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Improved driver behaviour at bus stops on local roads: Comparison of different treatments

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ABSTRACT

Every day, millions of students use school bus as a mean of transportation to and from schools. Nevertheless, most of the school bus related crashes occur at or near bus stops. The overtaking of stopped school buses during boarding and alighting of students imposes safety risks on students and drivers. This study aims to investigate the impact of three different treatments on driving behavior at bus stops. In total, this study compared four different conditions. Three of them were treatment conditions namely (Red Pavement, Road Narrowing, and smart LED), which were compared with a control condition (i.e., the default bus stop layout without any additional treatments as implemented in the State of Qatar). Each condition was tested for three situations. Situation 1 and Situation 2 were designed with the presence of a stopped school bus on the same and on the opposite travel directions, respectively, while, Situation 3 was designed without any school bus at the bus stop location. A total of 72 subjects participated in the experiment. Generalized Linear Mixed Model (GLMM) was employed to study the impact of several factors on the overtaking/crossing probability of the stopped school bus. In Situation 1, Road_narrowing condition outperformed the other conditions by making 94.3 % of drivers to stop for the bus, while in Situation 2, LED condition performed best by making 48.6 % of drivers stop for the bus that is stopped at the opposite travel direction. Moreover, the LED and Road_narrowing treatments were effective in moderating drivers' speed behavior, lowering their traveling speed by 5.16 km/h and 5.11 km/h, respectively even in the absence of any bus at the bus stop. Physical road narrowing condition outperformed the other tested conditions, and therefore, can be recommended as a low-cost treatment to improve safety at bus stops. In locations where the implementation of physical road narrowing is not feasible, LED treatment can be used to moderate driver traveling speed and stopping behavior.

1. Introduction

School bus is an important and efficient mode of transport for commuting students to and from schools. During the last few decades,

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laws and regulations associated with school bus/student's safety have been significantly improved together with technological developments. However, school bus related crashes that occur inside or outside school zones account for a substantial number of fatalities and injuries (Donoughe & Katz, 2015; Samerei et al., 2021). A report from the National Highway Traffic Safety Administration (NHTSA) showed that in the United States, 1,113 school bus related fatal crashes and 1,241 fatalities from 2008 to 2017 were reported (NHTSA, 2019). The report further clarified that the likelihood of students getting involved in school bus related crashes increases when they are on their way to the bus stop and when they are boarding or alighting from the bus. In addition, a survey of the total fatalities at boarding and alighting points of school buses in the United States from 2007 to 2016, showed an increase in the number of fatalities in the 2016–2017 academic year compared with the 2015–2016 academic year (KSDE, 2018). In China, despite the reduction in the overall road traffic crashes since 2002, a rapid increase in school bus related crashes was observed between 2009 and 2011 (Li et al., 2015). According to Donoughe and Katz (2015), most of school bus related fatal crashes involve mainly pedestrians. In the State of Qatar, a total of 6,061, 6,158, and 6,546 crashes (slight, severe, and fatal crashes) were reported in 2017, 2018, and 2019, respectively (Planning and Statistics Authority, 2020). Pedestrians' fatalities account one-third of the annual road crash fatalities placing high emphasis on pedestrian safety as high priority issue in the country (Planning and Statistics Authority, 2020; Timmermans et al., 2019a).

One of the leading causes of students' injuries and fatalities is the overtaking of stopped bus or crossing beside a stopped bus on the opposite direction of travel on the road (two-way two lane roads) during the boarding and alighting of students (Donoughe & Katz, 2015). In Sweden and UK, injuries and fatalities occurred mostly when the students were outside the bus, i.e., those struck by a vehicle when crossing the road from the front or backside of the bus (Anund et al., 2011). An explanation for this behavior could be that drivers simply fail to attend to the information aimed at guiding, controlling, or regulating traffic at bus stop locations and inside school zones. Kaplan & Prato (2012) reported that most bus related crashes that involved drivers of other vehicles were because of speeding and distraction of the other drivers. Another reason could be the lack of knowledge among the majority of drivers about the risks associated with overtaking/crossing stopped school buses.

In order to improve the safety of students during boarding and alighting processes, in the United States it has been made illegal to overtake/cross a school bus when the bus is stopped and the stop arm with the flashing red lights is extended (NHTSA, 2019). For example, in the United States and Canada, it is mandatory for all vehicles in both directions to stop when the school bus is stopped on the road and the stop arm is extended for boarding and alighting of students (NHTSA, 2016; MOT, 2009). However, according to NHTSA, it has been observed that there is a significant lack of compliance with the law and the violations are common and not always reported. The case for the State of Qatar is similar to North America where drivers are not allowed to overtake/cross the stopped school bus (Qatar Traffic Law, 2007). In addition, to improve students' safety, school buses are equipped with stop sign arms and warning lamps to alert other drivers during boarding or alighting (Rivera, 2016). Furthermore, the General Directorate of Traffic in the State of Qatar imposes large fines on different traffic violations such as speeding violations and red light running, etc. (Suzuki et al., 2022; Toriumi et al., 2022). However, due to the high income level, speeding violations and right of way violations are still widely observed in the country (Alhajyaseen et al., 2022).

The American College of Emergency Physicians (ACEP) has recommended that in order to enhance the safety of school buses and students, some measures should be taken: 1) increasing the visibility of the bus especially when students are boarding or alighting by using warning signs; 2) improving engineering solutions at the bus top locations and crosswalks at the bus stops (ACEP, 2000). It is important to mention that bus stops are common pedestrian crossing locations which highlight the importance of calming vehicle traffic around these facilities. Improving students' safety in particular and pedestrians' safety in general around bus stops have been prioritized in many countries. For instance, in the United States, the federal actions include increasing penalties and improving school bus technology by installing cameras on the backside of the buses (Cook & Shinkle, 2012). The "safeway2school" program by the European Commission aims to enhance school safety by using Intelligent Transportation System (ITS) technology and smart bus stops (Anund et al., 2010).

Therefore, it is important to introduce innovative and effective solutions which can improve the driving behavior and prevent the overtaking/crossing of the stopped school bus at bus stop locations. These treatments can also contribute to the improvement of driver behavior toward public buses which are considered as a major mode of public transport. In addition, the solutions should motivate drivers to reduce their traveling speed while entering the bus stops even if there are no buses since pedestrians' crossing activities are more frequent at these locations. According to Aarts and van Schagen (2006), there is an increased risk of crash rates at bus stops (i.e., slight and severe injury, and fatal crashes) with an increased vehicle speed. It is known that certain treatments would have different impacts considering the different driving populations. For instance, treatments with physical road narrowing could be more effective in reducing aggressive driving behavior, especially driving speed (Cai et al., 2021; Liu et al., 2016). On the other hand, treatments that have LED light units could help in attracting the drivers' attention due to the higher conspicuity that these light units offer (Hussain et al., 2021; Patella et al., 2020; Tydlacka et al., 2010). In terms of road markings, research shows that increased conspicuity due to paint could help in improving pedestrians' safety by altering the driving behavior and increasing the yielding rate of drivers to pedestrians as well as the distance from the stop line (Hussain et al., 2021; Pulugurtha et al., 2012).

There are several indicators that can be used to identify aggressive driving behavior. Some of these indicators are excessive speeding and risky overtaking maneuvers (Adavikottu and Velaga, 2021). Research show that drivers who drive at high speeds and/or with high variations in acceleration/deceleration can also be considered as aggressive drivers (Eboli et al., 2016). In terms of analyses, subjective assessment (i.e., Driving Behavior Questionnaire (DBQ)) and objective assessment (i.e., jerk) can be used to identify aggressive drivers (Bener et al., 2008; Feng et al., 2017). Jerk is defined as the rate of change of acceleration of which high values of jerk are an indicator of aggressive driving behavior (Bagdadi & Várhelyi, 2011; Feng et al., 2017). In addition to identifying aggressive driving behavior, jerk has also been used to identify crash prone locations (Feng et al., 2017; Huang and Wang, 2004; Itkonen et al., 2017; Li et al., 2021; Mousavi, 2015; Murphey et al., 2009; Pande et al., 2017).

2. Literature review

A statewide survey of school bus stop-arm violations by the Texas Department of Public Safety School Transportation Unit reported a total of 12,850 stop-arm violations on a single day in 63 % of the school districts in Texas (Turner & Stanley, 2008). More than half (53 %) of those violations occurred on two-lane roadways. Further to the survey results, a field evaluation was conducted using four video cameras attached to the school bus with a GPS to record any stop-arm violations. Based on the field observation results, the authors estimated that 9,072 stop-arm violations would occur in a typical academic year in College Station, Texas. Public awareness and education about the consequences of overtaking a stopped school bus were recommended to reduce the number of stop-arm violations. Tsai and Graham (2005) aimed at improving the safety of school buses in North Carolina by adopting a full program which consisted of recording the illegal overtaking, training bus drivers in making correct stops, and raising public awareness. After 18-months of applying the program, results showed a significant drop (i.e., 67 %) in the illegal overtaking of school buses.

To make bus stops safer for students, a modern intelligent transportation system telecommunication (ITST) was tested by using intelligent bus stop (IBS) to inform car drivers about the presence of students at the bus stop (Diederichs et al., 2011). Three warning conditions (i.e., static bus stop sign, static bus stop sign with flashing lights, and in-vehicle warning system) were tested with and without the presence of students at the bus stop. The study was conducted using a driving simulator with a total number of 60 participants. Various factors such as speed and lateral distance while passing the bus stop, number of collisions with students, and reaction time upon viewing a student were analyzed. Results showed that the static bus stop sign with flashing lights, and the in-vehicle warning system were effective in improving traffic safety at bus stops by reducing drivers' traveling speed. However, the two treatments did not significantly reduce the number of collisions. Therefore, the authors reported that warning systems can be used at bus stops to motivate drivers to reduce their traveling speed. An on-site study using the above three warning conditions by Diederichs et al. (2011) indicated that deploying warning systems at bus stop locations helped in significantly reducing drivers' speed (Anund et al., 2010). Similar results were found in a field study that used an active warning sign composed of flashing beacons attached to the static school bus stop sign at boarding/alighting locations (Carson et al., 2005). High speed rural sites with limited visibility and high traffic volumes were selected for the study. Speed profiles, erratic maneuvers, and the number of stop-arm violations were considered for analysis. The study found that there was a significant reduction in the approach speed of vehicles (13.9 km/h speed reduction) when the bus was present at the boarding/alighting zone and the active advanced warning sign was activated.

A driving simulator experiment by Zhao et al. (2016) studied the effectiveness of 17 different treatments in improving traffic safety at school zones located on two different roads (major roads with posted speed limit of 60 km/h and minor roads with posted speed limit of 50 km/h). The control condition did not have any sign indicating a school zone, while the existing condition was designed to have a school crossing ahead informational and warning signs. The tested conditions were to add different school zone signs and road markings to the existing condition. This included adding flashing beacon, speed limit sign, reduce speed and school crossing warning signs, and "school crossing ahead" red colored road marking. The average speed, relative speed difference, standard deviation (SD) of acceleration, and 85th percentile speed were used for the analysis to determine the most effective treatment. ANOVA and S-K-N tests confirmed that there was a significant difference in the speed for the different alternatives. More specifically, results from the 30 participants indicated that road markings were the most effective in reducing the speed compared to the other treatments which included several types of static signs and signs equipped with flashing beacons.

In Scotland, retroreflective high visibility school bus static signs (showing students with written "school bus" text) were compared with existing normal static signs which are not highly visible and do not emphasize the presence of the school bus (Fraser & Carreno, 2011). Both signs were attached on the front and rear sides of school buses. The main objective was to investigate if the new signs would improve the safety of school buses by improving driving behavior. Data was collected by means of surveys as well as field observations. Speed data was recorded using speed radars placed in the vicinity of the stopped school bus. Results showed that a speed reduction of 1.6 km/h to 4.8 km/h was achieved for the new signs in comparison with the existing signs. The survey results for both normal (911 respondents) and bus drivers (13 respondents) revealed that most drivers reported that the new signs were more visible and understandable.

In a study done by Baas et al. (2010), six different signs attached to the front and rear sides of the school bus were tested and compared. These signs include; sign A) current static sign with a word 'SCHOOL', sign B) current static sign along with the bus flashing hazard lights, sign C) symbolic sign showing children, sign D) dynamic message sign showing children with warning lights, sign E) dynamic message sign showing children, text and warning lights, sign F) speed limit flashing LED sign along with the current static sign. Compared with the current static sign, it was found that there was a considerable speed reduction of 12 km/h for sign D, 18 km/h speed reduction for sign E, and 23 km/h speed reduction for sign F. The authors recommended that priority should be given to improve bus stops instead of awareness campaigns.

Most studies in the literature have focused on improving the safety of school buses by improving bus visibility, increasing drivers' awareness about school buses, in-vehicle ITS technologies, and bus mounted signs. This study introduces innovative treatments at bus stops, which aim at improving the driving behavior through speed reduction and preventing the overtaking of the school bus. It is worth to mention that the State of Qatar is characterized by a heterogeneous driving population with various cultural backgrounds and ethnicities (Soliman et al., 2018; Timmermans et al., 2019b; Timmermans et al., 2020), which adds more challenges in identifying effective treatments in improving the safety of the road users.

3. Research aim and objectives

Based on the literature, there are clear safety concerns about the transportation of students and passengers. Although most countries around the globe prioritize the safety of students, there is still a lack of research in introducing and comparing new effective treatments at bus stop locations where more pedestrians' crossing behavior is observed. The main objective of this study is to investigate the effectiveness of different treatments in altering the driving behavior at bus stops. In addition, this study provides a detailed driving behavior assessment of the proposed treatments by considering three different situations for drivers when approaching the bus stop. To this end, smart LED based treatment, road narrowing treatment with a combination of physical and perceptual measures, and red pavement which includes high visibility pavement markings were used. The detailed objectives are formulated as follow:

- To improve the safety at bus stops by motivating drivers to avoid overtaking/crossing of stopped buses.
- To improve the stopping behavior of drivers.
- To simulate the drivers to slow down even in the absence of a bus since bus stops are common pedestrian crossing locations (usually considered as pedestrian crash prone locations).

4. Methods

4.1. Driving simulator

Driving simulator is an effective and useful tool that is widely used in research related to traffic safety (Faschina et al., 2021). Fig. 1 shows the driving simulator at Qatar Transportation and Traffic Safety Center which was used to carry out this experiment. The simulator consists of a driving unit and three large screens each of 5760 × 1080 pixels. The screens have a refresh rate of 60 Hz and can provide a 135° wide field of view. The driving unit is a fixed base cockpit of a Range Rover Evoque, with a force feedback steering wheel, indicators, a speedometer, pedals, and an automatic gearbox. The software used for scenarios design were STISIM Drive® 3 and CalPot 32. Both software are integrated to offer high-speed graphics and sound processing. The driving simulator is capable of collecting 67 different parameters such as speed, lateral/longitudinal positions, lateral/longitudinal acceleration, breaking characteristics, and headways. The simulator has been objectively and subjectively validated for actual speed and speed perception (Hussain et al., 2019a), and the accurate geometric field of view (GFOV) (Hussain et al., 2020a).

4.2. Participants

In this experiment, participants were recruited through social media websites and personal invitations for Qatar University students and staff. A total of 72 volunteers who had a valid Qatari driving license from an age group of 19 to 57 years participated in the study. One participant was dropped from the experiment due to simulation sickness. In addition, one participant was considered as an outlier (more information regarding the outlier analysis can be found in section 4.5 "Data Analysis"). Therefore, a total of 70 participants were considered for the data analysis. As reported in literature, the driving population in the State of Qatar is characterized by many nationalities and cultural backgrounds. According to Timmermans et al. (2020), the State of Qatar has approximately 55 different nationalities who live and work in Qatar. Thus in this study, we tried to have a heterogeneous driving population to represent the local driving conditions as closely as possible. Therefore, out of the 70 participants, 55 were men and 15 were women. Moreover, participants were representing 14 different nationalities (50 Arabs and 20 non-Arabs).

The average age was 26.37 years with a SD of 7.70 years. Moreover, the average driving experience of the participants was 6.64 years (ranging from 1 to 38 years) with 37 %, 34 %, and 13 % of the participants having driving experience of 2–5 years, 5–10 years,

Fig. 1. Driving simulator: Qatar Transportation and Traffic Safety Centre (QTTSC), Qatar University.

and more than 10 years, respectively in the Gulf region. The SD of the driving experience was 6.8 years.

4.3. Scenario design

The STISIM Drive® 3 interface was used to design the test conditions for two-lane, two-way local road in a residential area with a posted speed limit of 50 km/h and lane width of 3.65 m (MOTC, 2021a). Three level and tangent road sections of 9 km each, were designed for this experiment. Each participant drove the three test drives (i.e., 27 km total). In addition, vehicles, pedestrians, cyclists, and other roadside features such as buildings were designed in a way to mimic the real roadside environment in the state of Qatar as much as possible. This could help in overcoming the risk of simulation sickness and improving the sense of presence (Almallah et al., 2021a). Dummy events such as un-signalized intersections were added as filler pieces to the test drives in order to improve the driving experience. In total, three different treatment conditions were tested and compared with the Control condition. The Control condition was designed according to the Qatar Traffic Control Manual 2021 (MOTC, 2021b). Fig. 2(a) shows the layout of the Control condition, in addition, Fig. 2(b) shows the simulation view of the Control condition. The Control condition was designed with the pavement marking "BUS STOP", along with a solid median dividing line, a roadside bus stop sign and a 50 km/h posted speed limit sign (MOTC, 2021b).

Three treatment conditions namely; LED, Road_narrowing, and Red_pavement were compared with the Control condition. It is important to mention that the same basic markings and road signs used in the Control condition were also replicated in the treatment conditions with the additional elements. The schematic and simulation views of the LED condition are shown in Fig. 3(a-d). In the absence of a bus at the bus stop, the LED light units keep flashing with an amber color at a frequency of 2 HZ (see Fig. 3a and 3b for the schematic and simulation views, respectively) (Masuda et al., 2015). However, upon arrival of the bus at the bus stop, the LED light units turn into flashing red at the same frequency of 2 HZ (see Fig. 3c and 3d for the schematic and simulation views, respectively). Regarding the design of the LED lights, two lines of light units were placed at a distance of 5 m before the start of the bus stop.

Road_narrowing condition is shown in Fig. 3(e) and 3(f). In this condition, two treatments were combined which are the vertical poles for the physical road narrowing and pavement markings. The vertical poles were used to reduce the lane width from 3.65 m to 3.15 m. The vertical poles were placed along the taper starting at a distance of 5 m before the start of the bus stop. The median was hatched with red and white colors with a width of 1 m. In addition, red colored pavement marking "BUS STOP AHEAD" was provided 5 m before the bus stop. Crash events were created for the vertical poles. This means that if the driver drove over the poles, a crash would occur. Therefore, drivers would have to drive on the opposite lane in order to overtake the stopped bus.

The third treatment condition (i.e., Red_pavement) consisted of red marking outlined with a yellow line on the entire pavement for the length of the bus stop as shown in Fig. 3(g) and 3(h). Yellow colored worded markings "BUS STOP" in English as well as in Arabic were provided in both directions of the traffic flow. It is worth to mention that currently, the State of Qatar is adopting this kind of treatment (MOTC, 2021b). However, the effectiveness of this treatment is still not investigated.

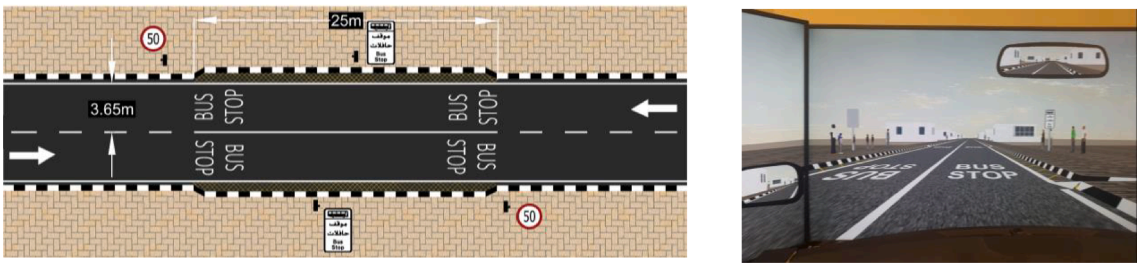
Each of the four conditions was tested for three different situations as follow:

- The first situation (Situation 1) was designed with a school bus stopped on the same driving lane at the bus stop location.
- The second situation (Situation 2) was designed with a school bus stopped on the opposite lane at the bus stop location.
- The third situation (Situation 3) was designed with the absence of any bus at the bus stop location.

In Situation 1 and Situation 2, the school bus was designed to stop at the bus stop with an opened stop arm.

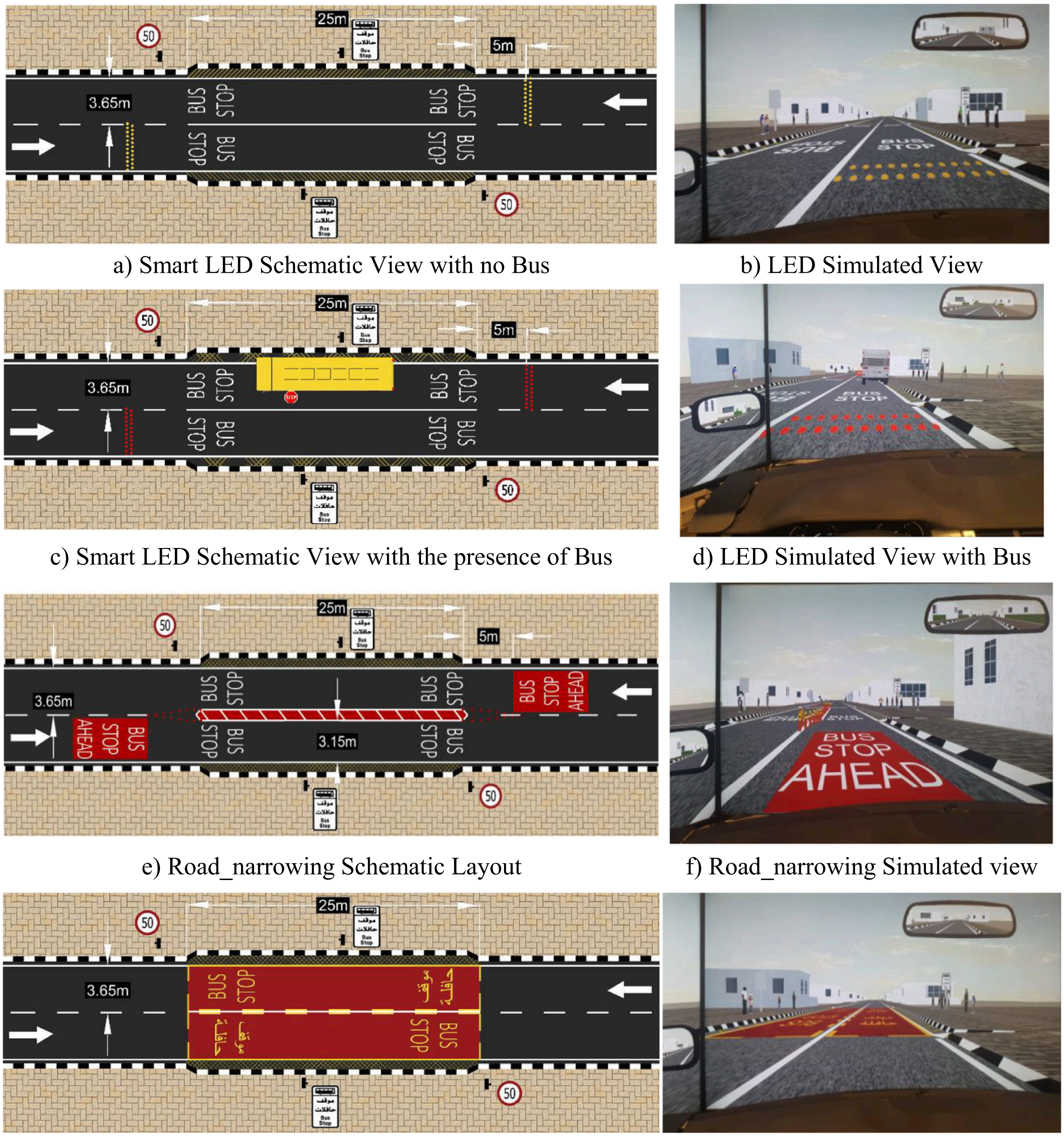
4.4. Procedure

The experiment was composed of four main parts: a pre-experiment questionnaire, a short familiarization drive followed by the three test drives, and a post-experiment questionnaire. The participants who arrived were given a brief description regarding the four different sections of the experiment and were asked to sign a consent form as well as to fill the pre-experiment questionnaire. The pre-experiment questionnaire consisted of general questions regarding socio-demographic factors. This part took approximately 10 min. The participants were then allowed to drive the simulator for up to 10 min to get familiarized with the simulation environment. Next,



a) Schematic layout b) Simulator view

Fig. 2. Illustration for the control condition.



a) Smart LED Schematic View with no Bus
b) LED Simulated View
c) Smart LED Schematic View with the presence of Bus
d) LED Simulated View with Bus
e) Road_narrowing Schematic Layout
f) Road_narrowing Simulated view
g) Red_pavement Schematic View
h) Red_pavement Simulated View

Fig. 3. Schematic and Simulated views of different treatments.

they drove the three test drives with short breaks in between. The order of the test drives was randomized to eliminate the bias effect. Before starting the test drives, participants were instructed to drive as they would normally do while following all the traffic rules. In addition, they were informed about their right of choice to quit the experiment anytime and for any reason. The third part took approximately 40 min. Finally, the participants then filled the post-experiment questionnaire which was comprised of questions regarding ranking and rating of all the scenarios and the drivers' awareness about the school bus stop-arm violations. The last section took around 10 min. In total, the total time required to finish the experiment was approximately 70 min (Please check the provided table in the Appendix for more details about the testing protocol).

4.5. Data analysis

The data recorded in the simulator for all the participants were converted into excel files using MATLAB software. The retrieved data included speed, acceleration/deceleration, longitudinal/lateral distances, elapsed time, and headways (time and distance). For achieving high accuracy, data was recorded in small intervals, i.e., every tenth of a second.

The analysis section considered in this study was 300 m (i.e., 200 m before the school bus and 100 m after the school bus). Data was extracted for every 1 m of the analysis section. Then, speed data was extracted at 16 consecutive points (point based approach) of 20 m equal spacing (as shown in Fig. 4). In addition, for studying the variations in drivers' ACC/DEC, the analysis section was divided into 15 zones (zonal based approach) of 20 m spacing. It is worth to mention that point based and zonal based approaches are used in most driving simulator studies (Ariën et al., 2017; Awan et al., 2020; Babić & Brijs, 2021; Mollu et al., 2018; Montella et al., 2011; Reinolsmann et al., 2019; Almallah et al., 2021b).

First, descriptive analysis was carried out to illustrate the number of drivers who stopped for each condition in Situation 1 (i.e., driver and school bus on the same driving lane) and Situation 2 (i.e., driver and school bus on opposite driving lane). Then, since the study includes repeated observations from participants, Generalized Linear Mixed Model (GLMM) was estimated to study the impact of several parameters on the probability of overtaking/crossing the stopped school bus (Choudhary & Velaga, 2018; Pawar & Velaga, 2021). Stopped drivers were coded as "0", while drivers who overtook/cross the stopped school bus were coded as "1". The categorical independent variables that were considered in the model were situation, condition, gender, ethnicity, age, knowledge of law about overtaking/crossing the stopped school bus, the total number of traffic tickets in the past 2 years, and driving experience.

To study the stopping behavior of drivers, between-subject ANOVA test was used to investigate whether the dependent variables (i.e., Condition and Zone) had any impact on the standard deviation of longitudinal ACC/DEC (SD-A/D) for drivers who stopped for the bus.

The analysis of speed was considered using the sample of drivers who had crossed in Situation 2 and Situation 3. A within-subject repeated measure ANOVA test was employed for Situation 3 since the cases were pairwise and a between-subject ANOVA test was employed for Situation 2. Since there were only few cases where the drivers overtook the bus in Situation 1, especially in the Road_narrowing condition, statistical analysis was not performed for Situation 1 on the speed differences.

Outlier analysis was performed on a total 192 possible combinations (i.e., 3 situations × 4 conditions × 16 points). Any participant who drove faster or slower than 1.5 interquartile range from the group's mean in more than 15 % of the combinations was considered as an outlier (Hussain et al., 2021). Only one participant was identified as outlier, which was removed from the analysis. Data analyses were carried out at a 95 % confidence interval using SPSS software (Version 26).

5. Results

Table 1 presents a summary of the drivers who stopped or overtook/crossed the stopped school bus for the 70 participants. In general, crossing the stopped school bus was more predominant in Situation 2 (63.6 %) compared to the overtaking behavior in Situation 1 (15.4 %). In Situation 1, Road_narrowing condition outperformed the other conditions in preventing the overtaking of the school bus up to 94.3 % compared to 85.7 % in LED, 81.4 % in Red_pavement, and 77.1 % in the Control condition. On the other hand, in Situation 2, the LED condition was more effective than the other conditions by making 48.6 % of the drivers to stop for the school bus compared to 41.4 % for Red_pavement, 30.0 % for Road_narrowing and 25.7 % for Control condition.

5.1. *Subjective assessment of the participants*

Table 2 and Fig. 5 present the results of the subjective assessments of the four conditions as obtained from the post-test questionnaire. Participants were asked to respond to two different types of questions (i.e., ranking and rating) about the effectiveness of the different conditions in motivating them to reduce their speed and stop if there was a stopped school bus. Participants ranked the LED (44 %) and the Road_narrowing (42 %) conditions almost equally as being the most effective condition. For rating, a 5-point Likert scale was used (1 = extremely not effective, 5 = extremely effective). In this regard, the Road_narrowing condition received the highest mean rating (mean: 4.41, SD: 0.6) followed by the LED (mean: 4.34, SD: 0.73), and the Red_pavement (mean: 3.93, SD: 0.8) conditions. On the other hand, the control condition received the lowest mean rating (mean: 2.47, SD: 0.92). Paired samples *t*-test showed a significant difference in the mean rating between the Control and the three other conditions. The subjective assessment of the tested conditions supports the results obtained from the objective evaluation showing that LED and Road_narrowing conditions outperformed the other two conditions.

In addition to the ranking and rating based questions, participants were also asked about the traffic rule of overtaking/crossing the stopped school bus. The question that was asked is "Are you aware of the traffic rule which states that when a school bus is stopped on a two lane road (one lane for each direction) and the stop arm is extended, vehicles approaching from either directions must stop?". The responses of participants were surprising as 76 % of the participants did not know about this traffic rule, while only 24 % of participants answered that they were aware of the rules. Based on the questionnaire results, more efforts should be directed towards drivers' awareness regarding school bus related traffic rules and even the safe driving behavior when encountering stopped public buses at bus

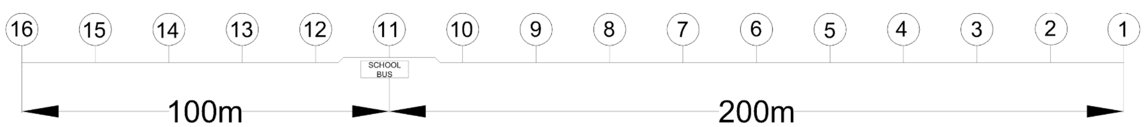


Fig. 4. Schematic layout of data collection points.

Table 1
A summary statistic of overtaking/crossing drivers for each condition.

Condition	Driver and bus on the same lane (S1)		Driver and bus on opposite lanes (S2)	
	Stop	Overtook	Stop	Cross
Control (n = 70)	54 (77.1 %)	16 (22.9 %)	18 (25.7 %)	52 (74.3 %)
LED (n = 70)	60 (85.7 %)	10 (14.3 %)	34 (48.6 %)	36 (52.9 %)
Road_narrowing (n = 70)	66 (94.3 %)	4 (5.7 %)	21 (30.0 %)	49 (70 %)
Red_pavement (n = 70)	57 (81.4 %)	13 (18.6 %)	29 (41.4 %)	41 (58.6 %)
Total	237 (84.6 %)	43 (15.4 %)	102 (36.4 %)	178 (63.6 %)

Table 2
Results for the subjective assessment.

Condition	*Ranking* *Percentage of 1st ranked*	*Rating* *Percentage of responses for each level of rating (1 = extremely not effective, 5 = extremely effective)*					*Mean Rating*	*SD Rating*
		1	*2*	*3*	*4*	*5*		
Control (N = 70)	0 %	16 %	34 %	39 %	10 %	1 %	2.47	0.92
LED (N = 70)	44 %	0 %	1 %	11 %	39 %	49 %	4.34	0.73
Road_narrowing (N = 70)	42 %	0 %	1 %	2 %	51 %	46 %	4.41	0.6
Red_pavement (N = 70)	14 %	0 %	7 %	14 %	57 %	21 %	3.93	0.8

Paired samples *t*-test: Control * LED: $t_{(69)} = -13.7$, $p < .001$; Control * Road_narrowing: $t_{(69)} = -15.5$, $p < .001$; Control * Red_pavement: $t_{(69)} = -14.4$, $p < .001$.

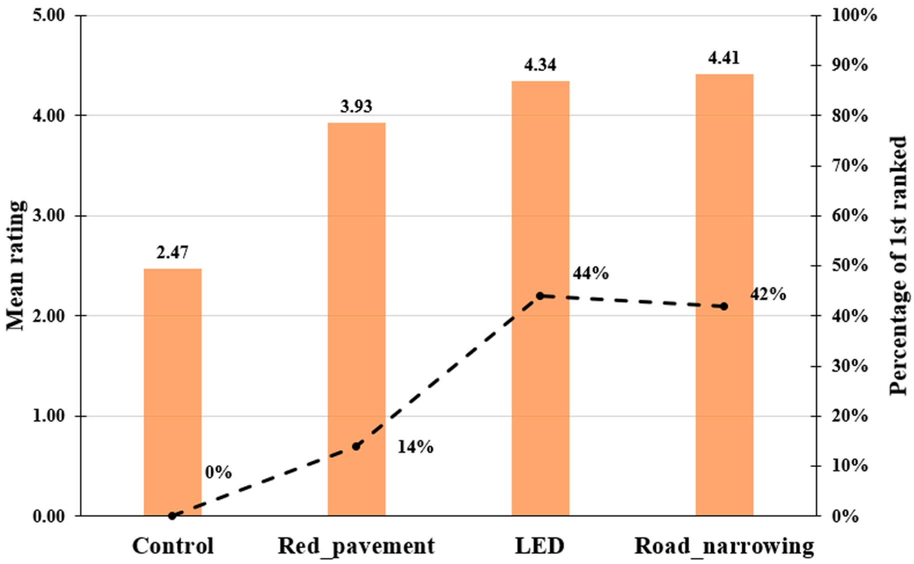


Fig. 5. Mean rating (bars) and the percentage of 1st ranked (line).

stops. This can be done through awareness campaigns, continuous driver training/education programs, or during the training or licensing stages at driving schools.

5.2. Analysis of speed

Drivers' speed was analyzed for two different cases. The first case was for the drivers who crossed the school bus in Situation 2. While the second case was for Situation 3 where there was no bus stopped at the bus stop. Speed analysis of drivers who overtook the school bus in Situation 1 was not included due to the very limited sample size (i.e., only 4 drivers overtook the school bus in the Road_narrowing condition).

5.2.1. Speed analysis when school bus is at the opposite lane (Situation 2)

The results of between-subject ANOVA test for the speed of drivers who crossed the stopped bus in the opposite travel direction (Situation 2) are presented in Table 3. Results show that the main effects of the 'Condition' ($F_{(3, 2672)} = 9.8$, $p < .001$) and 'Point' ($F_{(154,}$

$_{2672)}$ = 15.4, p <.001) were significant. This indicates that drivers' traveling speed was significantly different between the four conditions and along the analysis segment, independent of any other factor. On the other hand, the interaction effect of 'Condition × Point' was not significant. To better illustrate this interaction effect, Fig. 6 displays the mean speed profiles (in km/h) of vehicles who crossed the stopped bus at the opposite travel direction. The x-axis represents the analysis section (200 m before and 100 m after the bus), while each bar in the y-axis represents one of the four conditions. The figure shows that drivers crossed the school bus with significantly lower speed in the LED and Road_narrowing conditions compared to the Control and Red_pavement conditions. The lowest speed reduction of 5.32 km/h was observed in the LED condition at 20 before the bus, while the Road_narrowing condition stimulated drivers' speed reduction in advance from 80 m before the bus location. Moreover, post-hoc pairwise comparison (LSD) showed a significant reduction is drivers' speed starting at −40 before the bus in the LED and Road_narrowing conditions compared to the Control condition.

The results indicate that although drivers crossed the school bus in Situation 2 in the four conditions, their crossing speed was significantly lower in the LED and Road_narrowing conditions.

5.2.2. Speed analysis in the absence of school bus (Situation 3)

Speed analysis for Situation 3 was investigated by within-subject ANOVA test as presented in Table 4. Results show a significant main effects for the factors 'Condition' ($F_{(2.6,\ 180)}$ = 3.1, p =.035) and 'Point' ($F_{(2,\ 157)}$ = 43.5, p <.001). This means that independent of any other factor, drivers' traveling speed was significantly different between the four conditions and along the analysis section. Moreover, the interaction effect of 'Condition × Point' ($F_{(7,\ 516)}$ = 3.9, p <.001) was also found to be significant indicating that the speed was significantly different between the conditions along the analysis section. To illustrate this more in detail, Fig. 7 shows mean speed profiles (in km/h) of drivers for the four conditions in Situation 3. The x-axis represents the analysis section (200 m before and 100 m after the bus), while the y-axis shows the four conditions. The figure shows that the drivers' speed was significantly lower in the three treatment conditions, especially the LED and Road_narrowing conditions compared to the Control condition. Post-hoc (LSD) comparisons revealed that the mean speed significantly dropped in the LED and Road_narrowing conditions compared to the Control condition within the 80 m zone from the bus. Based on the pairwise comparison, the highest reduction in speed was obtained for the LED condition at −40 m (i.e 5.16 km/h) followed by the Road_narrowing at −60 m (i.e. 5.11 km/h).

Based on the results, it can be concluded that the LED and Road_narrowing conditions were both effective in motivating drivers to reduce their traveling speed even in the absence of the school bus.

5.3. Analysis of the overtaking/crossing behavior

The Generalized Linear Mixed Model (GLMM) was estimated to identify which predictors were significant for the probability of overtaking/crossing the stopped school bus. The results that were significant at 0.05 level are presented in Table 5. Regarding Conditions, the probability of overtaking of the stopped school bus was significantly reduced for the LED (β = −0.918, p =.003), Road_narrowing, (β = −0.624, p =.043) and Red_pavement (β = −0.621, p =.042), all compared to the Control condition. The highest reduction was observed for the LED condition i.e. 0.39 times lower probability of overtaking as compared to the Control condition. Furthermore, the probability of crossing the stopped school bus in Situation 2 was significantly higher (β = 2.206, p <.001) than the probability of overtaking in Situation 1. This means that the probability of drivers crossing the stopped bus on the opposite direction is 9.1 times higher than the probability of drivers overtaking the stopped bus stopped on the same direction.

Interestingly, the probability of overtaking/crossing the school bus was significantly lower for drivers who had knowledge about the laws associated with overtaking/crossing the stopped school buses. Finally, drivers' approaching speed was a significant predictor for the likelihood of overtaking/crossing the school bus (β = 0.111, p <.001). The odds ratio confirmed that for every 1 km/h increase in the drivers' approach speed, the overtaking/crossing probability increase by 11.1 %.

5.4. Stopping behavior of drivers

The analysis of the stopping behavior of the drivers was carried out by analyzing the standard deviation of longitudinal ACC/DEC (SD-A/D). It is used as a safety indicator for drivers' speed variation and the homogeneity of their stopping behavior (Marchesini &

Table 3
Analysis of speed for crossing drivers: between-subject ANOVA test.

Effect	*B*	*Standard error*	*Exp(B)*	*p value*
Intercept	−6.584	0.716	0.001	**<0.001**
Situation 2	2.206	0.232	9.1	**<0.001**
Condition (Base = Control)				
LED	−0.918	0.312	0.399	**0.003**
Road_narrowing	−0.624	0.308	0.536	**0.043**
Red_pavement	−0.621	0.305	0.537	**0.042**
Knowledge of Law (Yes = 24 %; No = 76 %)	−0.643	0.271	0.53	**0.018**
Speed (Mean = 48.4 km/h)	0.111	0.013	1.1	**<0.001**

Significance level α = 0.05.
Akaike Information Criterion (AIC): 513; Bayesian Information Criterion (BIC): 564.4; Log-likelihood: 488.4.

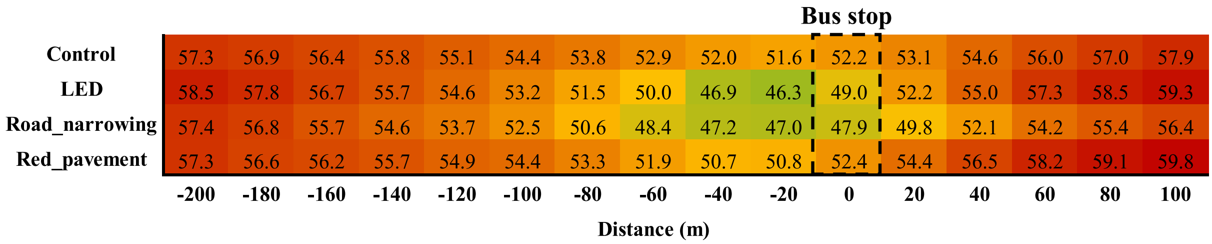


Fig. 6. Mean speed profile in km/h of crossing drivers in Situation 2.

Table 4
Analysis of speed: within-subject ANOVA test (corrected for Greenhouse-Geisser).

Effect	*F*	*Dfs*	*p*
Condition	3.1	2.6, 180	**0.035**
Point	43.5	2, 157	**<0.001**
Condition × *Point*	3.9	7, 516	**<0.001**

Significance level α = 0.05.

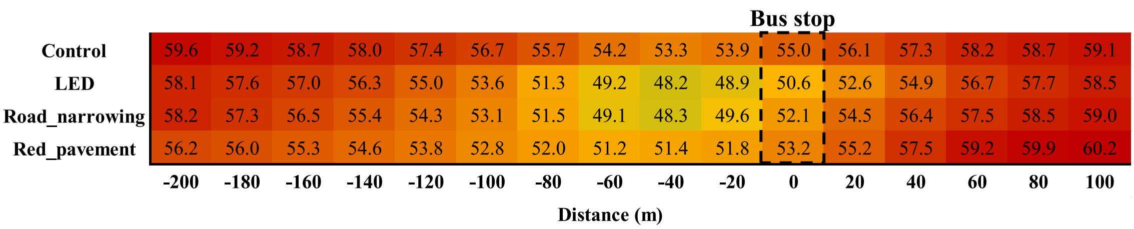


Fig. 7. Mean speed profiles in km/h of drivers in Situation 3.

Table 5
Probability of overtaking/passing the school bus (significant p-values at 95 % confidence level are indicated in bold).

Effect	*F*	*Dfs*	*p*
Condition	9.8	3, 2672	**<0.001**
Point	15.4	15, 2672	**<0.001**
Condition × *Point*	greater than1	45, 2672	0.995

Significance level α = 0.05.

Weijermars, 2010). According to Hussain et al. (2021), the higher SD-A/D during stopping behavior, the higher would be the risk for rear-end collisions. The results of ANOVA analysis are presented in Table 6. Model 1 shows the results for drivers who stopped in Situation 1, while Model 2 shows the results for drivers who stopped in Situation 2. Starting with Situation 1 (i.e., Model 1), the factor 'Condition' was significant ($F_{(3,\ 3495)} = 2.9$, p =.035). This indicates that the differences in SD-A/D were significant between the four conditions. For situation 2 (i.e., Model 2), the factor 'Condition' was not significant at 0.05 significance level, indicating that the variations in ACC/DEC were not significantly different between the four conditions when the school bus was stopped on the opposite driving lane. However, the interaction effect of 'Condition × Zone' (F (42, 1470) = 2.5, p <.001) was significant. This means that the difference in SD-A/D was significant between the four conditions along the analysis section.

Table 6
Between-subject ANOVA test for the SD-A/D for both situations.

Model	*Effect*	*F*	*Dfs*	*p*
1	*Condition*	2.9	3, 3495	**0.035**
(Situation 1)	*Zone*	93.4	14, 3495	**<0.001**
	Condition × *Zone*	1.1	42, 3495	0.246
2	*Condition*	greater than1	3, 1470	0.656
(Situation 2)	*Zone*	44.7	14, 1470	**<0.001**
	Condition × *Zone*	2.5	42, 1470	**<0.001**

Significance level α = 0.05.

To further explore the results, Fig. 8(a) and 8(b) illustrate the mean SD-A/D profiles of drivers who stopped in Situation 1 and Situation 2, respectively. The x-axis represents the 300 m analysis section (200 m before and 100 m after the bus) divided into 15 zones (each of 20 m), while the y-axis shows the mean SD-A/D. Fig. 8(a) shows that the highest SD-A/D for all conditions was recorded at −40 to −20 m zone in Situation 1, which is plausible as the participants stopped behind the bus. While comparing the SD-A/D at this zone, the lowest SD-A/D was observed for the LED condition. When it comes to Situation 2, Fig. 8(b) shows that the SD-A/D values for the Control and Red_pavement conditions were higher at zone −40 to −20 m compared to LED and Road_narrowing conditions. Post-hoc (Least Significant Difference "LSD") confirmed a significant higher variations in the Control condition compared with the LED and Road_narrowing conditions.

6. Discussion

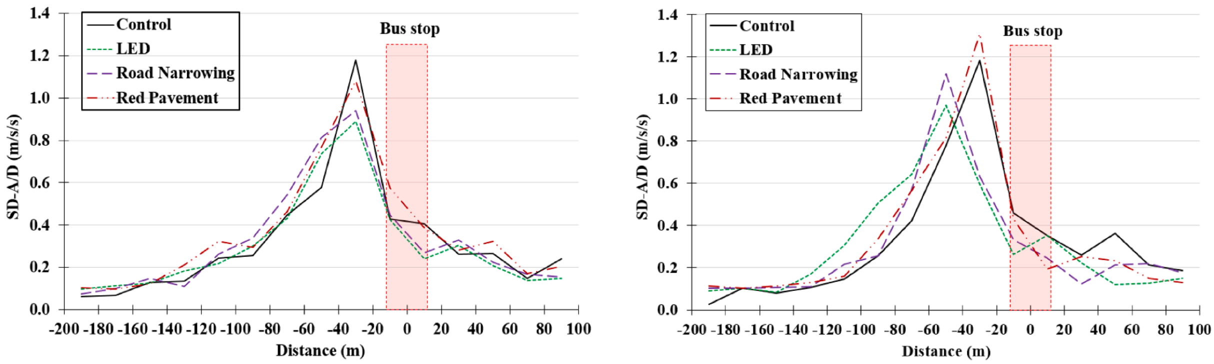
In this study, we aimed to investigate the impact of different innovative treatments at bus stops located at local roads in residential areas using a driving simulator. Three different treatments were compared with the Control condition which was designed according to the configurations provided by Qatar Highway Design Manual. Besides the Control condition, the three treatment conditions included smart LED light units, Road_narrowing and Red_pavement. Each participant encountered the four conditions for three different situations. Situation 1 and Situation 2 were designed with the presence of a school bus stopped on the same and opposite driving lanes, respectively, while Situation 3 was designed without any bus present at the bus stop location.

The overall performance of the conditions considering both situations (Situation 1 and Situation 2) was presented in the GLMM. Results showed that the smart LED condition got the lowest likelihood for overtaking/crossing the stopped school bus followed by the Road_narrowing and Red_pavement conditions, all in comparison with the Control condition. Looking into each situation separately, results showed that in Situation 1, Road_narrowing condition was the most effective in preventing 94.3 % of the drivers from overtaking of the stopped school bus. This can be attributed to the physical separation presented by the vertical poles that are used in this condition to force drivers to stay on the same lane while approaching the bus stop. Anund et al. (2011) reported that more than half of the causalities of students occurred when they were crossing the street from the front side of the school bus while another vehicle overtake the bus. Furthermore, it is important to highlight that most of the guidelines suggest that the students must cross the road while walking in front of the school bus. Therefore, stimulating drivers to avoid overtaking maneuvers from behind the bus is critical. Interesting to mention that all the drivers who overtook the stopped bus in the Road_narrowing condition (5.7 %, n = 4), did also overtook the stopped bus in the other three conditions (Control, LED, and Red_pavement). Those drivers have a higher level of risk taking or aggression which is reflected on the overtaking of the stopped school bus in all conditions, even with the presence of the physical barriers presented in the Road_narrowing condition. The smart LED condition was the second most effective treatment by preventing 85.7 % of the drivers from overtaking.

In Situation 2, the results showed that large proportion of the drivers (50 % to 74 %) crossed the bus stop while a bus was stopped at the opposite direction. This can be considered as an alarming issue that need to be addressed by engineering measures as well as awareness and educational campaigns. The results of the analysis showed that when the stopped bus was on the opposite driving lane, the smart LED condition was the most effective in stimulating almost half of the drivers (48.6 %, n = 34 out of 70) to stop for the school bus. Interestingly, it was found in the results from the post-experiment questionnaire that out of the 34 drivers who stopped, only 26.5 % of them were aware of the stop-arm violation law. This indicates that the flashing red LED light units on the ground at both travel directions helped in stimulating the drivers to stop for the school bus. Turner & Stanley (2008) indicated that drivers are not well informed about the requirements of the law associated with the overtaking/crossing of school buses. In this regard, literature indicates the importance and urgency of improving drivers' awareness about the overtaking/crossing to overcome safety issues (Fraser & Carreno, 2011; Tsai & Graham, 2005; Turner & Stanley, 2008). In recent studies, LED light units were found to be effective in nudging the drivers and alternatively improving traffic safety at signalized intersections (Hussain et al., 2020b) and uncontrolled midblock crosswalks (Hussain et al., 2021).

The analysis of driver stopping behavior by the means of standard deviation of longitudinal ACC/DEC (SD-A/D) showed that in each situation, the Control and Red_pavement conditions showed higher SD-A/D compared to LED and Road_narrowing conditions. Higher SD-A/D would mean that there is higher dispersion of the acceleration or deceleration rates indicating that some drivers decelerate more or less when compared to other drivers. The findings of this study indicate inconsistent and more unsafe stopping behavior for Control and Red_pavement conditions. This has been linked in previous research to an increased risk for rear-end collisions with following vehicles (Hussain et al. 2021; Kim et al., 2016; Tarko et al., 2009).

The safety related issues at bus stop locations remains present even in the absence of buses as pedestrian crossing activities are still common at these locations. Consequently, a significant positive relationship between pedestrians-involved crashes and bus stop locations has been reported in the literature (Ulak et al. 2021). On the one hand, our results confirmed that the smart LED and Road_narrowing treatments were effective in motivating drivers to reduce their travel speeds in the absence of buses at the bus stop location. Compared to the untreated condition, the highest speed reduction of 5.16 km/h and 5.11 km/h were achieved in LED and Road_narrowing conditions, respectively. This can be explained by the nudging effects produced by the flashing amber LED light units in increasing drivers' attention level while approaching the bus stop location and stimulating their speed behavior (Köhler et al., 2019). On the other hand, the Road_narrowing effects i.e., physical road narrowing by the vertical poles and perceptual road narrowing by the hatched median (Godley et al., 2004) could have triggered drivers' traveling speed in the Road_narrowing condition. Previous studies have shown that road narrowing treatments have positive effects in reducing drivers' speed (Distefano & Leonardi, 2019; Melman et al., 2020). Moreover, according to Godley et al. (2004), creating perceptual lane narrowing effect is as effective as using a physical lane reduction in reducing drivers' speed. Similar trends in the drivers' speed profiles were also found for drivers who



a) SD-A/D for situation 1 b) SD-A/D for situation 2

Fig. 8. SD-A/D of drivers who stopped in Situation 1 and Situation 2.

had crossed the school bus in Situation 2 where the traveling speed was significantly reduced in the LED and Road_narrowing conditions. This could indicate better safety performance for the two conditions in comparison with the Control condition especially with the high probability of pedestrian movements to/from the stopped bus. According to Hussain et al. (2019b), the odds of a pedestrian fatality increases exponentially with the increase in impact speed.

Based on the results, it can be concluded that the LED and Road_narrowing treatments were found to be effective in improving safety at bus stop locations, i.e., reducing the number of overtaking/crossing of the stopped bus and reducing drivers' speed while approaching to the bus stop. In terms of cost of the treatments, compared to the control condition, the approximate additional cost for the Road_narrowing would be $2500-$3500, while $3500-$4500 for the Red_pavement and $6500-$7500 for the LED conditions (FHWA, 2005; FHWA, 2009). A detailed cost/benefit analysis of the proposed treatments is needed as future research opportunity.

7. Research limitations and future work

Certain limitations should be taken into account in this study. Although the sample size of participants was large (i.e. 70 participants), only 21 % (N = 15) of the participants were females. Nevertheless, according to the General Directorate of Traffic in the Ministry of Interior of the State of Qatar, the actual percentage of female drivers in Qatar is around 17.8 %. The sample was skewed more toward younger age group. In addition, the results are based on heterogeneous population of the State of Qatar. Therefore, the results may vary for samples with different age groups distribution, and/or homogenous population. The results of the proposed treatments in this study are based on immediate effects. Follow-up research could study the long-term effects of these treatments.

Based on the results of this study, the Road_narrowing condition was the most effective condition in reducing the overtaking of the bus in Situation 1, while the LED condition was the most effective condition in reducing the crossing of the bus in Situation 2. Therefore, future research could focus on studying the combined effect of LED and Road_narrowing treatments. Moreover, future studies could also evaluate the effectiveness of the proposed treatments in a field trial. Follow-up research could focus on studying the effectiveness of treatments for roads with higher number of lanes (i.e., 4 lanes roads) which could produce different results.

8. Conclusion

Bus stops are critical locations for pedestrian safety in general and for students in particular. Identifying proper treatments to improve driver yielding and stopping behavior is demanded. This study investigated the impact of three innovative treatments (LED, Road_narrowing and Red_pavement) on driving behavior at bus stop locations using a driving simulator. Results showed that the untreated Control condition had the lowest safety performance in terms of reducing drivers' speed and preventing the overtaking/crossing of the stopped school bus. On the other hand, LED and Road_narrowing treatments were effective in improving safety at bus stops. These two treatments were effective in motivating drivers to stop for the school bus when it was stopped in the same travel direction and on the opposite travel direction. In addition, the treatments were effective in motivating drivers to reduce their traveling speed when there was no bus present at the bus stop location. Based on the results, it can be concluded that safety at bus stops can be significantly improved by means of the LED light units or physical lane narrowing treatments.

Although this study targeted improving the safety of school buses at bus stops, the results can be generalized to transit stops as well. However, in order to implement these treatments (i.e., LED and Road_narrowing) in the real-world, policymakers could focus on studying the cost/benefit of the proposed treatments and identification of critical locations that have safety related issues. This can be done for instance, by conducting Black-spot analysis which helps in identifying the critical location based on different factors such as number of crashes, crash rates, crash types, pedestrian flow, vehicles' speed, etc.

CRediT authorship contribution statement

Mustafa Almallah: Conceptualization, Software, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Qinaat Hussain:** Conceptualization, Investigation, Formal analysis, Methodology, Writing – review & editing. **Shabna SayedMohammed:** Formal analysis, Methodology, Writing – original draft. **Wael K.M. Alhajyaseen:** Conceptualization, Funding acquisition, Supervision, Project administration, Resources, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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Appendix

Appendix. . Testing protocol for the experiment

Step	Description	Time
pre-experiment questionnaire	After welcoming the participant, a brief introduction about the driving simulator was given to the participant by the research team. After that, the participant was asked to sign an informed consent form which contains information about simulation sickness and the right of the participants to stop the experiment at any time. Moreover, the form gives the rights to use the collected data for the research purposes. Then, the participant was asked to fill a pre-test questionnaire which focuses on socio-demographic background and driving experience.	10 min
Driving simulator familiarization drive	The participant was asked to undertake a familiarization drive. The main purpose of this drive was to allow participants to get familiar with the driving simulator controls before starting the experimental drives.	10 min
Experimental drives	Each participant drove three test drives, each of 9 km length with short breaks between the drives. All participants were instructed to drive normally and to follow the traffic rules as they do in the real world.	40 min
post-experiment questionnaire	Computer-based post-test questionnaire was filled by the participant to collect further information about the driving simulator and conditions' subjective assessment.	10 min
		Total time = 70 min

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