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Observational Study on Communication in Mixed Traffic Scenarios: Autonomous Vehicle Versus Pedestrian

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Abstract. This paper discusses the interaction between a pedestrian and autonomous vehicle during crossing the zebra lane by using inference statistical analysis. In this study, a video-based experiment was carried out at the university campus. On a straight road, two Perodua Myvi were utilized to test vehicle behaviour (yielding, non-yielding), driving style (assertive, defensive), and vehicle appearances (autonomous, manual) over distances of 100 m, 75 m, 50 m, and 25 m. The driver is dressed in a suit that hides the driver to signify that the driver is invisible to the pedestrian. Sixty-six (66) individuals were shown either manually or automatically operating the vehicle. Participants were asked to rate their decision to cross the road when the vehicle approached at the pre-defined distances. According to the findings, the vehicle's driving style and appearance has no substantial impact on participants' willingness to cross the zebra lane. For both automated and manually driven vehicles, the vehicle's behaviour had a considerable impact on pedestrians' willingness to cross a road. There was also no statistically significant ($p>0.05$) three-way interaction between vehicle behaviour, driving style, and vehicle appearance. There was no statistically significant ($p>0.05$) simple two-way interaction between vehicle behaviour and driving style. Finally, the experiment's limitations were reviewed, followed by recommendations for future study.

INTRODUCTION

Autonomous vehicles are an important part of the evolution of smart urban mobility. BMW, Mercedez-Benz, Audi, and Tesla have introduced their concepts of autonomous vehicles. Google and Facebook are also working with those vehicle companies in building autonomous vehicles by supporting them with communication technology. BMW has developed a Personal Co-pilot driver assistance system to help drivers provide extra protection on the road. Active Cruise Control with Stop & Go function and Collision and Pedestrian Warning with City Brake Activation are the driver assistance presence in recent BMW vehicles [1].

Unfortunately, autonomous vehicles have yet to be marketed because of the unanticipated mishaps that may occur if research data is insufficient. Autonomous vehicles should be able to monitor themselves for safe driving to the destination [2]. Sensor networks in autonomous vehicles depend on advancements in Deep Neutral Networks (DNNs) to detect pedestrians more accurately [3]. Various machine learning models in autonomous vehicles used DNNs for their strong computer vision in wide data [4].

Although automated testing techniques may uncover problems, these flaws may be challenging to understand due to their significant dimensionality [5]. Safety concerns will impact customers' desire to utilize autonomous vehicles. Numerous social and technological factors, such as automation level categorization, monitoring, vehicle activity, and traffic scenarios, may influence the safety of autonomous vehicles [6]. Human aspects are the most

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critical considerations for a completely autonomous vehicle. Even if drivers can take control of the autonomous vehicle system, the reaction time of drivers and pedestrians will be delayed by an average of 0.2 s [7].

The interactions between autonomous vehicles and pedestrians are being investigated in this study. Communication between them is essential because everyone is a pedestrian at some time during the day. Interactions between pedestrians and skillful drivers may often be aggravating. When autonomous vehicles become more common, they will require a simple pedestrian communication management approach to accept a wide range of pedestrian activities while maintaining enough travel demand [8]. Comprehension and trust, expectations, and artificial intelligence might impact pedestrians' attitudes toward autonomous vehicles [9]. In this study, a video-based experiment was conducted to see whether vehicle behaviour, vehicle appearance, and driving style affect pedestrians' decision to cross the zebra lane.

METHODOLOGY

The experiment was carried out at the campus university. Two similar Perodua Myvi were used in this experiment; one was equipped with lookalike LiDAR while another was just an ordinary passenger vehicle. To make the Perodua Myvi (with LiDAR) look more like a believable autonomous vehicle, the driver was required to wear a ghost driver seat suit while driving the vehicle. The whole scenarios were recorded and presented to two groups of participants through Google Form.

Participants

A total of 66 participants took part in this study. The first group of 32 participants watched the videos of the automated-driven vehicle, while another 34 participants watched the videos on the manually-driven vehicle. In this study, 66 individuals between the ages of 15 and 26 were recruited (mean = 22.833, standard deviation = 1.388), including 49 males and 17 females. The marital status of the majority of the participants was single, although there was one person who had married. All of the subjects used normal eyesight to watch the videos and respond.

IBM SPSS Analysis

The study focused on three independent variables: vehicle appearances (automated vs manual), vehicle behaviour (yielding vs non-yielding), and vehicle driving style (Assertive and Defensive). On the other hand, the dependent variable was a pedestrian's desire to cross the road in the presence of an oncoming car. Before the experiment, the three-way mixed ANOVA strategy was adopted to infer the statistical analysis in this study. The three-way ANOVA was used to determine if three independent factors affected a continuous dependent variable. Assumptions were made before experimenting. There must have one dependent variable and three independent variables. In this study, the dependent variable was the willingness of pedestrians to cross the road; independent variables were vehicle behaviour, vehicle driving style, and vehicle appearances. Besides, the study should not have significant outliers in the data collected. Any combination of the groups containing the three independent variables must be homogeneity of variances. It can be done using Levene's Test for Equality of Variances in SPSS. Same as the normal distribution, the result will not be valid if the value is more than $p < 0.05$. The dependent variable should be approximately normally distributed for any combination of the three independent factors. This assumption can be done by using the Shapiro-Wilk Test of Normality. If the value was more than $p <0.05$, it was not normally distributed. Sphericity assumed that the variance of differences across groups should be equal. If this is not possible, the degree of freedom can be adjusted. If the value was less than 0.05, the result was likewise invalid, indicating that it was not sphericity.

Experiment and Equipment Set-Up (Video-Based Experiment)

In this study, two cars with similar looks were employed to depict the scenarios of automated and manual driving. To mimic "automated" driving, a specially constructed vehicle known as the Automated Vehicle Simulator (AVS) was employed as shown in Figure 1 (a). A lookalike LiDAR (red circle) was equipped on the AVS to enhance the appearance of the Perodua Myvi to look more autonomous [10]. This study used the ghost driver technique to simulate an autonomous car driving on the road without a human driver, as shown in Figure 2. The ghost driver seat suit comprised wire mesh and was covered in a real automobile seat cover. On the other hand, Figure 1 (b) shows the appearance of manually driven Perodua Myvi, whereby a visible driver can be seen when driving the vehicle.

(a) (b)

FIGURE 1: Vehicle appearance of (a) Autonomous vehicle, (b) Manual driven vehicle

FIGURE 2: Ghost driver seat suit

Considering the difficulties of controlling the driving vehicle's parameters and the time of the pedestrian's response, the experiment was conducted as video-based research rather than in the field [11]. Due to the experiment being carried out in the campus university area, the vehicle's speed was controlled to prevent accidents. Both vehicles were undergoing assertive (40km/h) and defensive (20km/h) as different driving styles. Furthermore, yielding and non-yielding vehicles were also implemented in this study.

The willingness of pedestrians to cross the road in front of an oncoming automobile was examined at four different distances from the pedestrian. Both Perodua Myvi yielded at four various distances from the participants to determine when they would be willing to cross the road. The same goes for the non-yielding situation. The scenarios of the entire experiment are shown below:

Non-Yielding Behaviour

Scenario 1: When the automatically driven vehicle approaches the zebra lane at 40 km/h, the participants will need to decide on crossing the road.
Scenario 2: When the manually driven vehicle approaches the zebra lane at 40 km/h, the participants will need to decide on crossing the road.
Scenario 3: When the automatically driven vehicle approaches the zebra lane at 20 km/h, the participants will need to decide on crossing the road.
Scenario 4: When the manually driven vehicle approaches the zebra lane at 20 km/h, the participants will need to decide on crossing the road.

Yielding Behaviour

Scenario 5: When the automatically driven vehicle approaches the zebra lane at 40 km/h and decelerates at a certain distance until it stops, the participants must decide on crossing the road.

Scenario 6: When the manually driven vehicle approaches the zebra lane at 40 km/h and decelerates at a certain distance until it stops, the participants must decide on crossing the road.
Scenario 7: When the automatically driven vehicle approaches the zebra lane at 20 km/h and decelerates at a certain distance until it stops, the participants must decide on crossing the road.
Scenario 8: When the manually driven vehicle approaches the zebra lane at 20 km/h and decelerates at a certain distance until it stops, the participants must decide on crossing the road.

Route and Video Recordings of The Experiment

For safety reasons, this study's experiment was conducted at the University Tun Hussein Onn Malaysia (UTHM) Campus Pagoh. One of the ideal zebra lane roads was chosen from among all the existing zebra lane roads, as illustrated in Figure 3. This location was selected because fewer vehicles were going through the area, and the route was long and straight, allowing the experimental investigation to be completed safely.

Table 1 shows the combination of videos recorded in this study. There were two (2) behaviours, two (2) driving styles, and (2) two vehicle appearances. Therefore, a total of 8 stimuli were developed through the video recording. In this study, vehicle explicit communication (A1, A2) was investigated as a between-subject factor. Driving style (D1, D2) and behaviour (B1, B2) were tested as within-subject factors in this study. The likelihood of pedestrians crossing the zebra lane was tested at four different distances from the pedestrian: 100 m, 75 m, 50 m, and 25 m. When the incoming car reached the four distances, each of the four (4) videos was snipped at a certain timeframe. As a result, the videos were divided into 32 short video fragments (8 x 4) to serve as stimuli for the study. Figure 4 displays the position of the pedestrian angle viewpoint (camera position) and the distances between the four measurement points.

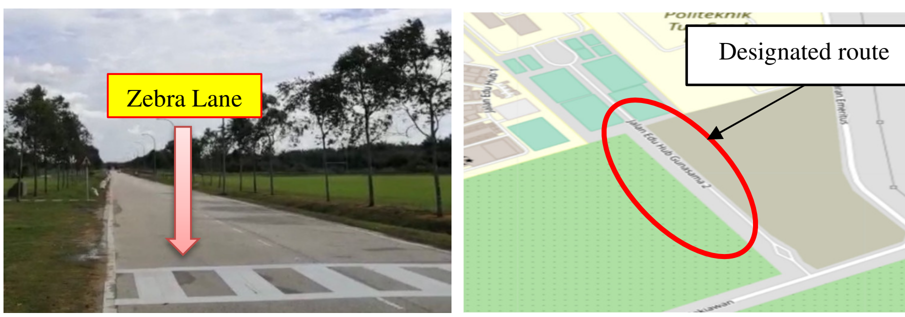

FIGURE 3: Zebra lane in designated route at Universiti Tun Hussein Onn Malaysia Campus Pagoh

TABLE 1: The setting used in this study. The vehicle appearance was defined as a between-subject measurement whereby the vehicle behaviour and driving styles are defined as a within-subject measurement

Vehicle Behaviour	Driving Style	Vehicle Appearance
B1: Non-yielding	D1: Assertive	A1: Automated
		A2: Manual
	D2: Defensive	A1: Automated
		A2: Manual
B2: Yielding	D1: Assertive	A1: Automated
		A2: Manual
	D2: Defensive	A1: Automated
		A2: Manual

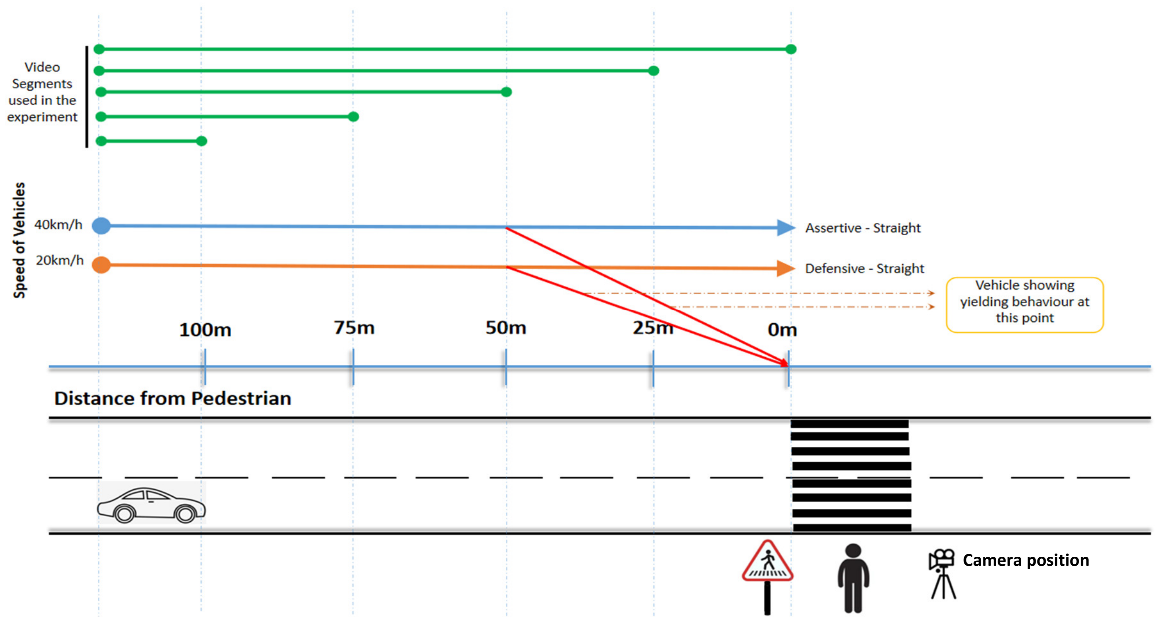

FIGURE 4: Illustration of the relative position of pedestrian and vehicle

RESULTS AND DISCUSSION

The mean scores and standard deviation of the pedestrian willingness to cross the zebra lane according to the vehicle behaviour and vehicle driving style are shown in Table 2. It was found that overall the participants' willingness to cross the zebra lane did not affected by the vehicle's appearance, which was autonomous and manual. The willingness of participants to cross the road decreased consistently as the vehicle approached closer to the participants, which was an expected response. Besides, the mean scores of yielding behaviours were higher than non-yielding behaviour in both assertive and defensive at 50 m and 25 m.

Analyses of variance (Mixed ANOVA) were executed for each distance (100 m, 75 m, 50 m, 25 m), with vehicle behaviour and driving style as within-subjects factors meanwhile vehicle appearance as a between-subjects factor. The dependent variable was the willingness of participants to cross the zebra lane. This was done to evaluate the main effects and the simple two-way and three-way interactions between these independent variables.

Table 3 shows Mauchly's test of sphericity results. The assumption of sphericity implies that the variances of all within-subjects (vehicle behaviour, vehicle driving style) effects have equal variances. In general, the validity of Mauchly's test of sphericity was by looking at the significant value, whether $p<0.05$ or $p>0.05$. The sphericity hypothesis is applied to each within-subjects effect in the investigation, and it is examined independently for each influence.

The interactions between the vehicle's appearance, driving style, behaviour, and pedestrians' willingness to cross the road when the vehicle reached particular distances (100 m, 75 m, 50 m, and 25 m) were investigated in this experiment. There were no statistically significant ($p>0.05$) three-way interactions between vehicle behaviour, vehicle driving style, and vehicle appearance based on the results. Besides, there was no statistically significant ($p>0.05$) simple two-way interaction between vehicle behaviour and vehicle driving style for distances 100 m, 75 m, 50 m, and 25 m.

The findings indicated that the vehicle's behaviour did significantly influence this investigation (see Table 2). In terms of yielding behaviour, most participants were willing to cross the road when the vehicle was between 100 m and 75 m away. When the car was 50 m away, most of the participants were hesitant to cross the zebra lane since the vehicle was ready to brake at that point, but some were still willing to cross the zebra lane (refer to Table 2). The vehicle decelerated at a constant speed that caused most participants to choose to stay until the vehicle came to a complete stop. The vehicle's appearance did not affect participants' willingness to cross the zebra lane. Phone's camera was used for recording the video; hence the quality of the video was not very clear to show the appearance of the automated driven vehicle. The tinted glass also distorts participants' eyesight, preventing them from properly seeing the car's interior. As a result of watching the video, the participants mistook the vehicle for a regular passenger car.

The findings revealed that the vehicle's driving style did not influence the willingness of participants to cross the road. The assertive driving style was set at 40 km/h, while the defensive driving style was set at 20 km/h. Most participants were willing to cross the zebra lane when the vehicle was 50 m and above for autonomous and manually driven vehicles. A vehicle travelling from 60 km/h to 80 km/h would be considered assertive in most cases. As a result, they could not distinguish between assertive and defensive pace.

TABLE 2: The average score (mean (SD) pedestrian willingness to cross the zebra lane across vehicle behaviour and appearance variations.

1 = totally unwilling to cross; 3 = undecided (neutral); 5 = totally willing to cross.

Behaviour	Driving Style	Appearance	Vehicle Distance from Pedestrian			
			100 m	75 m	50 m	25 m
Non-yielding	Assertive	Automated	4.844 (0.369)	4.250 (0.568)	3.094 (1.254)	1.906 (1.254)
		Manual	4.647 (0.691)	4.294 (0.760)	2.588 (1.201)	1.471 (1.080)
	Defensive	Automated	4.719 (0.457)	4.250 (0.672)	3.344 (1.125)	2.031 (1.204)
		Manual	4.676 (0.638)	4.382 (0.817)	3.088 (1.287)	1.559 (0.860)
Yielding	Assertive	Automated	4.781 (0.420)	4.156 (0.847)	3.500 (1.295)	2.875 (1.581)
		Manual	4.676 (0.727)	4.235 (0.987)	3.412 (1.104)	2.618 (1.557)
	Defensive	Automated	4.813 (0.397)	4.406 (0.798)	3.563 (1.134)	3.031 (1.596)
		Manual	4.735 (0.710)	4.235 (0.987)	3.471 (1.331)	2.971 (1.560)

TABLE 3: Test of within-subjects effects at distance 100 m, 75 m, 50 m and 25 m

Source	Distance		df	F	Sig.	Partial Eta Squared
Behaviour*style*vehicle appearance Error (behaviour*style)	100m		1	0.233	0.631	0.004
			64	-	-	-
	75m		1	2.030	0.159	0.031
			64	-	-	-
	50m		1	0.857	0.358	0.013
			64	-	-	-
	25m		1	0.014	0.907	0.000
			64	-	-	-

CONCLUSIONS

The study found a pattern of participant willingness to cross the zebra lane while engaging with the autonomously driven car at 50 m and 25 m distances. When compared to the group of manually driven individuals, the autonomously driven participants were more likely to cross the zebra lane. Furthermore, it was discovered that the vehicle's behaviour had the most direct effect on the willingness of pedestrians to cross the zebra lane. The limitation of this study was the participants unable to provide real-time data (reaction) when interacting with the vehicles. They were given flexible time to answer the questions as they watched the videos. Furthermore, the vehicle could not drive too fast to indicate the assertive driving style due to the experiment at the campus university. The ghost driver seat outfit was another constraint. The driver was hard to change the gear while wearing the outfit to drive the vehicle due to the outfit being made of sponge, leather, and barbed wire whereby the hand's movements were limited. Recommendations were made to improve the study's shortcomings. The experiment can be carried out in real traffic situations. This method can increase the accuracy of the data collected as the pedestrians will need to make an instant decision when the vehicle is approaching them [12]. Besides, the vehicle's appearance can be seen clearly by the pedestrians. The following recommendation was to experiment in an open area. The vehicle was able to drive at any speed without considering any dangers involved by any individuals. Last but not least, the ghost driver's clothing was recommended to be made as a regular costume with sleeves on it to make driving the car simpler for the driver. A second person was also required to assist as the driver's eye because the suit had decreased the driver's field of view.

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