended to have higher speed at the maximum loading zone or the minimum loading zone compared to the no loading zone condition. The random effect was significant (Wald Z=4, $p<0.001$). This supports the argument that a LMEM has higher efficiency compared with a fixed effect linear regression model. Regardless of CVLZ size and courier position, there is a suggestive probability that participants have higher speed (about 0.8 m/sec) with the presence of accessories ($p=0.035$).

There was only one two-way treatment interaction significant. However, others were considered in the pairwise comparison. Figure 4.3 plots the mean speed at each level of the independent variables. Keeping the accessories variable constant, on average the speed of bicyclists at the minimum loading zone with the presence of courier beside the parked trucked was almost half m/sec slower than the speed in the maximum loading zone size. This indicates that bicyclists felt more comfortable driving along the maximum loading zone than having a commercial vehicle parked exactly beside the bike lane.

5. Conclusions

The results of this study demonstrate a consistent narrative related to how bicyclists interact with courier's unique needs during the vehicle loading/unloading process in urban areas and how different levels of space adjacent treatments are effective. Overall, the results show that courier presence and designated loading zone size have an effect on bicyclist's performance, and this effect varies based on the treatments employed. There may be an increased risk of bicyclist conflicts with other transportation modes in proximity to delivery vehicle activities in urban loading zones, especially when no unique infrastructure treatment is used. The primary findings of this study include the following:

- Loading zone size and courier position had significant effects on bicyclist speed. A bicyclist passing by no loading zone (truck is obstructing bike lane) or minimum loading zone (truck next to the bike lane without a buffer) had a significantly lower speed than a bicyclist passing a maximum loading zone (truck has an extra buffer). A smaller loading zone had a decreasing effect on mean speed, with a courier exiting on the driver side of the truck causing the lowest mean speed.
- Loading zone size and courier position had significant effects on bicyclist speed. Lateral variability was significantly higher for the no loading zone scenario compared to maximum loading zone size. A courier on the driver's side of the truck had an increasing effect on mean lateral position, with a no CVLZ causing the highest divergence from the right edge of the bike lane. Consequently, bicyclists shifted their position toward the left edge of bike lane and into the adjacent travel lane. Moreover, some bicyclists used the crosswalk to avoid the delivery truck and the travel lane.
- Accessories (hand truck and boxes) had slight effect on bicyclist performance measures such as lateral poison and speed. Keeping other factors constant, bicyclists decreased their speed and diverged from the center of the bike lane in the presence of the hand truck. In terms of practice, the difference in performance measures between with or without accessories may not be functionally important, though it is statistically significant.
- Minimum CVLZ versus maximum CVLZ. The minimum loading zone size did not differ from the maximum loading zone size in terms of bicyclist performance measures. However, in the presence of a courier on the driver's side of the truck, the minimum CVLZ tended to be the most disruptive for bicyclists since they tended to depart from the bike lane toward the adjacent vehicular travel lane.

Table 4.3
Mean and Standard Deviation of Speed (m/sec) at Independent Variable Level

Commercial Vehicle Loading Zone (CVLZ)	Descriptive Statistics	No Accessories			Hand Truck		
		No Courier	Behind	Beside	No Courier	Behind	Beside
No CVLZ	μ	5.53	5.74	5.23	5.59	5.76	5.70
	(SD)	(1.06)	(1.12)	(1.35)	(1.13)	(0.95)	(1.03)
Min CVLZ	μ	6.29	6.27	5.40	6.16	6.25	5.63
	(SD)	(0.84)	(0.99)	(0.94)	(0.83)	(0.79)	(1.11)
Max CVLZ	μ	6.32	5.92	5.96	6.23	6.19	6.03
	(SD)	(0.96)	(0.85)	(0.78)	(0.82)	(0.77)	(0.84)

Table 4.4
Mean and Standard Deviation of Speed (m/sec) at Independent Variable Level

Variable	Levels	Estimate	DF	P
Participant random effect (SD)	-	(0.68)	-	<0.001*
Constant	-	5.90	47	<0.001*
Loading Zone Size	Max CVLZ	0.21	799	<0.001*
	Min CVLZ	0.10	799	0.003*
	No CVLZ	Base	-	-
Courier Position	Beside	-0.23	799	<0.001*
	Behind	0.12	799	<0.001*
	No Courier	Base	-	-
Accessories	AC	0.05	799	0.035*
	No Acc	Base	-	-
CVLZ x CP	Max CVLZ x Beside	0.12	799	0.007*
	Min CVLZ x Beside	Base	-	-
Summary StatisticsAdjusted R2				
	58%	Observations	864	
-2Log Likelihood	2011.76	Participants	48	
AIC	2015.78	Observations/Participant		18
Participant random effect (SD)	-	(0.68)		-
Constant	-	5.90		47

* Significant at the 95% confidence level

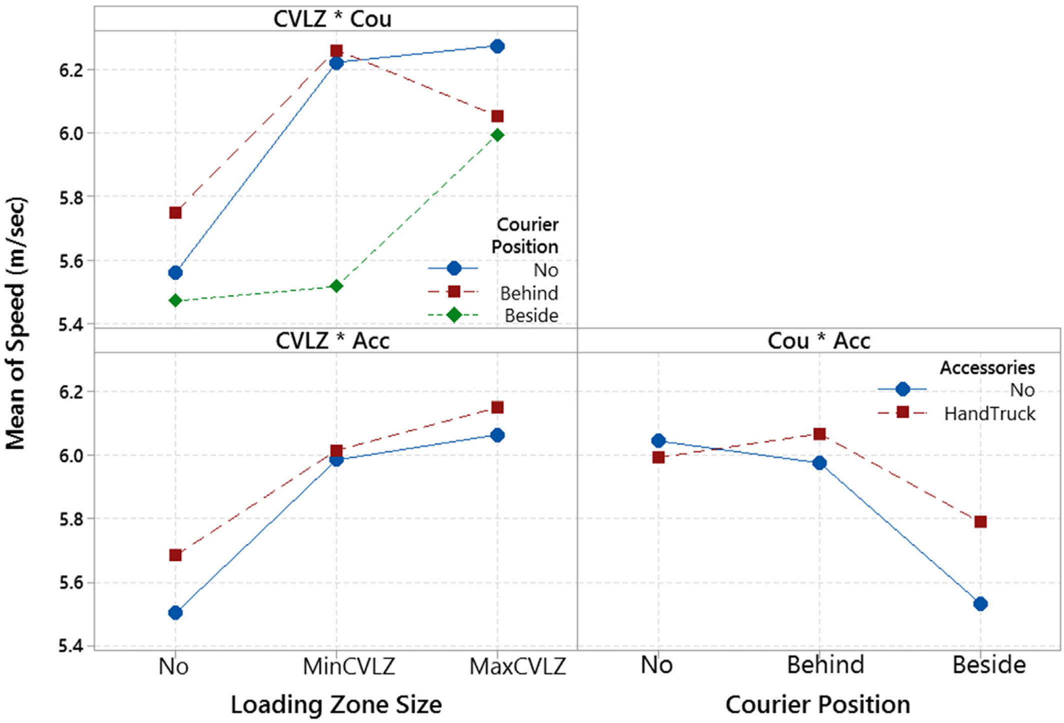

Figure 4.3. Two-way interactions plot of treatment variables on mean participants' speed: a) two-way interactions between loading zone size and courier position, b) two-way interactions between loading zone size and accessories, and c) two-way interactions between courier position and accessories

- Scenarios where bicyclists used the sidewalk. When there was no CVLZ, the delivery vehicle was parked at the bike lane. When the bicyclist approached such a scenario, they had to choose between using the travel lane or the sidewalk. About one third of participants decided to use the sidewalk.

5.1. Recommendations

Depending on the desired bicyclist response when approaching truck loading/unloading activities, different recommended treatments could be distinctly effective based on the output of the bicycling simulator experiment. These recommendations could support better roadway and CVLZ design guidelines, which will allow our urban street system to operate more efficiently, safely, and reliably for all users.

- No divergence from bike lane: Maximum loading zone size (enough buffer for courier to move around the vehicle)
- Lower divergence from bike lane: Minimum loading zone size and the courier located behind the truck.
- Speed reduction: Minimum loading zone size courier on side and no CVLZ regardless the courier location.
- Extra buffer in CVLZ for courier improves bicyclists performance measures positively. The use of sidewalk: In states where allow bicyclists to use the sidewalk, access for the sidewalk should be designed to accommodate bicyclists when a delivery truck is anticipated to obstruct the bike lane due to loading/unloading activities. The downside of this recommendation is the potential risk generated from the interaction between bicyclists and pedestrians.
- Placing barriers on the left side of the bike lane: To prevent the interaction between bicyclists and traffic from travel lane, barriers or buffer zones could be placed in zones where commercial vehicles exist.
- Passenger side instead of driver side: in situations where only minimum loading zone could be designed due to space restrictions, the courier should minimize the time they occupy the bike lane to move along the vehicle (e.g., similar to UPS drivers design).
- Provision of an additional curb ramp: placed upstream of the CVLZ to allow the bicyclist to transition to the sidewalk if legally permitted.
- Policy considerations regarding the width of the bicycle lane, if the minimum loading zone is present. The study found that lateral distance deviations exceeded the width of the bicycle lane in the scenario where the truck was parked in the minimum loading zone, which indicates that cyclists were using the traveled way (i.e., outside of the bicycle lane) to bypass or navigate around the truck, and ultimately putting themselves in unsafe scenarios. If cyclists react to this scenario and require space outside of the bicycle lane to feel safe when passing a truck, this could justify the need to increase the width of a bicycle lane, when a minimum loading zone is present.

5.2. Limitations

A basic limitation of within-subject design is fatigue and carryover effects, which can cause a participant's performance to degrade throughout the experiment as they become tired or bored. The order of the scenarios was partially randomized, and the duration of the test drives was relatively brief to minimize these effects. Additionally, the visual display of the bicycle simulator used in this study did not provide a peripheral field of view for participants. While peripheral vision was limited and bicyclists cannot view the coming vehicles before they enter the loading zone, surrounding sound systems were used so bicyclists can hear traffic sounds.

Another limitation is the application of the design. The simulation and design were based on commercial vehicle parking designs in the United States, and would likely have to be adjusted to apply to other cities and countries throughout the world. Furthermore, the design of the simulator was based on suburban/urban conditions and may not apply to all cycling conditions integrated with commercial vehicle loading and unloading zones in many larger metropolitan cities both in the United States and throughout the world.

Additionally, as risks play influence into cyclists' behaviors while riding, the study did not control for this and could be included in future studies to control for risk influence on cyclists riding.

5.3. Future Work

Additional research is needed to continue to explore the critical safety issue of understanding the interactions between delivery vehicles and other users in an urban environment, in particular, cases where CVLZ activity disrupts the activity of bicyclists and to extend the work of this study. The following are potential research threads that would augment this study and further expand this topic:

- This research studied loading zone size, courier position, and accessories as the independent variables for bike-delivery truck interactions. Many other variables could also be considered. For example, heavier traffic volume, pedestrians on the sidewalk, and leading bicyclists could potentially provide a different interaction behavior for bicyclists. Additionally, different forms of bike lanes, such as buffered bike lanes or contra-flow bike lanes could be modeled in a virtual environment to quantitatively compare the effectiveness of different design practices.
- Incorporating a wider range of truck sizes and loading zone sizes.
- Using an instrumented bicycle experiment in an urban area could help validate the results of this study.

CRediT authorship contribution statement

Hisham Jashami: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Roles/Writing – original draft, Writing – review & editing. **Douglas Cobb:** Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Roles/Writing – original draft, Writing – review & editing. **David S. Hurwitz:** Conceptualization, Writing – review & editing. **Edward McCormack:** Conceptualization, Writing – review & editing. **Anne Goodchild:** Conceptualization, Writing – review & editing. **Manali Sheth:** Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Roles/Writing – original draft.

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