Journal of Public Health Student Capstones

Research Project 1(1), 2022

The Impact of Changes in Vehicle Design on Pedestrian Safety in the United States

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Articleinfo

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DOI: https://doi.org/10.15586/jphsc.v1i1.47

Published: 1 August 2022

Abstract

Over the last 10 years, the United States has observed a 50% increase in pedestrian deaths. Changes in sport utility vehicle (SUV) and pickup design, namely increase in vehicle height and curb weight could be related to pedestrian injury and death.The objective of this study was to assess changes in pedestrian trauma rates over the last 30 years by measuring mediating effects of vehicle design. This study analyzed the relationship between crash year, characteristics of vehicle, and Abbreviated Injury Scale or death using fatal and nonfatal vehicle–pedestrian crash data from the National Highway Traffic Safety Administration (NHTSA). This study found that in the United States between 1991 and 2018, there was a decrease and then increase in pedestrian fatalities. The presence of SUV and pickup (vs. car) has increased pedestrian crashes over the last 30 years. SUV and pickup models are having increased height and curb weight. In this study, no relationship was observed between design of vehicle and pedestrian injury or death. The future research must examine confounders, such as vehicle speed and driver behavior, in order to clarify the risk of injury and death because of increasing height and curb weight.

Keywords: Epidemiology; pedestrian safety; vehicle design; safety

Introduction

An epidemic outbreak of pedestrian fatalities has taken place across the United States: 6,227 deaths in 2018 compared to 4,109 in 2009—a 50% increase in just under 10 years.[1] Changes in vehicle design and purchasing behaviors are two primary factors among many that relate to increased pedestrians deaths in car–person crashes.[2,3] Purchasing behaviors of sport utility vehicles (SUVs) have been rising since 2008. Based on the data from the US Bureau of Transportation, total sale of new vehicle has risen by 27% in 10 years since the recession in 2008, with a 97% increase in the sales of light trucks and a 25% drop in the sales of passenger cars.[2] In addition, SUVs, also known as "light trucks," have changed in design. Hoods and bumpers have become taller and the vehicles have been increasing in size and weight. Heavier and larger vehicles may be safer for occupants,[3] but are a trauma risk for smaller vehicles and pedestrians. Fatal single-vehicle crashes involving SUVs have increased by 81% in just 7 years in the United States between 2009 and 2016.[4]

Much of the research on the impact of car design on pedestrian safety comes from post-implementation research of European legislation called the New Car Assessment Program (NCAP). The program was introduced, among other reasons, to improve design of vehicle front for protection of pedestrians, for example, by reducing height of vehicle hoods. Research conducted in Germany comparing pedestrian trauma before and after enactment of NCAP regulations in 2009 established that newer vehicles with improved vehicle front shapes had improved overall safety for pedestrians as measured by the Abbreviated Injury Scale (AIS), with better protection, especially for lower body of pedestrians.[5,6] Other research estimated that implementation of programs such as NCAP that assess the safety of vehicles for pedestrians could decrease the burden of pedestrian injuries by up to 24% and daily adjusted life years (DALYs) by 20%.[7]

Pedestrian trauma from vehicles speeding around 20–30 miles per hour (mph) is enough to damage ligaments, while speed of 40 mph directly cause fracture to bones.[8] Sedans are more likely to cause injuries to the lower limbs and head when people are thrown onto the hood, while SUVs are more likely to cause injuries to the chest and pelvis of pedestrians which are more often thrown on the ground in front of the vehicle.[9,10] In all vehicles, of particular importance for safety of the lower limbs are the height and stiffness of the bumper,[11] while height and angle of hood are the most important elements for determining head injuries.[12] Recently, improvements have been made to personalize crash data based on bodily measurements,[13] yet we are still far from being able to implement this technology outside laboratory models for the purposes of vehicle design and policy.

The relationship between changes in vehicle design and pedestrian trauma is logically physical but has social implications beyond the scope of engineering. It is within the purview of epidemiology to evaluate the prevalence, incidence, and causal relationships between vehicle designs as a risk for pedestrian trauma. It is the responsibility of public health researchers to encourage appropriate policies for regulations that promote safer vehicle design and to spread awareness of the issue of pedestrian safety which could impact purchasing behavior. Therefore, the aim of this research study was to determine the impact that changes in vehicle design and purchasing behaviors had on pedestrian trauma between 1991 and 2018. It was hypothesized that the increasing usage of SUV and pickup trucks (PU) versus cars and increasing SUV/PU height and weight over the last 30 years had contributed to increase in the severity of pedestrian injuries and deaths. The results of this study could be used to inform targeted interventions for reducing pedestrian injuries and deaths.

Methods

Data for the current study were drawn from publicly available files of the National Highway Traffic Safety Administration (NHTSA) from 1991 to 2018. Data for all fatal crashes were obtained from the Fatality Analysis Reporting System (FARS), while data for a sample of nonfatal and fatal crashes were obtained from the General Estimates System (GES) for 1991–2015 and the Crash Report Sampling System (CRSS) for 2016–2018. Data on crashes that involved a pedestrian, cyclist, or unknown non-motorist were included in this analysis.

The aim of this research was to explore reasons for the differences in death rates between pedestrians and cyclists observed over the past 30 years. Based on the available literature, it was hypothesized that characteristics of the vehicle mediate the relationship between crash year and injury severity or death, measured by the AIS. The vehicle characteristics that were included in this study were the type of vehicle (SUV/PU or car), height of vehicle (as the available proxy for hood height), and weight of vehicle.

The exposures for this study were characteristics of vehicle (type, height, and weight of vehicle), while the outcome was severity of injury and death. Severity of injury was measured based on a 4-point scale of no injury (0) to death (4) using the AIS. Death was assumed by inclusion in the FARS dataset. Mediators included type (SUV/PU or car), height, and weight of vehicle. Note that the weight of vehicle in this study refers to vehicle's curb weight. This is the vehicle's dry weight plus an estimate of fuel weight and driver weight, which reasonably estimates a vehicle's weight on the road without a load. Classification as SUV/PU versus car was estimated using "body type" in the FARS, GES, and CRSS data. Height and curb weight of vehicle were estimated using online available market data on cars, assuming the smallest version of the make, model, and year described in the crash data. As there were more than a thousand different model-years involved in pedestrian crashes over the last 30 years, height and weight data were added for model-years that appeared most frequently in fatal pedestrian crashes (n = 325 model-years).

Data analysis was performed in R programming. Data parameters related to pedestrian deaths and design of vehicle were characterized and reported as trends through counts and averages, respectively, for every 9 years (i.e., 1991, 2000, 2009, and 2018). The year 1991 was chosen because it represented the first year in the datasets that variables relating to pedestrian involvement were included. Analysis was conducted at 9-year intervals to show a trend over the 1991–2018 period. In this 9-year interval analysis, the 325 most implicated vehicles were analyzed. The second annual analysis was performed using the top three most implicated vehicles.

For analysis of association, data for the 325 most commonly implicated vehicles were analyzed for every 9 years and a different method was used based on the categorical, ordinal, or interval nature of the parameters. To determine the association among crash year (predictor) and characteristics (outcome) of vehicle, logistic regression was used for types of car (SUV/PU or car) classification, and a linear regression was used for hood height and vehicle weight. Bi-variate analysis was performed initially, followed by multivariate analysis. Chi-square analysis was used for association between type of vehicle (SUV/PU or car) classification, and death, while linear regression was used to determine the association between classification of car and severity of injury. The association between vehicle measures (height and weight) as predictor and death as outcome was analyzed using Spearman's correlation tests. Logistic regression analyses were performed to analyze severity of injury as an outcome. Additional analysis was performed for the three most commonly implicated vehicles (the Ford F-150, Chevrolet Silverado, and Dodge RAM) for all years of data between 1991 and 2018.

Results

From 1991 to 2018, a decrease and then an increase in pedestrian fatalities were observed using the FARS dataset of fatal crashes (Table 1). An increase in the proportion of SUVs involved in pedestrian crashes (6.6% in 1991, and 17.5% in 2018) and a drop in pedestrian deaths involving cars (47.3% in 1991, and 37.1% in 2018) were observed. However, no clear pattern in the proportion of pedestrian deaths involving pick-up trucks (17.2% in 1991; 16.9% in 2018) was available. Both average height and curb weight of SUV/PUs in pedestrian crashes have increased. Based on the summary statistics, the average curb weights of SUV/PUs involved in fatal crashes are higher than those involved in all crashes.

From the GES/CRSS sample of fatal and nonfatal crashes, an average trauma score for vehicle occupants and pedestrians involved in pedestrian crashes was estimated. This study's findings of pedestrian trauma scores were consistently different from vehicle occupant pedestrian score, where vehicle occupants experienced an average AIS trauma score of 0.1 compared to 1.8–2.2 among pedestrians. Trends in severity of injury were generally consistent across crash years, with a slight drop in pedestrian trauma score in 2018.

Over time, there has been a significant increase in SUV/PUs involved in pedestrian crashes ($B1 = 0.26$, $P < 0.001$) and those SUV/PU models are becoming taller ($B1=0.07$, $P < 0.001$) and heavier ($B1 = 22.2$, $P < 0.001$) (Table 2). This increase in SUV/PU presence in pedestrian crashes is counterintuitively associated with a significant reduction in deaths ($Xsq = 245.4$, $P < 0.001$) and severity of injury ($B1 = -0.22$, $P < 0.001$). The increased vehicle weight observed over the past 30 years is weakly associated with reduction in death rates (rho [ρ] = 0.29). Otherwise, no associations were observed between height of vehicle and severity of injury or death, or weight of vehicle and severity of injury.

The top three most implicated SUV/PU models were PU models: Ford F-150, Chevrolet Silverado, and Dodge RAM. Some differences

Table 1. Characteristics of vehicle–pedestrian crash data from 1991 to 2018.

Characteristics	Unit	1991	2000	2009	2018
Pedestrians involved in fatal crashes	Count	7662	6391	5278	7802
Vehicles involved in fatal crashes of pedestrians	Count	21,001	17,609	16,175	21,165
Pedestrian deaths involving pickup trucks	%	17.2	16.9	16.4	16.9
Pedestrian deaths involving SUVs	%	6.6	6.7	17.4	17.5
Pedestrian deaths involving cars	%	47.3	47.8	36.4	37.1
Average height of SUV/PU*	Inches (SD)	69.1 (4.0)	69.0 (4.0)	70.6 (4.2)	70.7 (4.2)
Average curb weight for SUV/PU*	Pounds (SD)	3786 (578)	3771 (583)	4291 (688)	4305 (705)
Average trauma score for vehicle occupants involved in pedestrian crash	Scale** (SD)	0.1 (0.5)	0.1 (0.4)	0.1 (0.5)	0.1 (0.4)
Average trauma score for pedestrians involved in pedestrian crash	Scale (SD)	2.2 (0.8)	2.2 (0.7)	2.2 (0.7)	1.8 (0.9)

*Based on year/make/model of pickup trucks or SUVs that killed 5 or more in years 1991 (n = 82) or 2000 (n = 113), or 25 or more in either 2009 (n = 118) or 2018 (n = 180).
**Injury severity scale: 0 = no injury; 1 = possible injury; 2 = minor injury; 3 = serious injury; 4 = fatal injury.

Table 2. Associations between year of crash, characteristics of vehicle, and death and injury.

Association	Measure (SE)	P-value
Crash year and type of vehicle (logistic regression)	B1 = 0.26 (0.004)	<0.001
Crash year and height of vehicle (linear regression)	B1 = 0.07 (0.004)	<0.001
Crash year and weight of vehicle (linear regression)	B1 = 22.2 (0.43)	<0.001
Type of vehicle and severity of injury (logistic regression)	B1 = -0.22 (0.02)	<0.001
Height of vehicle and severity of injury (linear regression)	B1 = -0.01 (0.006)	0.08
Weight of vehicle and severity of injury (linear regression)	B1 = <0.001 (<0.001)	0.008
Type of vehicle and death (Chi^2 test)	Xsq = 245.4	<0.001
Height of vehicle and death (correlation)	$\rho = -0.13$	0.27
Curb weight and death (correlation)	$\rho = -0.29$	0.012

(Figure 1) were observed in the relationship between vehicle hood height and curb weight and death for the top three vehicle models. Vehicle height and curb weight have increased steadily at similar rates from 1991 through 2018 for all three PU models. However, the way these vehicle measurements relate to death has not been uniform by models. Based on linear trends, Dodge RAM model's increase in height and curb weight seems to be associated with increase in death, whereas Ford F-150's and Chevrolet Silverado's increase in height and curb weight seem to be associated with decrease in death. The findings for these three individual models did not reach statistical findings for height, but the relationships for curb weight were either statistically significant (F-150: $P < 0.001$) or nearly statistically significant (Chevrolet Silverado: $P = 0.052$, Dodge RAM: $P = 0.061$).

Discussion

The NHTSA data of 1991–2018 show that there had been a drop in pedestrian fatalities, with a recent increase in pedestrian fatalities back to the level of the early 1990s. It was hypothesized that increase in pedestrian trauma over the last 30 years was related to characteristics of the vehicle, namely, whether it was classified as SUV/PU or car, as well as the height and weight of SUV/PU. Our results show that involvement of SUV/PU has increased and the SUV/PU models involved have become taller and heavier. Regarding modeling, whether characteristics of these vehicles related to severity of injury and death, it was found counterintuitively that involvement of type of vehicle (SUV/PU or car) reduced severity of injury and death rates, and increased weight of vehicle was weakly associated with reduction in pedestrian deaths. The top three most implicated vehicle models involved in pedestrian crashes were PU vehicles. On examining the top three vehicle models across all 30 years, the present author observed differences in how the vehicle models' increasing vehicle curb weights related to pedestrian deaths, where the Chevrolet Silverado and Ford F-150 models increased curb weight correlated with reduction in deaths, while the Dodge Ram correlated with increase in pedestrian death.

The real-world data on how characteristics of vehicles relate to death are limited. The present research agreed with prior studies and statistics showing the increasing prevalence of SUV/PUs involved in pedestrian crashes and that those SUV/PU models had increased their height and weight.[14] In a physical sense, it is not be surprising that the NHTSA research supports that increasing weight of vehicles increases risk of pedestrian injury.[15] Also, there has been a focus on how increasing hood heights and aggressive hood front styles pose a risk to pedestrians involved in car crashes.[6,16,17] While results of the present study counteract this notion, it does not negate the probability that these physical realities are at play. Probably many factors,

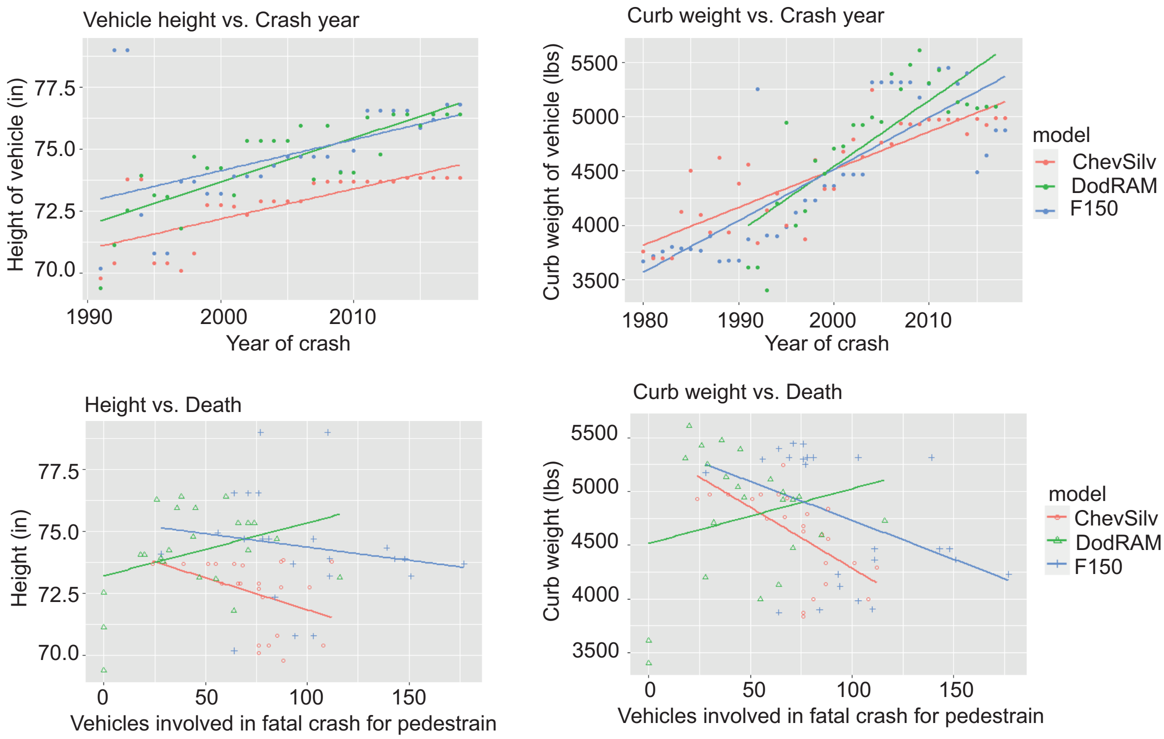

Figure 1. Association between characteristics of vehicle and crash year and death.*

*Within 5 years of the model being in the market.

uncontrolled in the present study, could explain why the author did not see relative increase in pedestrian injury and deaths. These include speed, improvements to road infrastructure for vehicles, improvements to pedestrian safety measures, and improvements in vehicle safety technology, among others.[18–21] An unpredictably significant portion also includes social factors, such as vehicle choices connected with cultural identities, socioeconomic status, and consumer psychology. Few studies have correlated social factors with choice of vehicle; however, a study conducted among residents of San Francisco demonstrated that PU drivers were more likely to be middle-aged males from lower education levels with middle incomes whereas SUV drivers probably were more educated with higher incomes.[22] More recent and generalizable research would be helpful in understanding social variables in vehicle choice and driver behavior.

Limitations of this study centered around the availability of data. Height of vehicle, a more widely available vehicle characteristic, was used as a proxy for suggestions from the literature that height of hood could be related to severity of injury. However, results indicated that height of vehicle does not accurately represent the risks observed with increasing height of hood observed in SUV/PU models over the last decade nor does it portray any information about the front shape of vehicle. Our models probably underestimated the association between increasing vehicle parameters of height and weight because the estimates for the smallest vehicle type were standardized within the make and model with no additional load. In addition, owing to limited availability of data, it was not possible to estimate the effects of confounders that may have skewed the association between design of vehicle and death or injury, including speed, vehicle technology, and characteristics of the built environment.

The implication of the physical reality of heavier and taller vehicles being more deadly for pedestrians remains unchallenged. With increase in the popularity of SUV/PUs and the number of miles driven per capita in the United States, pedestrians are at a risk of injury. The notion that these SUV/PUS are becoming heavier and taller puts pedestrians at a greater risk because pedestrians, especially children and wheelchair users, are less easily viewed over hoods of vehicles and the impact of a heavier vehicle at a given speed is more likely to cause injury. We need reliable public data on vehicle effects to pedestrians as well as drivers. The future research must focus on obtaining a greater level of details through private market data and access to data on potential confounders to build reliable models for impact of vehicle design on pedestrian trauma. Researchers and policy makers with access to private market data on changes to characteristics of vehicle such as height of hood and weight of curb, as well as front geometric design, could provide this level of details.

Conclusions

This research set out to assess changes in pedestrian trauma rates over the last 30 years by measuring mediating effects of vehicle design. With increasing heights and curb weights of SUV/PUs, pedestrians are at a potentially greater risk of injury and death. In order for automotive design policies protecting pedestrians and cyclists to be enacted, the public requires models assessing these risks that can incorporate complex changes in vehicle technology and the built environment.

References

1. Vision Zero Network. *With pedestrian fatalities on the rise, solutions found in Vision Zero*; 2020. Retrieved from https://visionzeronetwork.org/with-pedestrian-fatalities-on-the-rise-solutions-found-in-vision-zero/
2. Bureau of Transportation Statistics. *New and used passenger car and light truck sales and leases*; 2019. Retrieved from https://www.bts.gov/content/new-and-used-passenger-car-sales-and-leases
3. Insurance Institute for Highway Safety. *Fatality facts 2018*: *passenger vehicle occupants*; 2018. https://www.iihs.org/topics/fatality-statistics/detail/passenger-vehicle-occupants#driver-death-rates
4. Hu W, Cicchino JB. An examination of the increases in pedestrian motor-vehicle crash fatalities during 2009-2016. *J Safety Res*. 2018;67:37–44. https://doi.org/10.1016/j.jsr.2018.09.009
5. Li G, Wang F, Otte D, Cai Z, Simms C. Have pedestrian subsystem tests improved passenger car front shape? *Accid Anal Prev*. 2018;115:143–150. https://doi.org/10.1016/j.aap.2018.03.014
6. Nie B, Zhou Q. Can new passenger cars reduce pedestrian lower extremity injury? A review of geometrical changes of front-end design before and after regulatory efforts. *Traffic Inj Prev*. 2016;17(7):712–719. https://doi.org/10.1080/15389588.2016.1143096
7. Moran D, Bose D, Bhalla K. Impact of improving vehicle front design on the burden of pedestrian injuries in Germany, the United States, and India. *Traffic Inj Prev*. 2017;18(8):832–838. https://doi.org/10.1080/15389588.2017.1324200
8. Matsui, Y. Effects of vehicle bumper height and impact velocity on type of lower extremity injury in vehicle-pedestrian accidents. *Accid Anal Prev*. 2005;*37*(4):633–640. https://doi.org/10.1016/j.aap.2005.03.005
9. Han Y, Yang J, Mizuno K, Matsui Y. Effects of vehicle impact velocity, vehicle front-end shapes on pedestrian injury risk. *Traffic Inj Prev*. 2012;13(5):507–518. https://doi.org/10.1080/15389588.2012.661111
10. Roudsari BS, Mock CN, Kaufman R. An evaluation of the association between vehicle type and the source and severity of pedestrian injuries. *Traffic Inj Prev*. 2005;6(2):185–192. https://doi.org/10.1080/15389580590931680
11. Scattina A, Mo F, Masson C, Avalle M, Arnoux PJ. Analysis of the influence of passenger vehicles front-end design on pedestrian lower extremity injuries by means of the LLMS model. *Traffic Inj Prev*. 2018;19(5):535–541. https://doi.org/10.1080/15389588.2018.1432858
12. Yin S, Li J, Xu J. Exploring the mechanisms of vehicle front-end shape on pedestrian head injuries caused by ground impact. *Accid Anal Prev*. 2017;106:285–296. https://doi.org/10.1016/j.aap.2017.06.005
13. Chen H, Poulard D, Forman J, Crandall J, Panzer MB. Evaluation of geometrically personalized THUMS pedestrian model response against sedan-pedestrian PMHS impact test data. *Traffic Inj Prev*. 2018;19(5):542–548. https://doi.org/10.1080/15389588.2018.1450979
14. Environmental Protection Agency (EPA). *The 2019 EPA automotive trends report: greenhouse gas emissions, fuel economy, and technology since 1975*. Report No. EPA-420-S-20-001; 2020. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1013L1O.pdf
15. National Highway Traffic Safety Administration (NHTSA). *Relationship of vehicle weight to fatality and injury risk in model year 1985-93 passenger cars and light trucks*. United States Department of Transportation; 1997. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/808569
16. Martin JL, Lardy A, Laumon B. Pedestrian injury patterns according to car and casualty characteristics in France. *Ann Adv Automot Med*. 2011;55:137–146. PMID: 22105391; PMCID: PMC3256841.
17. Zhang G, Qin Q, Chen Z, Bai Z, Cao L. A study of the effect of the front-end styling of sport utility vehicles on pedestrian head injuries. *Appl Bionics Biomech*. 2018 Mar 20;2018:8502507. https://doi.org/10.1155/2018/8502507
18. Toran Pour A, Moridpour S, Tay R, Rajabifard A. Neighborhood influences on vehicle-pedestrian crash severity. *J Urban Health*. 2017;94(6):855–868. https://doi.org/10.1007/s11524-017-0200-z
19. Combs TS, Sandt LS, Clamann MP, McDonald NC. Automated vehicles and pedestrian safety: exploring the promise and limits of pedestrian detection. *Am J Prev Med*. 2019;56(1):1–7. https://doi.org/10.1016/j.amepre.2018.06.024
20. Lin, P., Guo, R., Bialkowska-Jelinska, E., et al. Development of countermeasures to effectively improve pedestrian safety in low-income areas. *J Traffic Transp Eng*. 2019:6(2):162–174. https://doi.org/10.1016/j.jtte.2019.02.001
21. Morris, N., Craig, C., van Houten, R. Effective interventions to reduce multiple-threat conflicts and improve pedestrian safety. *J Transp Res Board*. 2020:2674(5):149–159. https://doi.org/10.1177/0361198120914888
22. Choo S, Mokhtarian PL. What type of vehicle do people drive? The role of attitude and lifestyle in influencing vehicle type choice. *Transp Res Policy Prac*. 2004;38(3):201–222. https://doi.org/10.1016/j.tra.2003.10.005