Analysis of driver's yielding behavior at uncontrolled urban pedestrian crossings

Souvanthone Phetoudom
Multidisciplinary Doctoral School of Engineering Sciences
Széchenyi István University
Győr, Hungary
souvanthone.kiow@gmail.com

Emese Mako, PhD
Department of Transportation Infrastructure and Water Resources Engineering
Széchenyi István University
Győr, Hungary
makoe@sze.hu

***Abstract*— This paper analyses the effect of driver yield behavior at uncontrolled pedestrian crossings on pedestrian's crossing behavior and road capacity. Yielding to pedestrians crossing traffic will be a top safety priority for autonomous vehicles. Uncontrolled two-lane road pedestrian crossings with high pedestrian flow show the largest yielding rate according to the results. Some pedestrian crossing sites, where a much lower yielding rate was observed, have a remarkably more generous road alignment with wider lanes that encourage drivers to speed. Nevertheless, the number of crossing pedestrians was relatively low compared to other inspected locations. The four lane road pedestrian crossing sites have been indicated the lowest yielding rate because of the close vicinity of neighbouring traffic lights. The only four lane road pedestrian crossings, which resulted a relatively high yielding rate, is equipped with a pedestrian middle island helping pedestrians to cross more safely and giving drivers an opportunity to yield to them in two phases. The interaction between vehicles and pedestrians has been simulated by PTV Vissim software. Conclusively, the expected yielding rate of human-driven vehicles mixed by the presence of autonomous vehicles with 50% and 80% has been estimated.**

Keywords*— *yield behavior; pedestrian crossing; autonomous vehicle; road alignment; yielding rate

I. INTRODUCTION

This paper analyses the effect of driver yield behavior at uncontrolled pedestrian crossings on pedestrian's crossing behavior and road capacity. Yielding to pedestrians crossing traffic will be a top safety priority for autonomous vehicles. However, human drivers often save time by not yielding to pedestrians at uncontrolled crossings [1], [2], [3], [4].

The paper contributes to the scientific field of Cognitive Infocommunications, which "investigates the link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as a synergic combination of these sciences" [5].

Nowadays, the mode of communication between pedestrians and drivers correspond "to the intra-cognitive communication: information transfer occurs between two cognitive beings with equivalent cognitive capabilities (e.g., between two humans)". Nevertheless, in the presence of autonomous vehicles, this might gradually turn into "inter-cognitive communication: information transfer occurs between two cognitive beings with different cognitive capabilities (e.g., between a human and an artificially cognitive system)" [5].

The characteristics of the cross-sectional design (e.g., number of traffic lanes, lane widths) have a significant effect on the capacity of road sections and influence the effective speed of vehicles [6], [7], [8]. Visibility is another factor since both vehicles and pedestrians can be hidden by vegetation and roadside barriers. This would influence both pedestrian to decisions to cross and drivers' ability to brake for them [9], [11] [12], [13]. While autonomous vehicles can reduce the pedestrian fatalities [13], [14], some studies showed that pedestrians felt safer if they had eye-contact with the driver [15] [16], and were less confident of distracted drivers in conditionally autonomous vehicles [17]. Numerous studies were conducted to study pedestrian safety at undesignated urban midblock section [18], and drivers' and pedestrian's behavior at pedestrian crossings [19], [20], [21], [22], [23], [24].

In this study interactions between drivers and pedestrians at uncontrolled crossings are investigated through field surveys in order to analyze the yielding rate of drivers. Furthermore, the expected yielding rate of human-driven vehicles mixed by the presence of autonomous vehicles with 50%, 80%, and 100% have been estimated.

II. SITE SURVEYS

Video observations were performed to record the interaction between pedestrians and drivers in the studied site to identify the typical interaction between local pedestrians and drivers. Fourteen urban uncontrolled pedestrian crossings were selected for observation in the city of Győr, the sixth-largest city of Hungary, as follows:

1. Tihanyi St. - Kassak St.
2. Nagy Imre St. - Lomnic St.
3. Magyar St., kindergarten
4. Magyar St., hospital
5. Hedervari St., Tesco shop
6. Ronay St., primary school
7. Hedervari St,. univ. library
8. Radnoti Miklos St. - Akac St.

9. Lajta St. - Ikva St.
10. Szauter Ferenc St. - Praktiker store
11. Szauter Ferenc St. - Torok Ignac St.
12. Szigethy Attila St. - Tancsis St.
13. Szigethy Attila St. - Csokonai St.
14. Jozsef Attila St. - Pattantyus St.

The captured data were then simulated by the leading microscopic simulation software, PTV Vissim, which can presently simulate both conventional and autonomous driving by predefining the driving behavior parameters on the autonomous driving tabs [25]. Driver's travel time is partly an after effect of delay due to braking and stopping at pedestrian crossings. This is the argument why the investigation of driver's yielding behavior has been highlighted in this research.

The site survey was conducted on weekdays during peak hours. The sites' selection was based on driver and pedestrian traffic volume at nearby schools, kindergartens, hospitals, university buildings and residential areas. The road environments of two chosen crossing locations are shown in Figure 1 as examples.

Fig. 1. Pedestrian crossing conditions of two selected locations, on the top Lajta street – Ikva street, on the bottom Hedervari St, University library

The number and the output of interactions was registered for both directions of the streets. The driver's yielding behavior was evaluated at all locations specified for each direction. The ratio of yielding rate was calculated as:

$$YR = \frac{DGP}{AI} \quad (1)$$

where *YR* is the yielding rate (%); *DGP* is the number of the driver give priority; and *AI* is the number of all interactions.

Considering that an autonomous vehicle will always obey traffic rules and will automatically stop for crossing pedestrians and cyclists [14], the predicted yielding rate considering autonomous vehicles can be determined by multiplying the number of drivers not giving priority for pedestrians and the proportion of autonomous vehicles (market penetration) as follows:

$$EYR = \frac{DNG \times \%AV + DGP}{AI} \quad (2)$$

where *EYR* is the expected yielding rate (%); *DNG* is the number of drivers not giving priority; and *%AV* is the proportion of autonomous vehicles.

All interactions served as input for simulation in PTV Vissim software. The simulation images demonstrated in Figure 2 are generated by the software in the 3D view to present the interactions between pedestrians and vehicles. PTV Vissim simulation will have a significant role in the future steps of the research, when the impact of crossing pedestrian flow on road capacity in the presence of autonomous vehicles will be simulated.

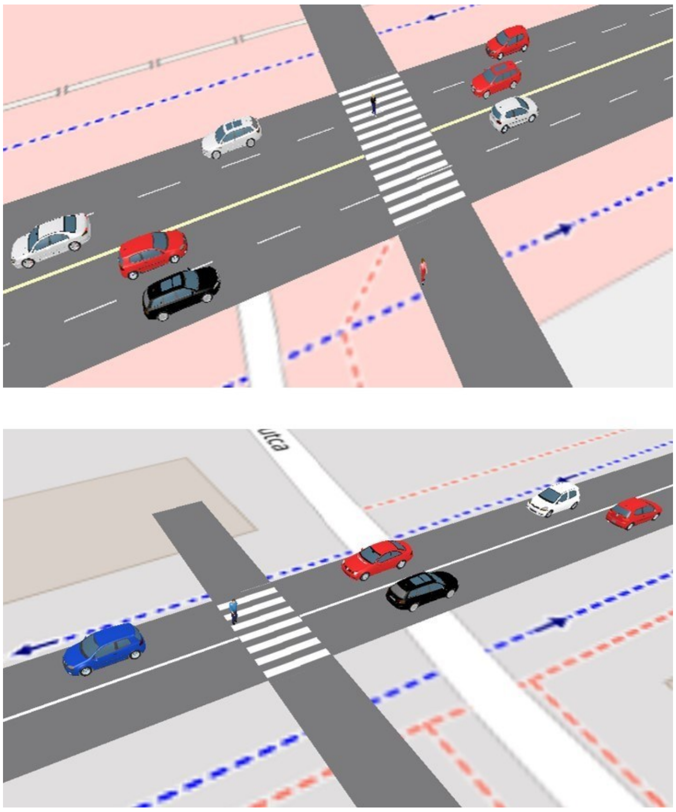

Fig. 2. Pedestrian crossing simulation of two locations in 3D view, on the top Szauter Ferenc street, Praktiker store, on the bottom Radnoti street – Akac street

The yielding rates of all sites averaged from both directions are summarized in Table 1.

TABLE 1. YIELDING RATE OF THE PEDESTRIAN CROSSING LOCATIONS

		AI	DGP	YR
1	Tihanyi St. - Kassak St.	103	72	72%
2	Nagy Imre St. - Lomnic St.	68	36	53%
3	Magyar St., kindergarten	100	72	72%
4	Magyar St., hospital	102	88	86%
5	Hedervari St., Tesco shop	37	25	68%
6	Ronay St., primary school	59	52	88%
7	Hedervari St., univ. library	112	88	79%
8	Radnoti Miklos St. - Akac St.	36	9	25%
9	Lajta St. - Ikva St.	32	22	69%
10	Szauter Ferenc St. - Praktiker store	105	54	54%
11	Szauter Ferenc St. - Torok Ignac St.	50	16	32%
12	Szigethy Attila St. - Tancsis St.	38	7	18%
13	Szigethy Attila St. - Csokonai St.	50	8	16%
14	Jozsef Attila St. - Pattantyus St.	14	11	79%

III. RESULTS

Road characteristics such as lane width, number of lanes, surrounding vegetation and roadside equipment have significant impact driver's driving speed and yielding behavior. Uncontrolled pedestrian crossings with high pedestrian flow (as outside a school, kindergarten, university hospital, shop) show an enormous yielding rate (68-88%) according to the results. Sites 1, 3, 4, 5, 6 and 7, are all located on two lane roads with excellent visibility conditions and a relatively low driving speed (30-40 km/h). At the remaining two-lane road crossings (sites 2, 8, 10 and 11) a much lower yielding rate was observed (25-54%). These sites have a remarkably more generous road alignment with wider lanes that encourage drivers to speed. In these cases, average driving speed has reached 55-65 km/h according to our measurements. Nevertheless, the number of crossing pedestrians was relatively low compared to other inspected locations. At the four lane road pedestrian crossings, the driver's behavior has been notably different from the two lane road sites. Location 12 and 13 have been indicated the lowest yielding rate with 16-18%. The reason behind these very low numbers can be found in the neighboring traffic lights in close vicinity to these locations. According to these observations, drivers are in an accelerating phase when leaving the previous crossing and do not respect uncontrolled midblock pedestrian crossings. The only four lane road pedestrian crossings, which resulted a relatively high yielding rate (69%), was site 9. This location is equipped with a pedestrian middle island helping pedestrians to cross more safely and giving drivers an opportunity to yield to them in two phases. Due to the overall expectations, the predicted yielding rate of all pedestrians in the presence of autonomous vehicles will increase tremendously. Even the locations with high driving speed such as Nagy Imre Street are expected to reach a significantly higher yielding rate by the presence of 50%-80% of the autonomous vehicles. The expected yielding rate with a penetration of AVS by 50% and 80% is calculated as shown in Table 2. With full market penetration of autonomous vehicles the yielding rate is assumed to be 100%.

TABLE 2. THE EXPECTED YIELDING RATE IN CASE OF PRESENCE OF AUTONOMOUS VEHICLES

		YR in 2021	50% of AV	80% of AV
1	Tihanyi St. - Kassak St.	72%	86%	97%
2	Nagy Imre St. - Lomnic St.	53%	77%	95%
3	Magyar St., kindergarten	72%	86%	97%
4	Magyar St., hospital	86%	93%	99%
5	Hedervari St., Tesco shop	68%	84%	97%
6	Ronay St., primary school	88%	94%	99%
7	Hedervari St., univ. library	79%	90%	98%
8	Radnoti Miklos St. - Akac St.	25%	63%	93%
9	Lajta St. - Ikva St.	69%	85%	97%
10	Szauter F. St. - Praktiker store	54%	77%	95%
11	Szauter F. St. - Torok Ignac St.	32%	66%	93%
12	Szigethy A. St. - Tancsis St.	18%	59%	92%
13	Szigethy A. St. - Csokonai St.	16%	58%	92%
14	Jozsef Attila St. - Pattantyus St.	79%	90%	98%

IV. CONCLUSION

At pedestrian crossing sites, where low yielding rate can be observed, road characteristics such as lane width, number of lanes, surrounding vegetation and roadside equipment need to be modified in order to discourage drivers to speed. At four lane road pedestrian crossing sites middle islands and other traffic management tools need to be applied, serving pedestrians to cross more safely and giving drivers the convenience to yield to them in two phases.

Apparently, the anticipated yielding rate of all pedestrian crossings with the presence of autonomous vehicles will increase enormously. Nevertheless, the upcoming 100% penetration of autonomous vehicles will create a safe road environment for all pedestrians and cyclists while crossing.

In the future steps of the research, it is crucial to observe more locations with different road environment and geometry, various traffic volumes and road categories. In order to involve different attitudes of drivers towards road traffic regulations and safe driving, locations of different countries can be eventually inspected. By means of PTV Vissim the impact of crossing pedestrian flow on road capacity in the presence of autonomous vehicles will be simulated, in other words how pedestrians will react to automated vehicles, and whether this would influence their behavior.

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