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STATISTICAL ANALYSIS OF JAYWALKING CONFLICTS BY A LIDAR SENSOR

Summary. The light detection and ranging (Lidar) sensor is a remote sensing technology that can be used to monitor pedestrians who cross an intersection outside of a designated crosswalk or crossing area, which is a key safety application of lidar sensors at signalized intersections. Hereupon, the Lidar sensor was installed at the Hillen Rd - E 33rd St. intersection in Baltimore city to collect real-time jaywalkers' traffic data. In order to propose safety improvement considerations for the pedestrians as one of the most vulnerable road users, the paper aims to investigate the reasons for jaywalking and its potential risks for increasing the frequency and severity of vehicle-pedestrian conflicts. In a three-month time, interval from December 2022 to February 2023, a total of 585 jaywalkers were detected. By developing a generalized linear regression model and using K-means clustering, the highly correlated independent variables to the frequency of jaywalking were recognized, including the speed of jaywalkers, the average PET of vehicle-pedestrians, the frequency of vehicle-pedestrian conflicts, and the weather condition. The volume of vehicles and pedestrians and road infrastructure characteristics such as medians, building entrances, vegetation on medians, and bus/taxi stops were investigated, and the results showed that as the frequency of jaywalking increases, vehicle-pedestrian conflicts will occur more frequently and

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with greater severity. In addition, jaywalking speed increases the likelihood of severe vehicle-pedestrian conflicts. Also, during cloudy and rainy days, 397 pedestrians were motivated to jaywalk (or 68% of total jaywalkers), making weather a significant factor in the increase in jaywalking.

Keywords: lidar sensor, jaywalking, post encroachment time threshold (PET), vehicle-pedestrian conflicts, safety

1. INTRODUCTION

Jaywalking refers to crossing a street illegally by a pedestrian [1]. The act of jaywalking involves crossing the street outside of a crosswalk or a designated area. When a pedestrian crosses against a red light or does not yield to oncoming traffic, it may also be considered jaywalking. There is no doubt that jaywalking can be quite dangerous, though it might not seem like it at first. Nearly 5,000 pedestrians are killed each year in traffic accidents, according to the National Highway Traffic Safety Administration (NHTSA) [2]. According to NHTSA statistics, 6,516 pedestrians were killed and 55,000 were injured in traffic accidents in the United States in 2020 [2]. Furthermore, in 2020, the states of California (with 986 killed pedestrians and a 2.5 fatality rate per 100,000 population), Florida (with 696 killed pedestrians and a 3.2 fatality rate per 100,000 population), and Texas (with 686 killed pedestrians and a 2.34 pedestrian fatality rate per 100,000 population) have the highest number of pedestrians killed in traffic accidents. There are several reasons for the increase in pedestrian deaths due to vehicle-pedestrian collisions, some of which cannot be avoided, including an improving economy and lower gas prices, while others can be prevented, including distracted driving and driving while impaired.

Other states, like Georgia (279, 2.61), New York (231, 1.19), North Carolina (228, 2.15), and Arizona (222, 2.99), have a high killed pedestrians and fatality rate per 100,000 people [3]. The reasons behind the increase in fatalities are multifaceted. Controlling some of them is impossible or very difficult. As a result of lower gas prices and an improving economy, there are simply more vehicles on the roads, which raises the risk of pedestrian accidents. In addition, more people are moving to urban areas, where such accidents are more likely to occur. However, some causes are entirely preventable. There is a correlation between pedestrian deaths and smartphone adoption rates, while states that have legalized recreational marijuana have seen an increase in pedestrian deaths. It is also important to consider street design. In poorer neighborhoods, pedestrian accidents are much higher, largely because they lack the protective and walkable street infrastructure that more affluent neighborhoods have [4-6].

Jaywalking can increase the risk of being struck by a vehicle, even when pedestrians are not at fault. Pedestrians may cross outside of a crosswalk for a variety of reasons. In some cases, it may be due to the distance between the crosswalk and their destination. Crosswalks may not be visible to others, or they may not be aware that they are supposed to use one. It is also possible for people to simply be in a hurry and attempt to cross, which can lead to serious or even fatal injuries to pedestrians. It is important to know that jaywalking is illegal in most states in the U.S. It is important to note, however, that state laws governing jaywalking may vary. In some states, jaywalking tickets may only be issued if the pedestrian is causing a traffic hazard. Jaywalking in California can result in a $196 ticket. Other states, such as Florida, allow the pedestrians to cross outside of a crosswalk if they yield to oncoming traffic. In busy cities with a lot of pedestrian traffic, jaywalking laws are also more strictly enforced. In cities like New York or Los Angeles, jaywalking can create an immediate hazard for both pedestrians and motorists. To prevent car accidents and promote pedestrian safety, police may even conduct sting operations to catch people who are illegally crossing the street.

Jaywalking infractions are handed out by authorities as a means of reducing pedestrian accidents. Traffic congestion can also result from jaywalking. Pedestrians crossing outside of a crosswalk can cause drivers to suddenly brake or swerve around them. As a result, traffic can back up, and accidents can occur. As well as causing accidents, jaywalking can cause pedestrian injuries, jaywalking can result in deaths, jaywalking can clog up traffic, and jaywalking can be costly (by imposing fines on pedestrians). Jaywalking can be caused by a variety of reasons, including being in a hurry, being too far from the crosswalk, not seeing a car coming, being distracted by their phones and other devices to get around, or following someone else. A pedestrian may jaywalk if they are drunk, if they are not from the area (pedestrians who are visiting an area for the first time), or if pedestrians don't think jaywalking is a big deal [7-9].

Lidar technology, as an efficient and recent technology can be used to study jaywalking at signalized or unsignalized intersections. For the purpose of discovering anything new regarding pedestrian safety and considering that jaywalking in different weather conditions has not been studied with a Lidar sensor, this paper seeks to fill this gap with a safety analysis of jaywalking. Furthermore, this study was conducted to recognize the importance of independent variables in determining the frequency of jaywalking. Thus, this study tries to identify whether Lidar has provided any additional insight over previous non-Lidar-based studies.

Considering the significance of jaywalking, the reasons for jaywalking and people's behavior during jaywalking time intervals should be studied. The paper aims to investigate the reason(s) for jaywalking, the independent variables associated with increased jaywalking frequencies, and the relationship between jaywalking and vehicle-pedestrian conflicts. Hereupon, a Lidar sensor was used to record the longitudinal and lateral positions of jaywalking, the trajectory of jaywalking, and the conflicts between vehicles and pedestrians at the Hillen Rd – E 33rd street intersection in Baltimore city, USA. The state-of-the-art demonstrated that jaywalking has not been investigated by Lidar sensor. Hence, the purpose of this paper is to fill this gap by examining the frequency of jaywalking over a three-month period from December 2022 to February 2022 in different weather conditions. The remainder of this article is structured as follows: Section 2: Literature Review, Section 3: Research Methodology, Section 4: Data Analysis, Section 5: Statistical Analysis of Jaywalking, Section 6: Discussion, Section 7: Conclusion, and Section 8: References.

2. LITERATURE REVIEW

In urban networks, pedestrians walk along and cross streets. Pedestrians are bound to face conflict with motor vehicles once they cross streets. Pedestrian and cyclist traffic accidents have become a critical safety issue worldwide [10]. There are various crossing facilities designed to assist pedestrians in crossing safely, such as crosswalks (signalized and unsignalized), pedestrian overpasses, and pedestrian underpasses at intersections and midblock. Pedestrian crossing facilities separate pedestrians from motor vehicles, either temporally or spatially. Pedestrians' crossing behavior is strongly influenced by human factors. Therefore, pedestrians may cross illegally rather than using crossing facilities. As a result of subjectivity and randomness, pedestrian behavior is complicated, and traffic engineers must pay more attention to pedestrian traffic [11].

Different characteristics can affect a pedestrian's behavior when crossing intersections. Studies on behavior, psychology, safety, and simulation were included by some scholars. The effect of low-income pedestrians interactions with approaching vehicles at midblock road crossings was studied by Vinod et al. [12]. To account for different pedestrian crossing paths, they [12] developed a trajectory-based pedestrian modified post-encroachment time (PET) model. Tarawneh [13] studied pedestrian crossing speed in Jordan and evaluated the effects of age, gender, and distance (street width). In another study, Pasha et al. [8] analyzed the pedestrians' perception on using road crossing facilities in Dhaka. To examine pedestrian perceptions about the use of road crossings, a questionnaire survey was conducted, and the results highlighted that pedestrians are concerned about insufficient security when using pedestrian facilities. Sisiopiku and Akin [14] examined pedestrian behavior at various urban crosswalks near university campuses. Different pedestrian level-of-service assessment models were introduced under various traffic conditions, and standards were estimated for each level [15]. Urban forms and environmental designs easily influence pedestrian behavior [16]. It is possible to design facilities in a way that encourages walking without compromising safety or convenience [17]. Waiting time and crossing distance (distance between the destination and crossing point) are also external factors [9] that may lead to unsafe crossings, such as jaywalking. Most pedestrians fail to comply with pedestrian signals or crossing facilities because they are in a rush or want to keep moving along the shortcut. The scholars, e.g., Lambrianidou et al. [18] and Li [19] studied pedestrian behavior influenced by time and distance. Guo et al. [20] examined the waiting behavior at street crossings using the reliability theory. They found that jaywalking violations increased quantitatively with a longer waiting time. Hamidun et al. [21] concentrated on the surrounding factors that influenced the occurrence of jaywalkers especially the presence of median and vegetation on median. Yannis et al. [22] assessed pedestrian crossing behavior in relation to accident risk during a trip. Another study [23] investigated pedestrian decisions on multilane streets by using logit models based on vehicle speed and headway.

As specified in the state-of-the-art, the rate of injuries and fatalities among pedestrians in interaction with motorized vehicles can be increased by jaywalking, particularly in areas without adequate pedestrian crossings or pedestrian traffic signals [24, 25]. It is important to know where to cross a street and what facilities are available at each crossing. The purpose of crossing facilities is to ensure safety and facilitate accessibility. It is true, however, that some pedestrians dislike using crossing facilities and even cross the street illegally because they feel that the facilities do not meet their needs. As a result of suddenly entering the intersection area and a lack of visibility for pedestrians, jaywalking may increase pedestrian-vehicle collisions [26]. Pedestrians decide where and when to cross based on perception-judgment-decision-action. Hereupon, in order to investigate the potential risk of jaywalking in signalized intersections, this paper aims to analyze the frequency and severity of jaywalking potential risk by using Lidar technology as a precise data collection tool.

3. RESEARCH METHODOLOGY

3.1. Data collection with a lidar sensor

Surveillance, control, and management of road traffic all rely on effective sensing and detection technologies [27]. Among many commercially available infrastructure-based sensor technologies, inductive loop, microwave radar, and CCTV (video camera) are probably the most popular technologies that are applied for long- and short-term traffic detection. The main problem of all these technologies is their shortcoming to the inability to get trajectory-level data and their low performance in the accurate detection and tracking of pedestrians and vehicles. One important question among traffic engineers is whether and how future infrastructure-based detection systems should be developed in alignment with self-driving technology to make the roads and all road users a seamless and cooperative system. Pedestrians and bicyclists, as the most vulnerable road users, should be taken into account since the current vehicle-based sensing system lacks strategic real-time interaction with non-motorized road users. The presence of bicyclists or pedestrians may not be detected by car drivers due to distraction, malfunction, or system failure. To fill this gap, a real-time collaborative system is needed in the long run to entail vulnerable road users receiving situational awareness and taking evasive actions through infrastructure-mounted sensors. The Lidar sensors are efficient infrastructure-based detection systems that greatly help researchers and practitioners elevate their capabilities in improving highway safety and enhancing traffic operation and control, traffic management, and performance measurement. Lidar sensors with much more processing and computing power can enhance the accuracy of traffic analysis, and Lidar sensors can cover "illumination condition" issues [28] – providing valid information regardless of the weather condition or recording video at night. It is worth mentioning that data from Lidar sensors are cloud points (high accuracy but relatively lower density), work individually, and can cover a much wider detection range around the vehicle.

3.2.Lidar accuracy

In order to evaluate the accuracy of the Lidar sensor at the Hillen Road – E 33rd street intersection, the frequency of pedestrians collected by Lidar was compared to the manually counted pedestrians from the recorded closed-circuit television (CCTV) videos. As part of the manual counting method, several videos were captured from two CCTV cameras at the intersection on two working days (Monday and Tuesday) in December 2022 and January and February 2023. A comparison of Lidar accuracy with CCTV datasets is shown in Table 1. As shown in Table 1, pedestrian recognition accuracy by Lidar sensor is in an acceptable range with CCTV counting.

Tab. 1

The accuracy of lidar in comparison with CCTVs at the 33rd street intersection

Month	Date	Day	Frequency of the daily collected pedestrians flow by Lidar	Frequency of the manual counted pedestrians flow by CCTVs	Difference of Lidar from CCTV
December 2022	5	Monday	118	118	0
	6	Tuesday	123	125	-2
	12	Monday	126	124	2
	13	Tuesday	182	182	0
	19	Monday	122	122	0
	20	Tuesday	125	125	0
	26	Monday	90	93	-3
	27	Tuesday	114	112	2
January 2023	16	Monday	203	201	2
	17	Tuesday	178	178	0
	23	Monday	95	95	0

	24	Tuesday	269	267	2
February 2023	13	Monday	168	169	-1
	14	Tuesday	188	186	2
	20	Monday	219	216	3
	21	Tuesday	177	177	0

3.3. Jaywalker's data collection by a lidar sensor

The Lidar sensor was installed on the north-eastern side of the Hillen Rd – 33rd street intersection in Baltimore city, MD. As shown in Figure 1, Hillen Rd. is a secondary north-south road with 3 lanes in each direction, and the 33rd street is a primary east-west road with 2 lanes in each direction. The location of the Lidar sensor is shown as a red circle in Figure 1.

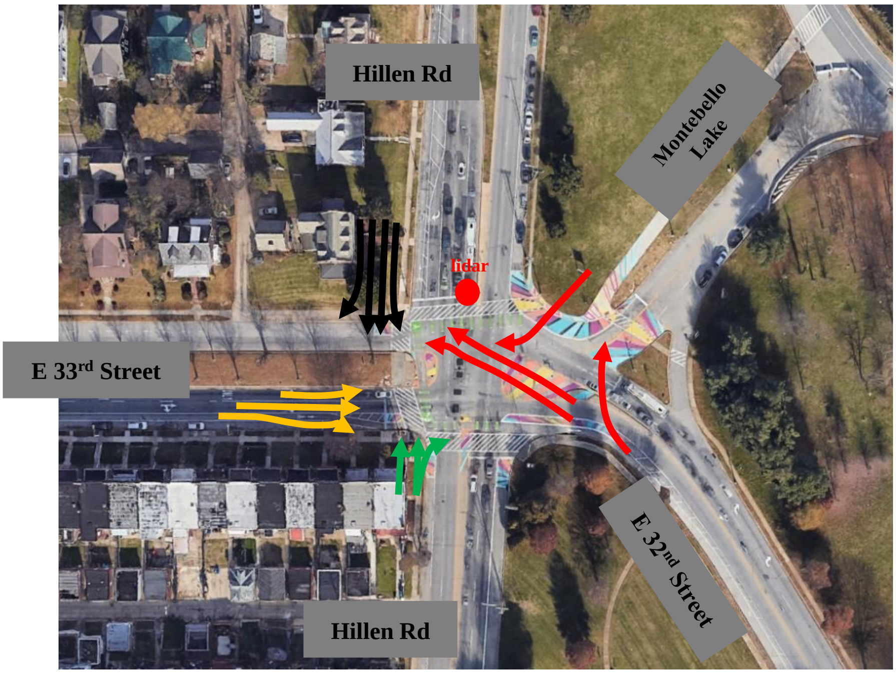

Fig. 1. Hillen Rd - E 33rd Street intersection

In order to analyze the frequency of jaywalking in different approaches to the intersection, the average speed changes, the average daily vehicle counts, the average number of passing pedestrians, and the frequency and severity of vehicle-pedestrian conflicts in different approaches to the intersection were collected. Lidar was used to identify the trajectory of jaywalking, including the geographical coordinates (X, Y) per second (99.4% precise) from the first moment Lidar recognized the jaywalkers to the last second, he/she left the intersection. For each approach, the sections outside of the cross-section were identified as potential jaywalking areas. Based on the exact longitudinal and lateral positions of the jaywalkers who do not pass from the crosswalk, the trajectory of each jaywalker was drawn. On different approaches to the intersection, Lidar can detect jaywalkers who pass the sections outside of the cross-section location. The time duration of jaywalking was collected by the Lidar sensor. Based on the distance and duration of jaywalking, the average speed of jaywalkers was calculated. During a 3-month time interval, the weather condition, daily speed of vehicles, vehicle and pedestrian counts, timing and phasing of the traffic signal and pedestrian signal, sight triangle, gradient of each approach and, frequency, and severity of vehicle-pedestrian conflicts were assessed. Furthermore, road infrastructure characteristics such as the presence of median, building entrance, side fence, vegetation on median and the presence of bus/taxi stops at each approach were also recorded during field observation. It is worth mentioning that SPSS software was used for statistical analysis.

4. DATA ANALYSIS

4.1.Vehicle and pedestrian counts

The average daily traffic and the average pedestrians counts per approach were investigated. The Lidar sensor captures vehicle counts (including car, bus, truck, trailer, and motorcycle types) and pedestrians counts in 15-minute time intervals. Figure 2 shows the average daily vehicle count (PCU/day) and Figure 3 shows the average daily pedestrian counts (people/day) over a 3-month period.

Figures 2 and 3 show the considerable vehicle and pedestrian counts on the northern approach (northern Hillen Rd) to the intersection.

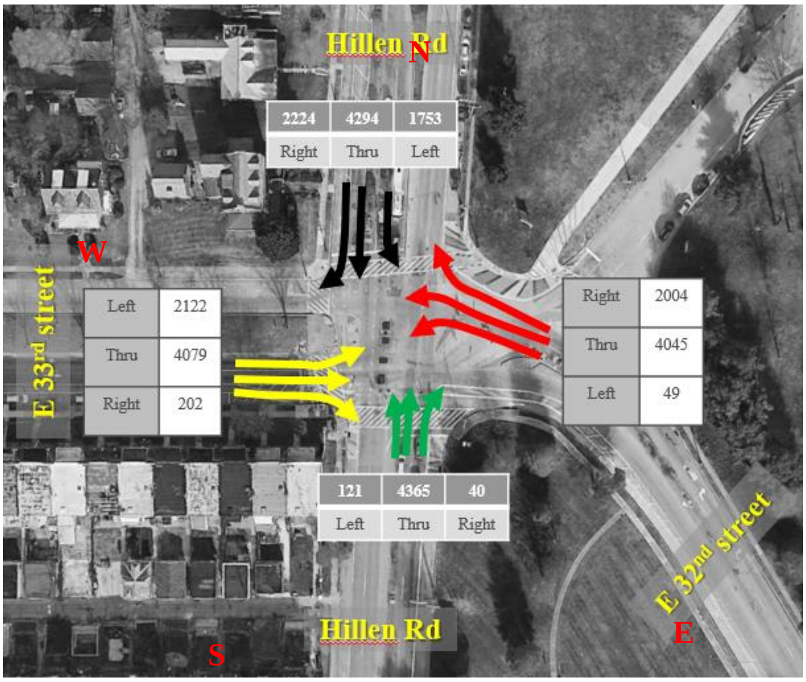

Fig. 2. ADT of vehicle counts

4.2. Speed changes

During a three-month period, the vehicle traffic speed at different approaches to the intersection was monitored. A graph of average daily speeds for directions "east-west & west-east" and "north-south & south-north" is shown in Figure 4.

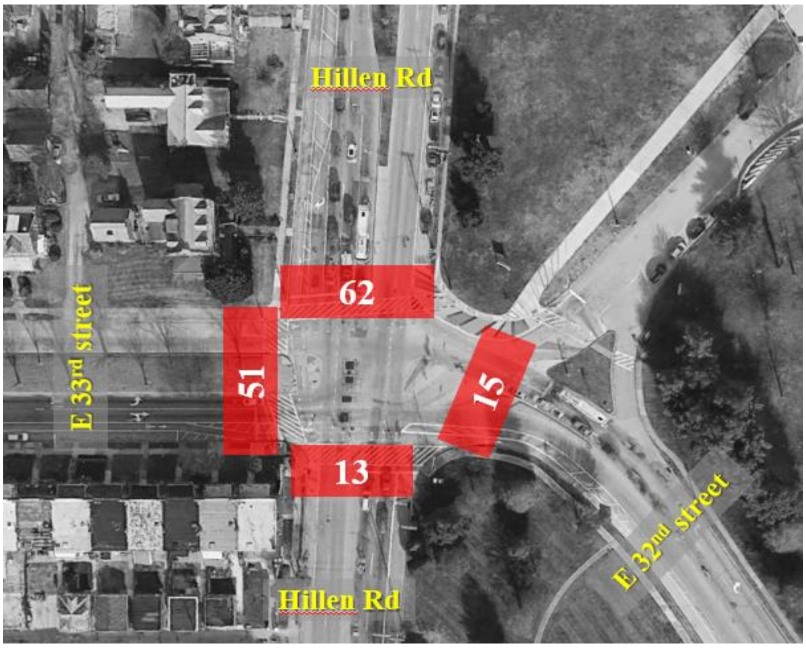

Fig. 3. ADT of pedestrians counts

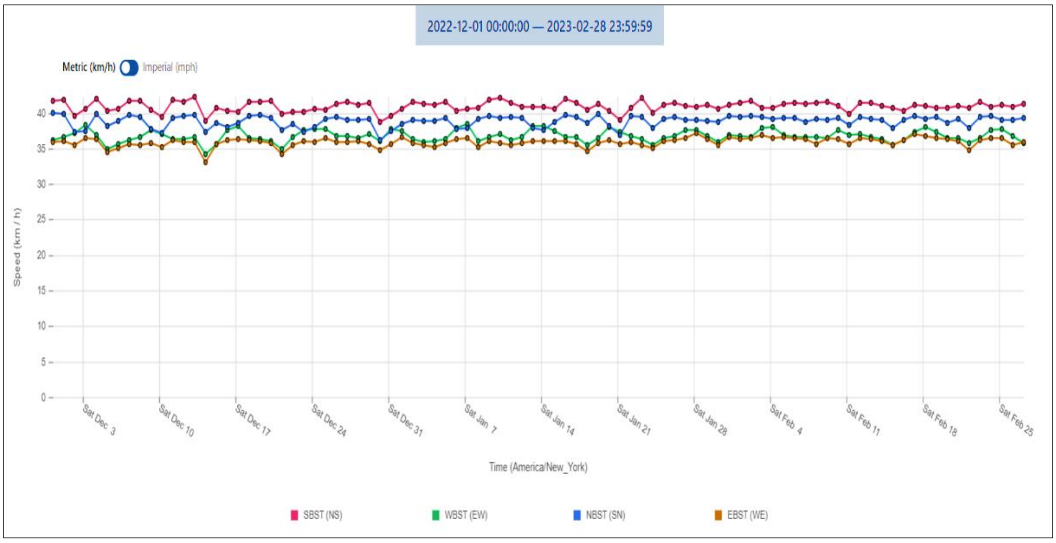

Fig. 4. Average daily speed graph

Figure 5 shows the box chart of vehicle speed changes in directions "east-west & west-east" and "north-south & south-north" to the intersection.

As can be seen in Figure 5, the average vehicle speed in the north-south direction was changed from 33 to 47 km/hour, in the south-north direction was changed from 34 to 43 km/hour, in the east-west direction was changed from 35 to 39 km/hour, and in the west-east direction was changed from 30 to 40 km/hour. Vehicle-pedestrian crashes are more likely to occur in the north-south and south-north directions due to the higher average daily speed.

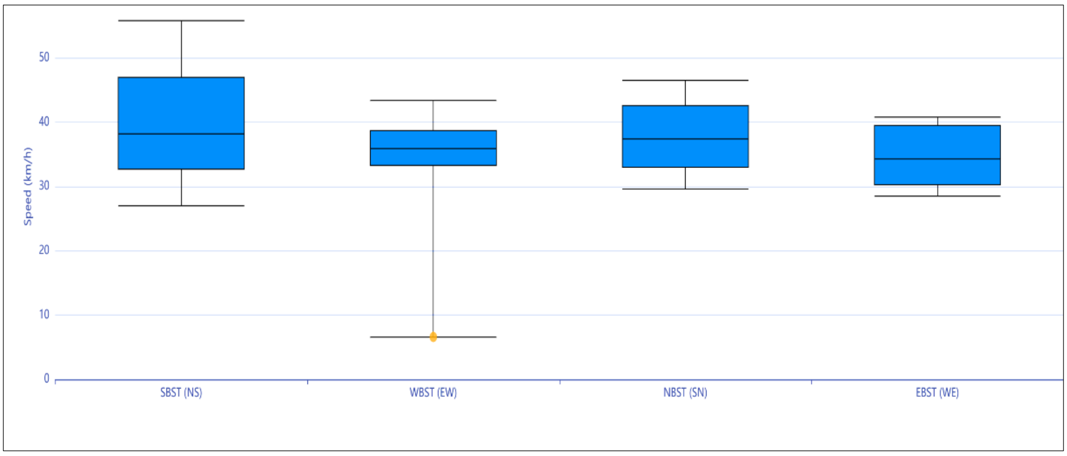

Fig. 5. The box chart of vehicle speed changes

4.3.The frequency and severity of vehicle-pedestrian conflicts

The Lidar sensor is capable of collecting hourly vehicle-pedestrian conflicts. Furthermore, the Lidar sensor's API collects the conflict's Post Encroachment Time (PET) values. PET is the difference between the end of encroachment by the first vehicle and the entry by the second vehicle into the conflict zone [29]. Non-zero PET values indicate crash proximity, while PET values of 0 indicate a crash. Lower PET values indicate a more severe crash, whereas higher PET values indicate a less severe crash. The Lidar sensor collected 3614 vehicle-pedestrian conflicts over three months. The frequency of vehicle-pedestrian conflicts is shown in Table 2. The severity of conflicts was calculated by $\frac{1}{\sum PET\ values}$. The higher the numerical value of a conflict's severity, the more serious conflict is [29].

Tab. 2

The frequency and severity of collected conflicts by the lidar sensor

Movement	Frequency of collected conflicts	Severity of conflicts (1/PET)	Percentage of Conflict's frequency (%)	Critical movement
EN	22	7.33	1%	
EW	428	176.37	12%	*
ES	858	353.17	24%	*
NW	4	1.85	0%	
NS	308	111.53	9%	
NE	21	8.06	1%	
WS	423	158.55	12%	
WE	281	106.33	8%	
WN	13	3.18	0%	
SE	474	175.38	13%	*
SN	315	122.49	9%	
SW	467	192.26	13%	*
SUM	**3614**	**1416.5**	**100**	

As shown in Table 2, movements ES (24%), SE (13%), SW (13%), EW (12%), WS (12%), SN (9%), NS (9%), and WE (8%) have a considerable frequency of vehicle-pedestrian conflicts. Considering the severity of conflicts, more severe conflicts were collected for ES, SW, EW, and SE movements. The critical movements were recognized based on the frequency and severity of conflicts. Movement becomes more critical as conflicts become more frequent and severe.

4.4. The frequency of jaywalking pedestrians collected by lidar sensor

Within a 60-meter radius (=197 ft.) from the location of the Lidar installation, a Lidar sensor can detect jaywalking pedestrians. Over a three-month period, 585 jaywalkers were collected. The Lidar sensor collected 572 jaywalking pedestrians in the northern approach, 12 jaywalking pedestrians in the western approach, and 1 jaywalking pedestrian in the eastern approach. Figure 6 shows the heat map of jaywalking pedestrians at each approach to the intersection.

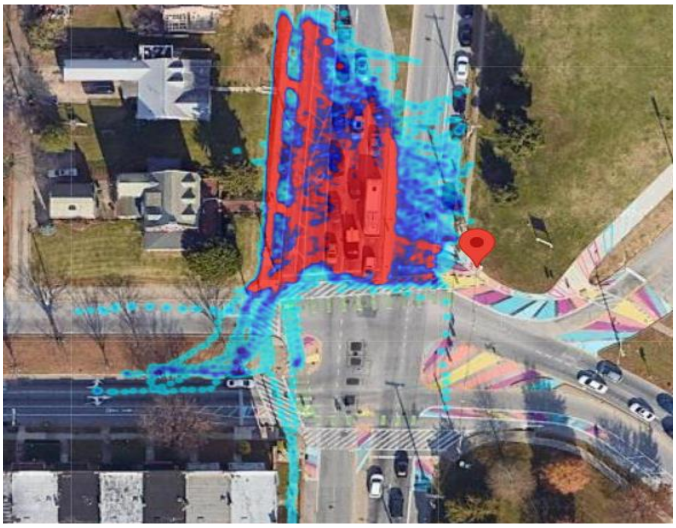

Fig. 6. The frequency of jaywalkers at different approaches to the intersection

The trajectory of jaywalking pedestrians was investigated. Figure 7 shows the trajectory of jaywalkers over a three-month time interval.

As shown in Figures 6 and 7, 98% of jaywalking pedestrians were recognized on the northern approach. As a total, 289, 172, and 124 jaywalking pedestrians were collected in December 2022, January 2023, and February 2023, respectively. Based on each pedestrian's trajectory and duration of jaywalking, the jaywalking average speed of each pedestrian was calculated. The collected results revealed an average speed of 2.82 mile/hour (=1.26 m/se) for jaywalking pedestrians in December, 2.99 mile/hour (=1.33 m/se) for pedestrians in January, and 3.02 mile/hour (=1.35 m/se) for pedestrians in February. Figure 8 shows the average speed of jaywalking pedestrians over a three-month time interval.

Fig. 7. The trajectory of jaywalkers

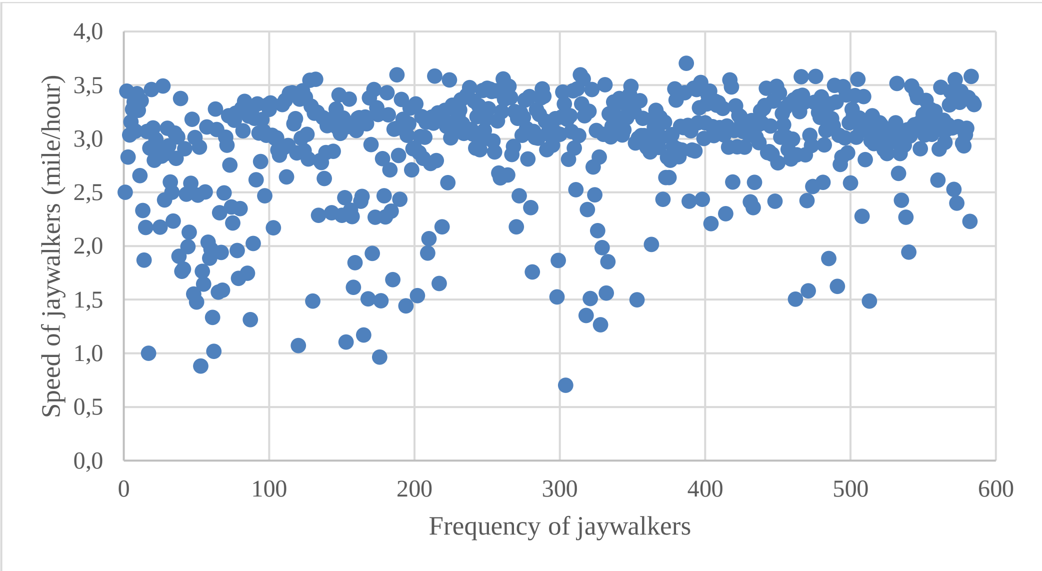

Fig. 8. Average speed of jaywalkers

5. STATISTICAL ANALYSIS OF JAYWALKING

The independent variables were specified in order to analyse the behaviour of jaywalking pedestrians over a 3-month period. The Lidar sensor collected 572 jaywalking pedestrians (=98% of total jaywalking pedestrians) in the northern approach. Hereupon, this paper examines the behaviour of jaywalkers on the northern approach by taking into account the flow of vehicles. Considering the date and time of occurrence (month/day/hour) of each jaywalking, the independent variables, including “the average speed of jaywalking (mile/hour),” “the duration of jaywalking (sec)”, “the performance of pedestrian traffic signals”, “average PET values for vehicle-pedestrian conflicts in northern approach in time intervals when jaywalking occurred”, “the frequency of vehicle-pedestrian conflicts in northern approach in time intervals when jaywalking occurred”, and “the weather conditions during jaywalking” were investigated.

The performance of the pedestrian traffic signal in the northern approach was monitored by two Closed Circuit Television (CCTVs). As a result of assigning pedestrians proper/improper green time for passing the northern approach, the motivation of pedestrians for doing jaywalking was investigated. As residential land uses are located eastbound of the intersection, Montebello Lake is located westbound, and the presence of a vast median with vegetation in the northern approach motivated most pedestrians not to cross the northern cross-section. As shown in Table 2, the Lidar sensor collected 333 vehicle-pedestrian conflicts in the northern approach (NE, NS, and NW). Table 3 shows the overall findings of jaywalking in the northern approach.

Tab. 3

The findings of jaywalking in northern approach

Weather	Frequency of Jaywalking	Frequency of Vehicle-pedestrian conflicts	Average PET	Average duration of jaywalking (se)	Average speed of jaywalking (mile/hour)
Cloudy	337	172	3.1	10.06	2.88
Sunny	184	124	2.9	9.42	2.96
Rainy	60	34	3.3	9.62	2.93
Snowy	4	3	2.1	6.57	2.90

As shown in Table 3, the frequency of jaywalking and vehicle-pedestrian conflicts increases in cloudy weather. The severity of conflicts is higher in sunny weather than in cloudy weather, and the highest severity of conflicts may be seen in snowy weather. During rainy days, conflicts were less severe than during cloudy or sunny days. On snowy days, pedestrians prefer not to jaywalk. The highest severity of conflicts (PET=2.1) was collected on snowy days; however, jaywalker speed was less than the speed on sunny and rainy days.

In order to specify the highly correlated independent variable(s) with the frequency of jaywalking, Pearson correlation test [30, 31] and k-means clustering [32] were used. K-means clustering is a method to divide the whole set of objects into a predefined number (k) of clusters, and the criteria for such subdivision are normally the minimal dispersion inside clusters (minimizing Euclidean distances between them) [33]. Table 4 shows the significant correlations between the frequency of jaywalking and independent variables.

Tab. 4

Pearson correlation test results

Correlations

		Frequency of jaywalking	Average speed of jaywalking pedestrians	Duration of jaywalking	Average PET	Frequency of vehicle-pedestrian conflicts	Weather condition
Frequency of jaywalking	Pearson correlation	1	.244**	-.217**	.250**	-.542**	.291**
	Sig.		0.000	0.000	0.000	0.000	0.000

	(2-tailed)						
Average speed of jaywalking pedestrians	Pearson correlation	.244**	1	-.821**	.089*	-.218**	0.051
	Sig. (2-tailed)	0.000		0.000	0.032	0.000	0.214
Duration of jaywalking	Pearson correlation	-.217**	-.821**	1	-0.069	.185**	-0.063
	Sig. (2-tailed)	0.000	0.000		0.096	0.000	0.126
Average PET	Pearson correlation	.250**	.089*	-0.069	1	.144**	0.014
	Sig. (2-tailed)	0.000	0.032	0.096		0.000	0.743
Frequency of vehicle-pedestrian conflicts	Pearson correlation	-.542**	-.218**	.185**	.144**	1	-.274**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000
Weather condition	Pearson correlation	.291**	0.051	-0.063	0.014	-.274**	1
	Sig. (2-tailed)	0.000	0.214	0.126	0.743	0.000	

**The correlation is significant at the 0.01 level (2-tailed).
* The correlation is significant at the 0.05 level (2-tailed).

As can be seen in Table 4, jaywalking frequency is positively correlated with average speed, average PET of vehicle-pedestrian conflicts, and weather conditions. In addition, it negatively correlates with the duration of jaywalking and the frequency of vehicle-pedestrian conflicts. Based on the significant error of independent variables (=.000), it is evident that independent variables are highly accurate. The K-means clustering results revealed that after 16 iterations and categorizing the independent variables into 5 clusters (which is the optimal valid number of clusters) including cluster #1 with 83 records, cluster #2 with 14 records, cluster #3 with 39 records, cluster #4 with 366 records, and cluster #5 with 83 records, all of the independent variables had a significant error of less than 5% confidence interval. Table 5 shows the ANOVA results of k-means clustering for five optimum clusters.

The K-means clustering results demonstrated that there is a significant relationship between the frequency of jaywalking and the average speed of jaywalkers, duration of jaywalking, average PET, frequency of vehicle-pedestrian conflicts, and weather conditions. In order to specify the statistical relationship between dependent and independent variables, a generalized linear regression model was developed. As shown in Table 6, Wald Chi-Square values confirmed that a set of independent variables is collectively significant for the model.

Tab. 5

K-means clustering for frequency of jaywalking

ANOVA						
	Cluster		Error		F	Sig.
	Mean square	df	Mean square	df		
Average speed of jaywalking pedestrians	27.929	4	.101	580	276.143	.000
Duration of jaywalking	2585.775	4	5.720	580	452.050	.000
Average PET	2.154	4	.788	580	2.732	.028
Frequency of vehicle-pedestrian conflicts	6481.453	4	6.047	580	1071.900	.000
Weather condition	8.455	4	.437	580	19.341	.000

Tab. 6

The result of the generalized linear regression model

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
Intercept	31.242	1	.000
Average speed of jaywalking pedestrians	282.019	137	.000
Duration of jaywalking	204.707	110	.000
Average PET	29.200	1	.000
Frequency of vehicle-pedestrian conflicts	420.989	12	.000
Weather condition	8.615	1	.003

The “duration of jaywalking” is negatively significant with the frequency of jaywalking as shown in Table 4. Although the duration of jaywalking may be significant with the frequency of jaywalking based on Tables 5 and 6, it might increase the significant error of a generalized linear regression model by more than 5% (=0.054). Two models were developed, and it was found that the significant error of the model increases when the duration of jaywalking is included. Hereupon, the best model was developed by excluding this variable. Table 7 and Equation 1 show the developed model by including “duration of jaywalking” independent variable.

Tab. 7

ANOVA table by including the duration of jaywalking
Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Generalized linear regression model	Constant	103.872	70.550		1.472	.014
	Average speed of jaywalking pedestrians	19.876	17.402	.064	1.142	.025
	Average PET	59.779	6.063	.316	9.860	.000
	Frequency of vehicle-pedestrian conflicts	12.618	.808	.530	15.613	.000
	Weather condition	32.724	7.885	.136	4.150	.000
	Duration of jaywalking	-1.257	1.924	-.036	-.653	.054

*Frequency of jaywalking = 103.872 + 19.876 * Average speed of jaywalker + 59.779 * Average PET + 12.618 * Frequency of vehicle-pedestrian conflicts + 32.724 * weather condition – 1.257 * duration of jaywalking* (1)

Table 8 and Equation 2 show the developed model by excluding “duration of jaywalking” independent variable.

Tab. 8

ANOVA table by excluding the duration of jaywalking
Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Generalized **Linear Regression**	Constant	64.486	36.612		1.761	.029
	Average speed of jaywalking Pedestrians	29.110	10.144	.093	2.870	.004
	Average PET	59.750	6.060	.316	9.860	.000
	Frequency of vehicle-pedestrian conflicts	12.62	.808	.530	15.621	.000
	Weather condition	32.907	7.876	.137	4.178	.000

*Frequency of jaywalking = 64.486 + 29.110 * Average speed of jaywalker + 59.750 * Average PET + 12.62 * Frequency of vehicle-pedestrian conflicts + 32.907 * weather condition* (2)

6. DISCUSSION

As shown in Tables 4, 5, and 6, in the northern approach to the intersection, the average speed of jaywalking, the average duration of jaywalking, the average PET of vehicle-pedestrian conflicts, the frequency of vehicle-pedestrian conflicts, and the weather condition correlated with jaywalking frequency. In addition, as the frequency of jaywalking increases, vehicle-pedestrian conflicts will occur more frequently and with greater severity. In addition, jaywalking speed increases the likelihood of severe vehicle-pedestrian conflicts. Table 7 demonstrated that the duration of jaywalking may increase the significant error of the model (=0.054). Table 8 with higher accuracy specifies that the speed of jaywalking, average PET, the frequency of vehicle-pedestrian conflicts, and the weather condition can increase the frequency of jaywalking. It is directly associated with an increase in the frequency of jaywalkers, as well as an increase in the probability of vehicle-pedestrian conflicts. Additionally, the effect of weather on the frequency of jaywalking is greater than the effect of speed.

This paper specified that a significant percentage of jaywalking occurred on the northern approach due to the lack of cross-section visibility, the shorter distance from residential land uses to recreational land uses such as Montebello Lake, and the presence of a vast median with vegetation that motivates pedestrians to jaywalk. Additionally, the paper concentrated on surrogate safety measures such as vehicle-pedestrian PETs, the speed of jaywalkers, and the effect of weather that had not been investigated simultaneously in the state-of-the-art. In order to decrease the frequency of jaywalking at the Hillen Rd – E 33rd street intersection, the following suggestions are proposed:

- Making pedestrian cross-sections more visible through visible markings.
- Changing the timing and phasing of pedestrian traffic signals in the northern approach.
- Making jaywalking fines. However, the jaywalking laws are not flexible enough to accommodate a wide range of scenarios pedestrians face, such as prolonged signal timing and delays that prioritize automobiles.
- Improve pedestrian crossing safety by installing pedestrian signs.

Before-and-after studies and daily monitoring of jaywalking frequency are necessary to investigate these suggestions. Pedestrian safety at the Hillen Rd - E 33rd street can be improved with these suggestions, according to the author's opinion.

7. CONCLUSION

As a result of jaywalking, there are many risks involved, including injury, death, and traffic congestion. Crossing the street requires pedestrians to keep an eye on their surroundings and obey the law. Pedestrians should always use crosswalks when crossing the street and look both ways before crossing. It may seem harmless, but jaywalking can pose quite a threat to pedestrians when interacting with motorized vehicles. Human factors and traffic circumstances strongly influence pedestrian crossing behavior. Perception-judgment-decision-action is how pedestrians decide where and when to cross. There are a number of factors that influence a crossing decision (e.g., origin and destination, complexity and length of the route), infrastructure (e.g., types of pedestrian facilities, road geometry, and traffic conditions), and individual characteristics (e.g., age and gender, and safety awareness). The behavior of crossing appears to be subject to a significant amount of subjectivity and randomness, in accordance with human nature. Thus, pedestrian crossing behavior may become risk-taking and result in conflicts with motor vehicles. According to the utility maximization theory, pedestrians want to choose the best facilities and crossing points to cross the street. In this way, pedestrians are able to maximize their utility. A pedestrian's most satisfactory decision will depend on the type and location of the crossing facility. Hereupon, the behavior of pedestrians may be changed case by case to include jaywalking. In order to study the behavior of jaywalkers in a signalized intersection, the Lidar sensor, as a recent and efficient technology, was installed at the Hillen Rd – E 33rd street intersection in Baltimore city. Lidar sensors have become one of the most innovative technologies available in recent years, allowing users to interact with and analyze traffic data in stunning detail. By improving the extent of the data obtained by Lidar technology, existing problems related to data collection in bad weather conditions, limited access routes, and restricted routes can be resolved. The installed Lidar sensor's API at the Hillen Rd – E 33rd street intersection is capable of collecting real-time vehicle-pedestrian conflicts and the frequency of jaywalking. The frequency of jaywalkers over a three-month time interval was investigated to specify the relationship of various independent variables to the frequency of jaywalking. The Lidar results demonstrated 585 jaywalks, and in the northern approach to the intersection, nearly 98% of total jaywalking occurred. The origin-destination of jaywalkers and the geographical positions of jaywalkers per second were analyzed. The average speed of jaywalkers and the duration of jaywalking were obtained. Additionally, the frequency and severity of vehicle-pedestrian conflicts in the northern approach were analyzed. Post-encroachment time (PETs) as one of the crucial Surrogate safety measures (SSM) were collected by the Lidar sensor for each vehicle-pedestrian conflict. In different weather conditions, the frequency and severity of jaywalking and the probability of vehicle-pedestrian conflicts were analyzed. The statistical analysis demonstrated that the frequency of jaywalking and vehicle-pedestrian conflicts increases in cloudy weather. The severity of conflicts is higher in sunny weather than in cloudy weather, and the highest severity of conflicts may be seen in snowy weather. During rainy days, conflicts were less severe than during cloudy or sunny days. On snowy days, pedestrians prefer not to jaywalk. The highest severity of conflicts (PET=2.1) was collected on snowy days; however, jaywalker speed was less than the speed on sunny and rainy days.

The Pearson correlation test and k-means clustering method were used to specify the highly correlated independent variables related to the frequency of jaywalking. The independent variables, e.g., the average speed of jaywalking, the average PET of vehicle-pedestrian conflicts, the frequency of vehicle-pedestrian conflicts, and the weather conditions, correlated strongly with jaywalking frequency. Furthermore, a generalized linear regression model was developed to demonstrate the statistical relationship between dependent and independent variables. As shown in Equations 1 and 2, as the frequency of jaywalking increases, vehicle-pedestrian conflicts will occur more frequently and with greater severity. In addition, jaywalking speed increases the likelihood of severe vehicle-pedestrian conflicts. Also, jaywalking is affected by the weather to a considerable extent, since the weather motivates the jaywalkers to cross illegally.

The main limitation of the study is worth mentioning, within a limited time interval of 3 months. Due to privacy concerns, the gender and age of jaywalkers were not investigated. The Lidar sensor can collect a short video from the jaywalkers which, was not possible for the authors to analyze due to privacy considerations. Future work includes developing machine-learning models for the combination of vehicle-pedestrian conflicts and jaywalking.

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Disclosure of information and conflicts of interest
The authors declare that they have no conflict of interest.

References

1. Norton P.D. 2007. „Street rivals: Jaywalking and the invention of the motor age street”. *Technology and culture* 48(2): 331-359. DOI: 10.1353/tech.2007.0085.
2. NHTSA. *Pedestrian Safety*. 2021. Available at: https://www.nhtsa.gov/road-safety/pedestrian-safety#:~:text=Unfortunately%2C%20pedestrian%20injuries%20and%20fatalities,tips%20to%20keep%20pedestrians%20safe.
3. NHTSA. *Statistics of killed pedestrian in traffic accidents in the U.S*. 2021. Available at: https://www-fars.nhtsa.dot.gov/states/statespedestrians.aspx.
4. Tyndall J. 2021. „Pedestrian deaths and large vehicles”. *Economics of Transportation* 26: 100219. DOI: 10.1016/j.ecotra.2021.100219.
5. Thomas M., T. Williams, J. Jones. 2020. „The epidemiology of pedestrian fatalities and substance use in Georgia, United States, 2007-2016”. *Accident Analysis & Prevention* 134: 105329. DOI: 10.1016/j.aap.2019.105329.
6. Eluru N., C.R. Bhat, D.A. Hensher. 2008. „A mixed generalized ordered response model for examining pedestrian and bicyclist injury severity level in traffic crashes”. *Accident Analysis & Prevention* 40(3): 1033-1054. DOI: 10.1016/j.aap.2007.11.010.
7. Guo H., F. Zhao, W. Wang, Y. Zhou, Y. Zhang, G. Wets. 2014. „Modeling the perceptions and preferences of pedestrians on crossing facilities”. *Discrete dynamics in nature and society* 2014(1502):1-8. DOI: 10.1155/2014/949475.
8. Pasha M.M., S.M. Rifaat, A. Hasnat, I. Rahman. 2015. „Pedestrian Behaviour on Road Crossing Facilities”. *Jurnal Teknologi* 73(4). Special Issue on Highway and Transportation Engineering Part 2. DOI: 10.11113/jt.v73.4292.
9. TSS. *What Is Jaywalking and Is It Really Illegal? – A Look at the Infamous Traffic Violation*. 2022. Available from: https://www.trafficsafetystore.com/blog/what-is-jaywalking-and-is-it-really-illegal/.
10. Mei H., Y. Xiaobao, J. Bin. 2013. „Crossing reliability of electric bike riders at urban intersections”. *Mathematical problems in engineering* 2013: 108636. DOI: 10.1155/2013/108636.
11. Mullen B., C. Copper, J.E. Driskell. 1990. „Jaywalking as a Function of Model Behavior”. *Personality and Social Psychology Bulletin* 16(2): 320-330. DOI: 10.1177/0146167290162012.
12. Vasudevan V., R. Agarwala, A. Tiwari. 2022. „Lidar-Based Vehicle-Pedestrian Interaction Study on Midblock Crossing Using Trajectory-Based Modified Post-Encroachment Time”. *Transportation Research Record* 2676(7): 837-847. DOI: 10.1177/03611981221083295.

13. Tarawneh M.S. 2001. „Evaluation of pedestrian speed in Jordan with investigation of some contributing factors". *Journal of safety research* 32(2): 229-236. DOI: 10.1016/S0022-4375(01)00046-9.
14. Sisiopiku V.P., D. Akin. 2003. „Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data". *Transportation Research Part F: Traffic Psychology and Behaviour* 6(4): 249-274. DOI: 10.1016/j.trf.2003.06.001.
15. Sarkar S. 1995. „Evaluation of safety for pedestrians at macro-and microlevels in urban areas". *Transportation Research Record* 1502: 105-118.
16. Elvik R., M.W. Sørensen, T.O. Nævestad. 2013. „Factors influencing safety in a sample of marked pedestrian crossings selected for safety inspections in the city of Oslo". *Accident Analysis & Prevention* 59: 64-70. DOI: 10.1016/j.aap.2013.05.011.
17. Shriver K. 1997. „Influence of environmental design on pedestrian travel behavior in four Austin neighborhoods". *Transportation Research Record* 1578(1): 64-75. DOI: 10.3141/1578-09.
18. Lambrianidou P., S. Basbas, I. Politis. 2013. „Can pedestrians' crossing countdown signal timers promote green and safe mobility?". *Sustainable Cities and Society* 6: 33-39. DOI:10.1016/j.scs.2012.07.005.
19. Li B. 2013. „A model of pedestrians' intended waiting times for street crossings at signalized intersections". *Transportation research part B: methodological* 51(C): 17-28. DOI: 10.1016/j.trb.2013.02.002.
20. Guo H., W. Wang, W. Guo, X. Jiang, H. Bubb. 2012. „Reliability analysis of pedestrian safety crossing in urban traffic environment". *Safety Science* 50(4): 968-973. DOI: 10.1016/j.ssci.2011.12.027.
21. Hamidun R., A. Shabadin, A. Roslan, R. Sarani, N.M. Johari. 2021. „Analysis of Pedestrians' Jaywalking at the Signalized Midblock in Kuala Lumpur, Malaysia". *International journal of road safety* 2(1): 54-61.
22. Yannis G., J. Golias, E. Papadimitriou. 2007. „Modeling crossing behavior and accident risk of pedestrians". *Journal of Transportation Engineering* 133(11): 634-644. DOI: 10.1061/(ASCE)0733-947X(2007)133:11(634).
23. Nassiri H., Y. Sajed. 2009. „Using a Logit Model to Predict Pedestrian Crossing Behavior Based Upon Vehicle Speed and Headway on Multi-lane Street". *Transportation Research Board 88th Annual Meeting* 09-3793. Available at: https://trid.trb.org/view/882465.
24. Museus S.D., J.J. Park. 2015. „The continuing significance of racism in the lives of Asian American college students". *Journal of College Student Development* 56(6): 551-569. DOI: 10.1353/csd.2015.0059.
25. Li D., Y. Li, X. Yuan. 2014. „Effect of situational factors on pedestrian intention to jaywalk". *17th International IEEE Conference on Intelligent Transportation Systems (ITSC). IEEE*. DOI: 10.1109/ITSC.2014.6957949.
26. González-Gómez K., M. Castro. 2019. „Evaluating Pedestrians' Safety on Urban Intersections: A Visibility Analysis". *Sustainability* 11(23): 6630. DOI: 10.3390/su11236630.
27. Zhao J., H. Xu, H. Liu, J. Wu, Y. Zheng, D. Wu. 2019. „Detection and tracking of pedestrians and vehicles using roadside Lidar sensors". *Transportation Research Part C: Emerging Technologies* 100: 68-87. DOI: 10.1016/j.trc.2019.01.007.

28. Mukhtar A., L. Xia, T.B. Tang. 2015. „Vehicle detection techniques for collision avoidance systems: A review”. *IEEE transactions on intelligent transportation systems* 16(5): 2318-2338. DOI: 10.1109/TITS.2015.2409109.
29. Ansariyar A., A. Taherpour. 2023. „Statistical Analysis of Vehicle-Vehicle Conflicts with a lidar Sensor in a Signalized Intersection”. *Advances in Transportation Studies* 60: 87-106.
30. Sedgwick P. 2012. „Pearson’s correlation coefficient”. *BMJ Clinical Research* 345(jul04 1):e4483-e4483. DOI: 10.1136/bmj.e4483.
31. Ansariyar A., S. Laaly. 2022. „Statistical Analysis of Connected and Autonomous Vehicles (CAVs) Effects on the Environment in Terms of Pollutants and Fuel Consumption”. *International Conference on Frontiers of Artificial Intelligence and Machine Learning (FAIML) IEEE*: 151-156, DOI: 10.1109/FAIML57028.2022.00037.
32. Hamerly G., C. Elkan. 2003. „Learning the k in k-means”. *Advances in neural information processing systems* 16 (NIPS 2003). Available at: https://proceedings.neurips.cc/paper_files/paper/2003/file/234833147b97bb6aed53a8f4f1c7a7d8-Paper.pdf.
33. Everitt B., S. Landau, M. Leese, D. Stahl. 2011. *Cluster analysis*. Wiley. Chichester, UK. ISBN: 978-0-470-74991-3. Available at: https://www.wiley.com/en-us/Cluster+Analysis%2C+5th+Edition-p-9780470749913.

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