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COMPARISON OF ESTIMATED YIELDING RATE AND PROBABILITY OF YIELDING RATE AT UNSIGNALIZED PEDESTRIAN CROSSINGS

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At present, the introduction of environmentally friendly modes of transport is the focus of several countries to solve urban traffic and environmental problems. The sustainability of transport is becoming a global objective, especially with the recent strong increase in urban population and travel activity. Transport is one of the main contributors to environmental pollution. Walking is one of the most sustainable modes of transport for short distances, but the increase in pedestrian casualties is a cause for concern. When approaching the uncontrolled crosswalk, drivers naturally slow down and drive carefully to avoid collisions. Therefore, the number of pedestrians at the crosswalk has a direct impact on the capacity of the roadway to delay vehicles on a given stretch of road. The aim of the present study is to investigate the interaction between drivers and pedestrians in order to know how much pedestrians influence the flow of vehicles, which can affect the capacity of the road. The Hungarian city of Sopron, a city with a population of approximately 62,000 (2023) close to Hungary’s western border with Austria, was chosen as the study area. The study also aims to evaluate how pedestrians and drivers behave at the studied locations. To predict the yielding rate of drivers seeing pedestrians crossing the road, logistic regression was used. The results of the multiple linear regression calculation show that the independent and dependent variables have a correlation of 91 %. The p-value of each parameter is greater than 0.05, which means that it is not statistically significant. However, this does not mean that the results cannot be used, as there is still a probability that the return will be close to the initial return. The smallest p-value for the variable length equal to road width is the main factor that causes drivers to slow down and give priority to pedestrians. As a result, the p-value of each parameter is more significant than 0.05, which means that no effect was observed at the locations studied. It is necessary to observe more locations with different road environments, geometries, traffic volumes, and road categories. The impact of pedestrian crossing flows on road capacity in the presence of autonomous vehicles needs to be investigated in further research, as well as how pedestrians will react to automated vehicles and whether this would affect their behaviour.

1. Introduction

To solve urban traffic and environmental problems, several countries are currently focusing on the introduction of cleaner modes of transport (Ku et al., 2021). Transport sustainability is becoming a global objective, especially with the recent strong growth in urban population and travel activity. The transport sector is one of the main contributors to environmental pollution (Bencekri et al., 2021). Walking is one of the most sustainable ways to travel short distances, but pedestrians are fast becoming one of the largest groups of road casualties, which is a major concern. Despite this, road travel has become much safer for most road users over the decades, largely due to improvements made by car manufacturers to protect vehicle occupants.

In order to better understand pedestrian casualties, it is necessary to study the interaction between the driver and the pedestrian, which is influenced by the characteristics of the road layout.

The cross-sectional design is an essential characteristic of road categories and is a major factor affecting the capacity of road sections and influencing the effective speed of vehicles (Boroujerdian et al., 2016). Sufficient capacity is achieved by the number of lanes, while speed depends on the traffic volume itself, the road alignment and the lane widths (Montella et al., 2010). Clear information about the visibility of the pedestrian while crossing can positively influence the driver to reduce speed before entering the pedestrian crossing (Bella and Silvestri, 2016). Another factor for pedestrians to cross the road or the vehicle to brake for the pedestrian is vegetation and concrete barriers, which can hide the visibility of cars and pedestrians (Sisiopiku and Akin, 2003). In addition, some researchers have studied the safety of pedestrian crossings based on gender, age, education, purpose of travel and frequency of crossing, and it can be distinguished that female pedestrians crossing or crossing in a group feel safer than male pedestrians crossing individually (Parmar et al., 2019). Therefore, it is important to consider many aspects of traffic engineering.

The aim of this study is to investigate the interaction between drivers and pedestrians at the unsignalised crosswalks by conducting a field survey at the selected sites to analyse the yielding rate of drivers in the city of Sopron, Hungary. The estimated yielding rate of all eight pedestrian crossings was used to perform the probability (logistic regression) of drivers' yield or not to yield by calculating the yielding rate and other road and pedestrian factors. Among other things, a driver's travel time on a given road segment is a consequence of the delay due to stopping and waiting at pedestrian crossings. For this reason, the study of drivers' yielding behaviour was the focus of this research period.

Thus, this paper is organised as a general investigation of driver-pedestrian interaction at the uncontrolled crossing, then explores the methodology of site surveys to assess the outcome of driver yielding at each location. The probability of yielding is then compared with the initial yielding rate, which is calculated as the number of drivers yielding to pedestrians divided by the number of all interactions in the selected areas.

2. Vehicle and pedestrian at unsignalized pedestrian crossings

Driving behaviour is an important factor in traffic flow (Takahashi et al., 2005). The characteristics of pedestrians and vehicles are similar in terms of traffic flow, but the difference is the movement and speed, the pedestrian manoeuvre can move freely or change the desired direction of travel (Iryo-Asano et al., 2017).

Safe interaction between pedestrians and drivers should be promoted, as vehicle-pedestrian conflict can increase the likelihood of accidents due to the lack of proper crosswalks (Andre et al., 2019). The pedestrian crossing should be located and marked at the safest point for the pedestrian to cross (Antov et al., 2007). The safety of the pedestrian crossing without collision at any location is the high rate of vehicle yielding while approaching the pedestrian crossing. A driver is influenced before approaching the crosswalk within the decision zone at 50 m to 40 m (Varhelyi, 1998). In order to increase the yielding rate from the driver, some authors have developed a logit model to validate and analyse the vehicle yielding behaviour (Malenje et al., 2019). A logistic regression model was applied to impose the influential probability factors of driver deceleration from the recorded information at two unsignalized crosswalks, the existing one- and two-way streets, to implement the case studies of pedestrian-vehicle interaction (PVI) (Amado et al., 2020).

Furthermore, autonomous vehicles can reduce pedestrian fatalities (Combs et al., 2019). However, some studies have found that pedestrians' crossing experience is affected by distracted driver behaviour in conditionally autonomous vehicles, where pedestrians feel safer crossing the road when they have eye contact with the driver (Su, 2014). Pedestrians prefer to evaluate the available gap in all directions of the roadway in relation to the traffic volume in the lane to cross the road without any interaction with the driver (Dhamaniya et al., 2014). Moreover, different pedestrians react differently when encountering an automated vehicle due to the personal attitude of each pedestrian, which cannot guarantee the avoidance of accidents between pedestrians and autonomous vehicles (Razmi Rad et al., 2020). Therefore, the correlation between pedestrians and cars is imperative to be studied for the future of the upcoming autonomous vehicles.

3. Data Collection

Pedestrian crossings can be evaluated by two types of studies: a field study using video cameras and a survey of pedestrian preferences using questionnaires (Vissers et al., 2016). In this study, the field study method was used to analyse the yielding rate of drivers' influence on pedestrians while crossing. Eight unsignalised pedestrian crossings (two lanes and two directions) in the city of Sopron were selected (Table 1). At each location, a video recording is made, focusing on both directions of the road and the crosswalk during an average weather working day. The observation was carried out by video recording during the peak hours of the weekdays. The video recording tools were mobile phones (Nokia 5.3 and iPhone 6S) and selfie sticks mounted on a tripod.

The sites were selected based on the volume of pedestrian and vehicle traffic, the speed of the vehicles, and the proximity of schools, kindergartens, supermarkets, and university buildings. The recorded videos were replayed to see the relationship between pedestrian vehicles and other conditions in the study area. However, this paper focuses on the geometry of the road and the total number of pedestrians and drivers. The surrounding area of the two crossing locations is shown in Figure 1 as an example.

Figure 1: Pedestrian crossing conditions at two sample locations (with poor visibility), to the left Ferenczy Janos St - Vitnyedi, to the right Csatkai Endre St - Deak square

The road parameters observed at the selected locations are summarised in Table 1. All pedestrian crossings are two-way streets with two lanes.

Table 1: Road parameters of selected locations in the city of Sopron, Hungary

	Locations	Width (m)	Length (m)	traffic volume of vehicles (veh/h)	traffic volume of pedestrians (ped/h)	Speed of vehicles (km/h)	Visibility condition
1	Ferenczy Janos St - Vitnyedi St	3.25	7.5	585	165	23	not good
2	Martirok St.	3.25	7.5	519	129	34	good
3	Beke Way	4.5	8	876	108	31	good
4	Csengery St - Frankenburg St.	3.5	11	1095	63	50	good
5	Csatkai Endre St - Deak Sq.	3.25	8	771	87	42	not good
6	Banfalvi Way - Ojtozi St.	3.5	10	942	96	38	good
7	73 Varkerulet	3.5	9	525	99	25	good
8	49 Varkerulet	3.5	9	600	78	20	gogood

According to Table 1, the visibility of two locations, Ferenczy Janos Street - Vitnyedi Street and Csatkai Endre Street - Deak Square (Figure 1), cannot be classified as good because the parked cars obscure the drivers' view. Pedestrians have to look carefully for approaching vehicles, and the vehicles cannot see behind the parked cars.

There are many factors that can influence a driver's intention to yield or not to yield. In this study, five dependent variables are used to interpret the yielding rate as an independent variable.

- Width, W: This is the geometric parameter of the crosswalk. It is measured in metres.
- Length, L: This is another geometric parameter of the crosswalk. It is measured in metres.
- Vehicle traffic volume, VV: The number of vehicles that pass through the crosswalk in 1 h.
- Pedestrian volume, VP: The number of pedestrians successfully crossing the road in one hour.
- Speed of vehicles, SV: The average speed of vehicles passing through the crosswalk in free flow, with no pedestrian crossing action. It is measured in km/h.
- Yielding rate, YR: The proportion of drivers who stop and give way to pedestrians at crossings.

The ratio of the yield rate has been determined for all observed sites:

$$YR = \frac{DGP}{AI} \tag{1}$$

where YR is the yielding rate, DGP is the number of drivers who give priority, AI is the number of all interactions. The yielding rate of all locations has been calculated and is shown in Table 2.

Multiple linear regression (MLR) was used to estimate the effect of all influencing variables to develop a statistical model. Logistic regression models were used to predict the likelihood of the studied crosswalk and whether drivers gave priority to pedestrians crossing. Drivers yielding or not yielding is the outcome variable in this research. It is a binary variable where a value of 1 indicates that the driver did yield, and a value of 0 indicates that the driver did not yield.

Table 2: Calculated Yielding rate with all variables

Locations	yielding rate	Width (m)	Length (m)	traffic volume of vehicles	traffic volume of pedestrians	Speed of vehicles (km/h)	Visibility condition
1	0.7	3.25	7.5	585	165	23	poor
2	0.74	3.25	7.5	519	129	34	good
3	0.87	4.5	8	876	108	31	good
4	0.9	3.5	11	1095	63	50	good
5	0.58	3.25	8	771	87	42	poor
6	0.82	3.5	10	942	96	38	good
7	0.79	3.5	9	525	99	25	good
8	0.86	3.5	9	600	78	20	gogood

The multiple linear regression function can be expressed in terms of logistic regression as the following equation:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad (2)$$

where: n is the number of independent variables, α: constant (y intercept); β is beta coefficients and Xn is the nth predictor (independent) variable.

Thus, the multiple linear regression model used in this study can be written as follows:

$$\mathrm{Y} = \alpha + \beta_1 \mathrm{W} + \beta_2 \mathrm{L} + \beta_3 \mathrm{V_V} + \beta_4 \mathrm{V_P} + \beta_5 \mathrm{S_V} \quad (3)$$

The probability of yielding p(y) or not yielding p(1-y) in this study can be expressed by the following equation:

$$P(y) = \frac{1}{1+e^{-(\alpha+\beta_1 W+\beta_2 L+\beta_3 V_V+\beta_4 V_P+\beta_5 S_V)}} \quad (4)$$

4. Results and discussion

The results obtained by calculating the multiple linear regression in Excel have shown that the independent and dependent variables have a correlation of 91 % (Table 3). The p-value of each parameter is greater than 0.05, which means that it is not statistically significant. However, this does not mean that the results cannot be used, as there is still the probability of yielding rate will be close to the initial rate. The smallest p-value of the variable length equal to road width is the main factor for drivers to slow down and give priority to pedestrians.

Table 3: Statistics Outcomes from Excel

Regression	Statistics		Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%
Multiple R	0.913	Intercept	-0.7102	0.8163	-0.8701	0.4759	-4.2225	2.8020
R Square	0.835	Width	0.1968	0.1207	1.6301	0.2446	-0.3226	0.7162
Adjusted R Square	0.423	Length	0.1013	0.0528	1.9183	0.1950	-0.1259	0.3285
Standard Error	0.080	Vehicles	-0.0002	0.0004	-0.5974	0.6108	-0.0020	0.0015
Observations	8	Pedestrians	0.0010	0.0016	0.6383	0.5886	-0.0058	0.0078
		Speed of vehicles	-0.0002	0.0067	-0.0311	0.9779	-0.0291	0.0286

The results of the multiple linear regression derived from the calculation in Excel, which are the coefficients of each parameter, can be written as follows:

$$\boldsymbol{Y = -0.71 + 0.19W + 0.1L - 0.00025V_V + 0.001V_P - 0.0002S_V} \quad (5)$$

The actual equation for predicting the probability of the yielding rate in this study can be written as follows:

$$\boldsymbol{P(y) = \frac{1}{1+e^{-(-0.71+0.19W+0.1L-0.00025V_V+0.001V_P-0.0002S_V)}}} \quad (6)$$

Referring to Table 4, the values or probabilities of yielding rate for all sites are nearly to the yielding rate calculated by the number of drivers who give priority to pedestrians divided by all interactions, as shown in Figure 2, the comparison between initial yielding obtained by site survey, which calculates the rate of them and the probability of yielding rate predicted by logistic regression. It can be noted that this logistic model is suitable for this study by estimating two values (yield or no yield). Furthermore, it can be seen that the highest speed of vehicles, which is location 4 (Csengery St. - Frankenburg St.), does not significantly affect the yielding rate of drivers due to the fact that the length of the crosswalk is 11 m, which allows drivers to clearly see the pedestrian while crossing. On the other hand, the low speed of vehicles at site 1 (Ferenczy Janos St.- Vitnyedi St.) cannot increase the opportunity for drivers to yield because the visibility at this location was not good or it was not clear to see the pedestrian crossing behind the parked cars. The lowest yielding rate at location 5 (Csatkai Endre St. - Deak square) is 0.58, which is really close to 50 % not yielding, and the probability was also very low due to the poor condition. The widths of the pedestrian crossings in this study are not different and cannot be distinguished because they are mostly 3.5 m. Only the width of location 3 (Beke square), which is 4.5 m, has a yield rate of 0.87, and the probability of yielding is 0.7043, which might be the condition for many drivers to stop and give way to pedestrians.

Table 4: Calculations of Probability of Yielding Rate by Logistic Regression

Locations	yielding rate	Width (m)	Length (m)	traffic volume of vehicles	traffic volume of pedestrians	Speed of vehicles (km/h)	Visibility condition	Linear Scores	Probability of Yielding Rate
1	0.7	3.25	7.5	585	165	23	poor	0.7046	0.6692
2	0.74	3.25	7.5	519	129	34	good	0.6823	0.6643
3	0.87	4.5	8	876	108	31	good	0.8679	0.7043
4	0.9	3.5	11	1095	63	50	good	0.8698	0.7047
5	0.58	3.25	8	771	87	42	poor	0.6248	0.6513
6	0.82	3.5	10	942	96	38	good	0.8434	0.6992
7	0.79	3.5	9	525	99	25	good	0.8533	0.7013
8	0.86	3.5	9	600	78	20	gogood	0. 0.8139	0 0.6929

In addition, the calculations of yielding rate and probability of yielding rate in this study can support the interaction between Autonomous Vehicles and Pedestrians due to the average outcomes of yielding rates being over 0.5, which drivers preferably give priority to pedestrians as well as that autonomous vehicles will slowly stop when approaching the obstacles.

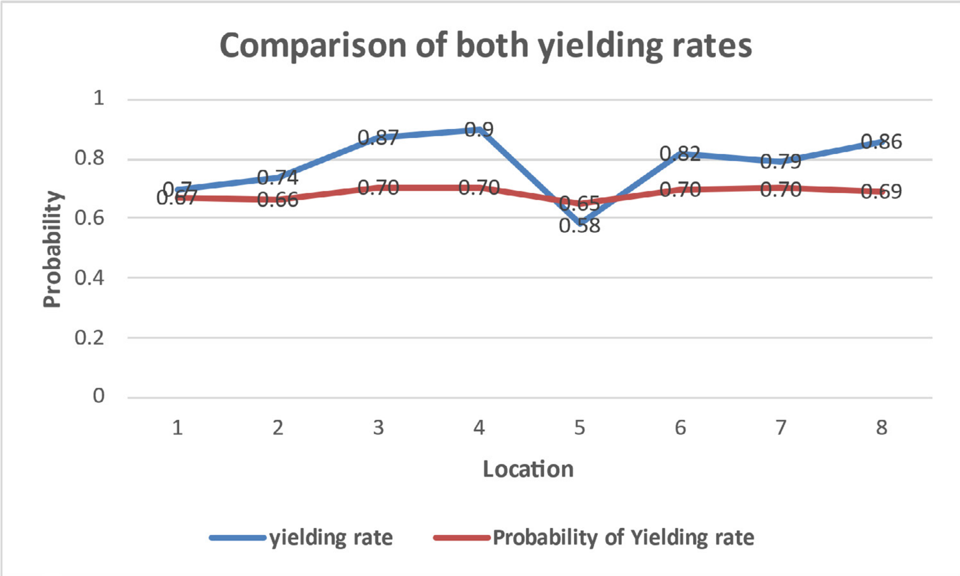

Figure 2: Comparison of estimated yielding rate and probability of yielding rate

5. Conclusions

Autonomous driving is expected to bring many benefits to individuals and society, including improved road safety, reduced congestion and a better environmental footprint. This paper has proposed a predictive model that can be used to predict the probability of drivers to yield or not to yield, which depends on the width and length of the crosswalk, the volume of vehicles and pedestrians, the speed of vehicles, which depends on the excellent visibility conditions. The interaction between pedestrians and vehicles in the selected locations is not significant because the population of the selected city is not high enough. The p-value is therefore greater than 0.05, which is not statistically significant.

The effect of pedestrian-conventional interaction at the uncontrolled pedestrian crossings studied in this research may be fundamental knowledge in the future when widespread acceptance of autonomous vehicles becomes a reality. Therefore, it is necessary to observe more locations with different road environments, geometries, traffic volumes and road categories. The impact of pedestrian crossing flows on road capacity in the presence of autonomous vehicles needs to be investigated in further steps of the research, as well as how pedestrians will react to automated vehicles and whether this would affect their behaviour.

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