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Analyzing driver-pedestrian interaction in a mixed-street environment using a driving simulator

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ABSTRACT

This paper presents the design, analysis and results of a driving simulator experiment conducted to study the interaction between drivers and pedestrians in a mixed-street environment. Ninety-six students of the American University of Beirut (AUB) participated in the experiment that took place in the Transportation and Infrastructure Laboratory of AUB. The study looked at the driver-pedestrian interaction from the driver's perspective, by quantifying the effects of different scenario variables on the driving behavior of the participants. Kruskall-Wallis test shows that drivers' behavior in proximity of pedestrians tends to be statistically significantly less aggressive when their approach velocity is lower, curb-side parking is not allowed, a crosswalk exists, and the number of pedestrians crossing the street is higher. A discrete choice model for the yielding behavior of the drivers was also developed as a function of different predictor variables. Five out of the six predictors considered (except for gender) had a statistically significant effect on the yielding behavior, particularly the effects of curb-side parking, number of pedestrians crossing, and approach velocity. The model was then used to evaluate the effect of policy variables on the yielding probabilities of the drivers. The results of this study enrich current knowledge and understanding of drivers' behavior and their interaction with pedestrians, especially with studying the effects of scenario variables that were not addressed before; this would help planners propose and evaluate safety measures and traffic calming techniques to reduce the risks on pedestrians. The study also confirms the effectiveness of driving simulators in studying driver-pedestrian interactions.

1. Introduction

Pedestrians are one of the most unprotected road users with around 22% of all worldwide traffic deaths involving pedestrians (World Health Organization, 2015). In particular, pedestrian death constitutes 27% of all road traffic deaths in the Eastern Mediterranean part of the world. Moreover, National Center for Statistics and Analysis (2015) records a 73% pedestrian fatality rate occurring in urban areas (where there are more pedestrians) and 69% occurring at non-intersections. These high percentages confirm the need to study the different factors that contribute to a safer environment for pedestrians.

In previous work (Danaf et al., 2016), we studied vehicular-pedestrian interactions focusing on pedestrian crossing behavior on dense urban streets using videography, pedestrian surveys, and vehicular speed measurement as well as pedestrian and traffic simulation. The current paper develops a methodology to study the driver-pedestrian interaction from the driver's point of view, focusing on young drivers and university students in an urban context where pedestrian crossing facilities are often lacking respect by drivers. A driving simulator experiment was designed to assess the driving behavior under several scenarios, varying experimental variables that affect the vehicular-pedestrian interaction. The aim was to test the impacts of various potential measures (such as presence or absence of crosswalks) and factors (such as number of pedestrians crossing) on driving behavior in such contexts, including speeding, yielding to pedestrians, etc. This would help planners propose and evaluate safety measures to reduce risks to pedestrians (crosswalks or other traffic calming techniques).

The objective of this research is to contribute to a better understanding of driver-pedestrian interactions and driver yielding behavior by adding two new independent variables: street setting (university vs. non-university) and curb-side parking that we have not encountered in the yielding models previously developed in the literature. Moreover, street sequence was studied to identify its impact, if any, on driving behavior, manifested by five dependent variables (minimum velocity

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(V_{min}), distance at which minimum velocity occurs (L_{min}), average velocity over the 20-m stretch before the crosswalk (V_{20}), distance at reaction (D_r) and deceleration (Dec)) and yielding. A policy analysis was also done to study the effects of policy variables (like approach velocity, curb-side parking, and crosswalks) on the yielding behavior of drivers. The study further lends support to the effectiveness of driving simulators as a tool for studying driver-pedestrian interactions, by supporting the findings of other authors obtained from field studies.

2. Literature review

2.1. Pedestrian safety measures

Pedestrian safety is often overlooked while designing transportation facilities (Cafiso et al., 2010a). Nonetheless, several pedestrian safety indices have been proposed in the literature. A methodology that considers the safety of pedestrians and the operational conditions of the facility to measure the level of service (LOS) of midblock crosswalks was proposed by Chu and Baltes (2003). The authors used pedestrian injuries and fatalities from crashes, number of vehicle-pedestrian conflicts or pedestrians' perception to measure safety. Moreover, in relation to crosswalks, measures of risk have been developed and used in the literature, such as TTC (time to collision), TTZ (time to zebra crosswalk) and vehicle stopping time. Because these measures are limited in their ability to differentiate among different conflicts, Cafiso et al. (2010a) proposed a new method to measure the severity of vehicle-pedestrian conflicts as an indicator of safety. The authors take into account the potential impact speed in addition to the above mentioned variables to calculate a Pedestrian Risk Index (PRI). This methodology was applied along a cross road in the Spanish town of Belgida. Studying the data of the different traffic calming techniques, *t*-tests showed a statistically significant reduction of PRI values when using humps before the crosswalks or using raised crosswalks, in comparison with a standard zebra crosswalk. Moreover, no statistically significant reduction was detected after re-painting the crosswalk. More interestingly, PRI values suggest that drivers do not necessarily react only to pedestrians' presence, as indicated by no statistically significant difference in PRI values between pedestrian and no pedestrian cases. The above studies confirm the need to consider safety and study the risk implications of different traffic calming techniques during the design phase.

2.2. Driver speeding and yielding behavior

Several studies have analyzed driving speed and yielding behavior at marked and unmarked crosswalks using different methodologies. Some of these studies involve field experiments with trained pedestrians or instrumented vehicles while some others have used driving simulators. Even though ideally the yielding compliance rate of drivers at crosswalks is expected to be 100% since pedestrians have the right-of-way on zebra crosswalks (Cafiso et al., 2010b), many of these observational studies refute this assumption. However, they also show that yielding rates may increase when safety treatments are applied at these crosswalks, as described below.

In 1975, Katz et al. studied factors that influence drivers' behavior in giving way to pedestrians. Trained pedestrians performed the crossing of the street, while three observers recorded the variables of interest. It was found that crossing speed (average vehicle speed over the 20-m stretch before the crosswalk) was statistically significantly lower at marked crosswalks compared to unmarked ones and mean relative speed reduction was higher. Drivers were also found to stop more often when approach velocity was low. Furthermore, crossing velocity was statistically significantly lower when the distance from the pedestrian to the vehicle was higher, when pedestrians were crossing in groups, and generally lower when pedestrians were looking at the approaching driver. Lastly, female drivers and older drivers slowed down more than other drivers.

Fisher and Garay-Vega (Fisher and Garay-Vega, 2012) used a driving simulator to compare drivers' performance at standard zebra crosswalks to advance yield markings and pedestrian crosswalk prompt signs. Using data acquired from an eye tracker, the authors found a statistically significant increase in the frequency of looking for pedestrians when they encountered advance yield markings. The authors also studied if the place of a visibility obstruction affects drivers' performance at advance yield markings and found no statistically significant effect. Also, the percent of drivers yielding to pedestrians was recorded; no drivers yielded to pedestrians crossing on standard yield markings, while 61% yielded to pedestrians crossing on a crosswalk with advance yield markings.

Bertulis and Dulaski (Bertulis and Dulaski, 2014) studied the yielding behavior of drivers to pedestrians on marked crosswalks. The study was conducted in nine uncontrolled, marked crosswalks in two locations: Boston and Brookline, Massachusetts. The 85th percentile of approach speeds versus yielding to pedestrians indicated a very strong inverse correlation, with low yield rates on high-speed roadways. This suggests that drivers, although aware, tend not to respect pedestrians' right-of-way on marked crosswalks.

Bella and Silvestri (Bella and Silvestri, 2015) used a driving simulator to study the influence of several safety treatments at zebra crosswalks, combined with different driver-pedestrian interactions, on the speeding behavior of drivers and their yielding compliance. The results showed that curb extensions induced a change towards a safer speeding behavior; the distance from the crosswalk at which the driver reacted to the presence of a pedestrian, the minimum velocity during deceleration, and the distance where the minimum velocity occurred were statistically significantly higher for the curb extensions compared to the other safety treatments. Furthermore, the highest percentage of yielding was recorded for the curb extensions, and the lowest for parking restrictions.

Zheng et al. (2015) studied driver-pedestrian interactions and driver-jaywalker interactions. Jaywalkers are those who cross the street on unmarked crosswalks or outside of marked crosswalks. Since unanticipated crossings decrease the reaction time of drivers, the safety of jaywalkers is compromised. The authors studied the corresponding interactions using a GPS-enabled vehicle that records the vehicle position and speed. The study was done in the campus of University of Florida, where 15 drivers were selected to drive the designated routes. Driver yield rates were found to be 50.67% to jaywalkers and 72.66% to permissible crossings. Another important aspect studied was the distance at which drivers reacted to the presence of pedestrians. The mean distances of reaction to permissible crossings and jaywalkers were found to be statistically significantly different. The above two observations confirm that drivers tend to have a shorter reaction time to jaywalkers than to permissible crossings, and hence a lower probability of yielding.

2.3. Modeling driver yielding behavior

The studies described above have analyzed driver-pedestrian interactions descriptively. Other studies have also developed models that predict driver yielding behavior under such interactions, as described below.

In 1988, Himanen and Kulmala used multinomial logit modeling to study driver-pedestrian interaction on seven crosswalks at street junctions in Helsinki and Salo, Finland, using videotapes to collect the data. The authors found that the driver's probability of yielding to the pedestrian increases as the number of pedestrians in the group and the distance of the pedestrian to the driver increase. On the other hand, the probability significantly decreases as the speed of the approaching vehicle (20 m away from the crosswalk), the number of cars in the platoon, and the city size increase. The probability of yielding considerably increases by 0.4 for pedestrians crossing the street on marked crosswalks rather than crossing the street elsewhere.