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Modelling Driver-Pedestrian Interaction at Raised Crosswalks

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Abstract

The concept of traffic calming emerged in the 1960s as a response to road safety concerns and the need to improve pedestrian environments. Raised crosswalks became a popular measure in the late 20th century, providing a physical restraint to counter potentially dangerous conflicts between fast-moving vehicles and pedestrians at crosswalks, and to enhance environments that promote walking as a mode of transport. Understanding the dynamics of driver-pedestrian interaction at raised crosswalks is crucial for promoting road safety and efficient urban mobility. This research was conducted in Universiti Tun Hussein Onn Malaysia (UTHM) campus to investigate driver yielding behaviour and pedestrian attitudes towards drivers to forecast driver yielding probabilities at raised crosswalks using logit modelling. Data collection was conducted at a raised crosswalk in front of the Faculty of Civil Engineering and Built Environment. Five contributory variables that were historically found to have affected driver yielding behaviour at pedestrian crossing facilities, i.e., gap size, vehicle speed, position of pedestrians, position of vehicles and number of pedestrians waiting, were chosen to develop the logit model. Two equations were developed as part of the analytical process. The first being a yielding function that was developed to describe the driver yielding behaviour with the selected variables, and the second, a logit function that was developed to predict the probability of drivers yielding to pedestrians at the crosswalk. Results showed that all five variables had significantly influenced drivers' yielding decision, with p values less than 0.05. The model shows strong validity, with an average accuracy rate of 90.83%. It was found that yielding behaviour among drivers increases with larger gap sizes, higher vehicle speed and vehicles located on the near lane or on both lanes. Based on these findings, it can be concluded that conflicts between vehicles and pedestrians at raised crosswalks can be reduced, hence promoting harmonious and safe road user interactions.

1. Introduction

Pedestrian safety on urban roadways is a critical concern globally, with approximately 23% of fatal accidents worldwide involving pedestrians. The South East Asian region reports a relatively lower percentage of pedestrian-related road deaths at 14% [1]. In Malaysia, pedestrians are the third largest road user group involved in road fatalities behind motorcyclists and car occupants [2]. Mid-block crossings are the most dangerous locations for pedestrian crossing [3]. In urban regions, where pedestrian traffic is dense, 73% of pedestrian fatalities were found to occur at mid-blocks [4]. Achieving a safe balance between various road users is essential, and understanding the factors influencing pedestrian safety is crucial for developing effective countermeasures.

Despite legal protections, pedestrians sometimes make poor choices when faced with aggressive or unyielding vehicles [5]. Driver-oriented countermeasures include improved yield lines, removing parking near crossings, curb extensions for enhanced visibility, flashing beacons, and warning signs with in-pavement lights [6]. However, the effectiveness of these measures depends on various contributory variables.

This study explores contributory variables influencing driver-pedestrian interactions, focusing on gap size, vehicle speed, the position of pedestrians and vehicles, the number of pedestrians waiting, and countermeasures such as raised crosswalks. Raised crosswalks have been found to significantly reduce speed. A study in UTHM reported speed reductions at raised crosswalks of between 31 to 48%. It was also reported that drivers start reducing their speed as far as 50 m from the raised crosswalk [7].

Understanding gap acceptance behaviour is crucial, as it is influenced by factors like walking speed, age, gender, and group dynamics [8]. Additionally, vehicle speed plays a significant role in road safety, with speeding being a major contributor to accidents [9].

The position of pedestrians and vehicles in driver-pedestrian interactions is explored, emphasising the importance of marked crosswalks, sidewalks, and the impact of jaywalking on safety [10]. The number of pedestrians waiting influences decision-making during crossings, with waiting times affecting choices [11]. The position of vehicles, especially lane-changing behaviour, also plays a crucial role in road safety [12].

To address these challenges, countermeasures such as traffic calming interventions have been implemented globally, aiming to slow down vehicles and enhance pedestrian safety [13]. As our understanding of driver-pedestrian interactions has evolved, research methodologies have diversified, incorporating video analysis, simulated experiments, and modelling techniques to gain deeper insights into yield behaviour.

This research focuses on understanding the dynamics of driver-pedestrian interactions, specifically at raised crosswalks, aiming to achieve two main objectives. Firstly, the study aims to investigate the yield behaviour shown by drivers when pedestrians are present at raised crosswalks. This involves a thorough examination of how drivers respond to elevated pedestrian crossings, considering factors such as visibility, awareness, and adherence to traffic rules. Secondly, the research seeks to predict the probability of drivers yielding at raised crosswalks through the application of logit modelling. By employing statistical modelling techniques, the study intends to develop a predictive framework that accounts for various variables influencing driver yielding behaviour at these specific road features. Ultimately, these objectives aim to contribute valuable insights into improving pedestrian safety at raised crosswalks and inform strategies to enhance the overall effectiveness of such traffic calming interventions.

2. Research Methods

This section explains the methods used for data collection and analysis in order to fulfil the objectives stated previously.

2.1 Data Collection

Observations were made over a span of four days at the raised crosswalk in front of the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia (see Fig. 1) during peak hours from 8:00 AM to 9:00 AM and 4:00 PM to 5:00 PM, as well as during non-peak hours from 11:00 AM to 12:00 PM. The selected raised crosswalk was 7.0 m in length, 2.5 m in width and 50 mm in height. It was installed on Persiaran Tun Ghafar Baba, which is a one-way street with two lanes. The raised crosswalk was commonly used by students who regularly travel to the faculty by bus.

The observations involved five key contributory variables, i.e., gap size, position of pedestrians, the number of waiting pedestrians at the crosswalk, position of vehicles before the raised crosswalk and vehicle speed approaching the raised crosswalk.

2.1.1 Gap Size

The gap size and the time it takes for an oncoming car to go from the observation site to the crosswalk, where the location is the main subject of this research. When deciding whether to attempt to cross the road or pass up the available gap, pedestrians' decision-making is significantly influenced by the size of the gap.

To collect gap size data, the equipment used was a video camera and a stopwatch. The procedure for data collection was used as follows: First, set up the video camera at a suitable location that provides a clear view of the area where vehicles and pedestrians interact, ensuring stability and correct focus. Begin recording the traffic conditions, capturing the movement of vehicles and pedestrians as they cross the raised crosswalk. A stopwatch is used to measure the gap between two consecutive vehicles (see Fig. 2), starting when the back bumper of the first vehicle passes the crossing spot and stopping it when the front bumper of the second vehicle passes the crossing spot.

Fig. 1 *Raised crosswalk in UTHM campus installed on one one-way street with two lanes*

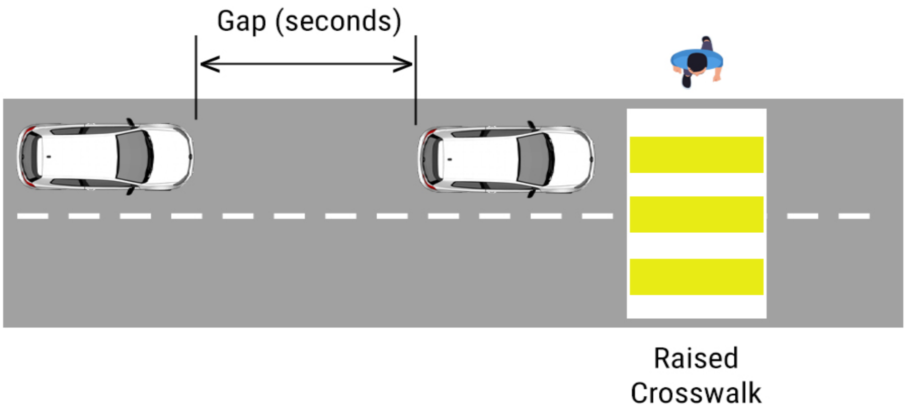

Fig. 2 *Measurement of gap size*

2.1.2 Vehicle Speed

To obtain the speed of vehicles approaching the crosswalk, a video camera was used to observe spot speeds. The procedure for spot speed data collection (see Fig. 3) is as follows: First, mark two points along the road that leads to the raised crosswalk and measure the distance between the two points. Then, place a video camera at a suitable location so it can clearly record vehicles passing the two points. Make sure the camera is steady and has a good focus. Start recording with the video camera. Use a stopwatch to determine the time taken for the vehicles to pass the two points.

To determine the speed, this basic formula is used: Speed = Distance ÷ Time, where distance is measured in meters and time is counted in seconds. These values will then be converted into kilometres per hour.

2.1.3 Position of Pedestrians

The position of pedestrians is the exact location where pedestrians stand and prepare to cross the street at the raised crosswalk. It is a discrete binary variable with two potential positions: 0: At the raised crosswalk i.e., the person is waiting or beginning from the side of the road, usually by a pedestrian crossing line, and 1: Away from the raised crosswalk - The person is standing or preparing to cross away from the raised crosswalk (see Fig. 4).

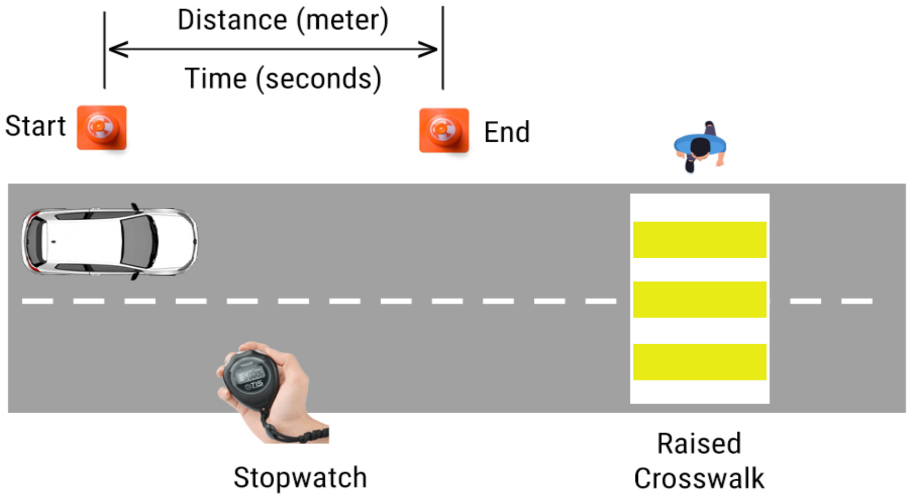

Fig. 3 *Measurement of vehicle speed*

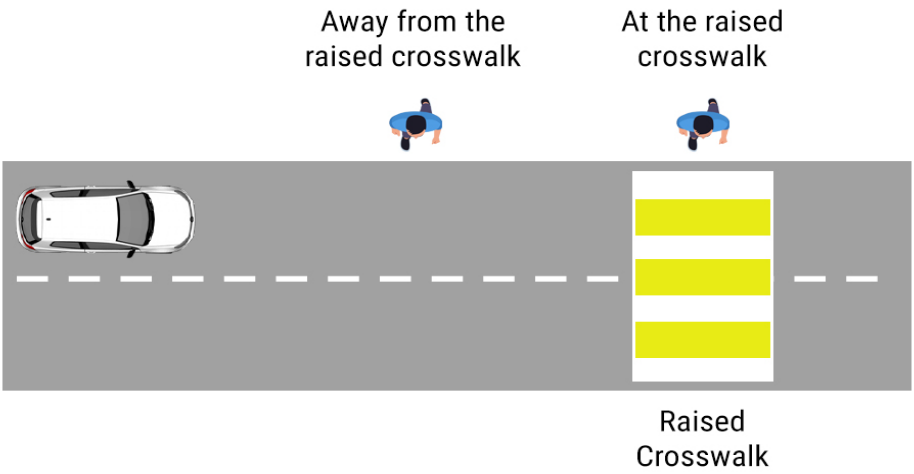

Fig. 4 *Position of pedestrians relative to the raised crosswalk*

It is important to consider the position of a pedestrian because it affects how they act, what choices they make, and the way drivers will react to them. To collect data on the position of pedestrians, the required equipment is a video camera. The procedure for data collection is as follows: First, set up a video camera at a suitable location that can capture the position of pedestrians at or in the vicinity of the raised crosswalk. Ensure the camera is stable and correctly focused. Capture the movement of pedestrians who are preparing to cross the street. Track their positions relative to the raised crosswalk. Accurately record the positions of the pedestrians for further analysis.

2.1.4 Number of Waiting Pedestrians

The number of waiting pedestrians is basically the number of pedestrians who are present at a particular moment just before they begin the crossing (see Fig. 5). A driver's decision to go or yield may be influenced by the amount of waiting pedestrians. If there are many pedestrians awaiting, it could appear as though they have been waiting for a long time. The driver might decide to stop and let them cross if they get this impression.

The equipment required for collecting this data includes a video camera and a tally counter. To collect data on the number of waiting pedestrians, these steps are followed: Firstly, use a video camera to record the number of pedestrians waiting at the raised crosswalk. Place the video camera at a suitable location, make sure it is steady and aiming correctly. Begin recording with the video camera and using the tally counter, observe how many people are waiting to cross.

2.1.5 Position of Vehicles

The position of the vehicle is used to indicate where the vehicle is when drivers first encounter a pedestrian or a group of pedestrians waiting to cross at the raised crosswalk. The position of a vehicle, particularly on multilane streets, may significantly affect crossing decisions. Pedestrians will have to take into consideration the position of vehicles on the lanes in order to decide whether it is safe to cross or not.

For analytical purposes, values between 0 and 3 are assigned to this variable to represent the position of vehicles, as follows (also refer to Fig. 6 to Fig. 8):

0: No cars - No vehicles on both lanes
1: The far lane - Vehicles are on the far lane
2: The near lane - Vehicles on the near lane
3: Both lanes - Vehicles are on both lanes

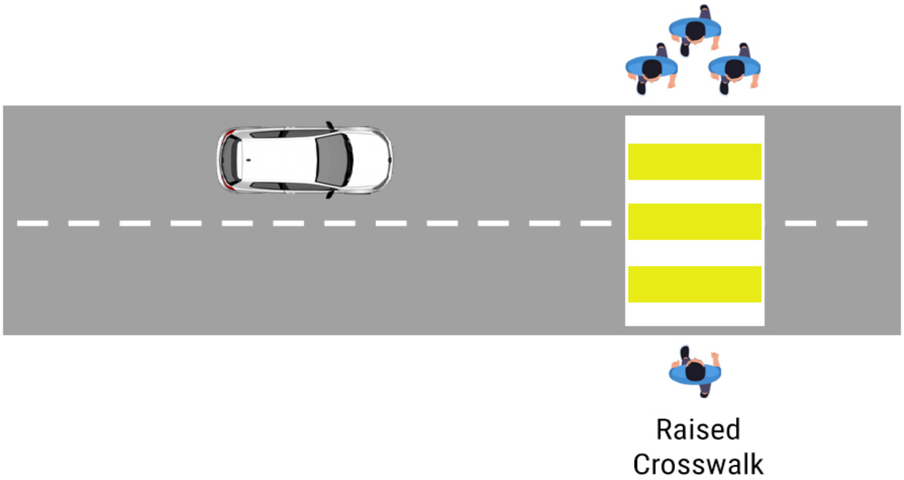

Fig. 5 *Number of waiting pedestrians*

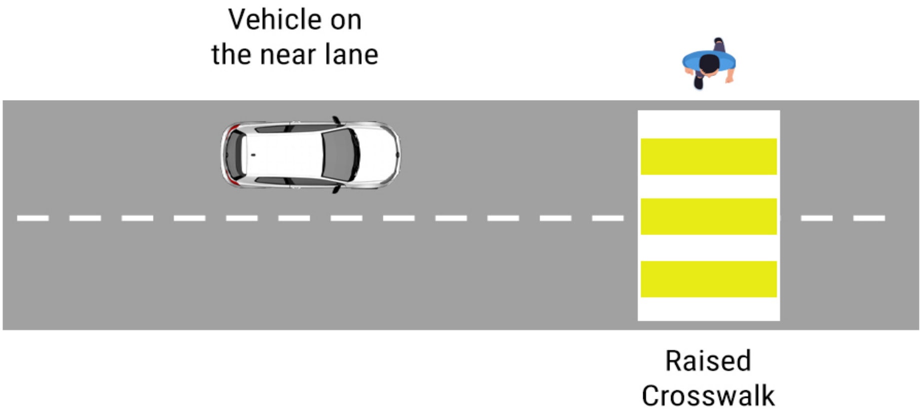

Fig. 6 *Vehicle on the near lane*

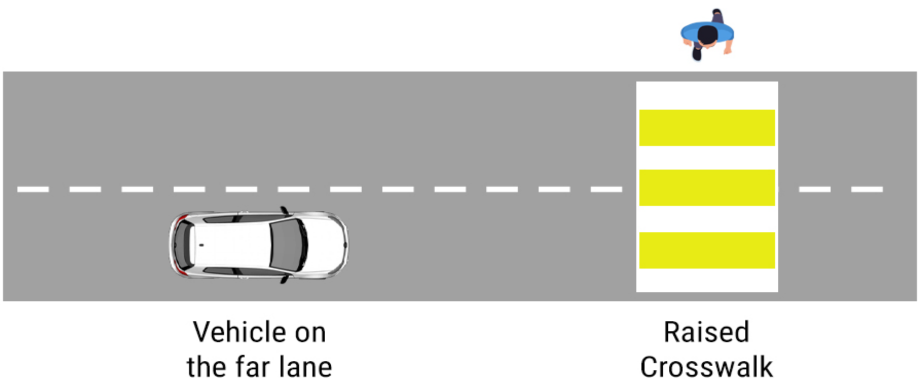

Fig. 7 *Vehicle on the far lane*

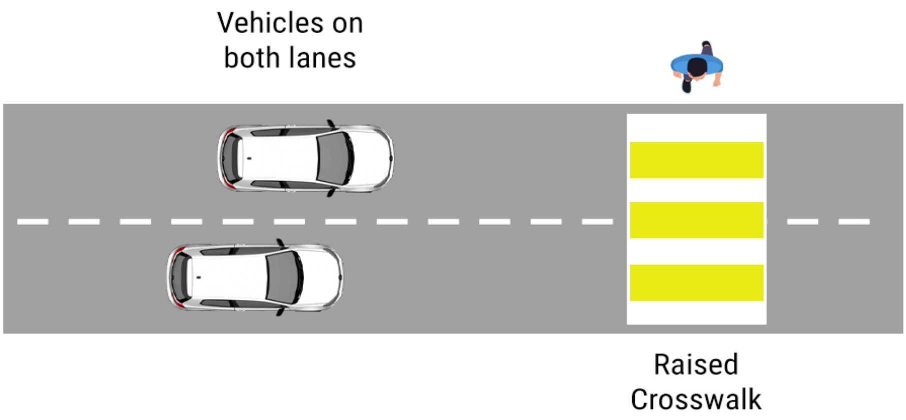

Fig. 8 *Vehicles on both lanes*

2.2 Data Analysis

Once data of the five selected contributory variables (gap size, vehicle speed, position of pedestrians, position of vehicles and number of waiting pedestrians have been collected and sorted, the data were then analysed using SPSS statistical software, whereby two models were developed, the first being a multiple linear regression model (to examine driver yielding behaviour) and the second, a logit model (to predict the probability of yielding by drivers).

2.2.1 Yielding Function

Regression models are generally used to establish relationships between variables by fitting a regression line to the observed data. Regression enables us to study how a dependent variable changes as the independent variables change. For this research, binary logistic regression was employed using five independent variables that were specifically selected to estimate their relationship with the dependent variable.

This model was called the yielding function, denoted as Y, which is a binary function indicating whether drivers yielded to pedestrians (assigned a value of 1) or did not yield to pedestrians (assigned a value of 0). The yielding function, *Y* can be described by the following equation:

$$Y = \beta_0 + \beta_1 G + \beta_2 V + \beta_3 P_P + \beta_4 N_P + \beta_5 P_V \quad (1)$$

where, *Y* is the yielding function; *G* is the gap size (in seconds); *V* is the vehicle speed (in kilometres per hour); P_P is the position of pedestrians; N_P is the number of waiting pedestrians; P_V is the position of vehicles and β_i is the regression coefficients, *i* = 0, 1, 2, 3, 4, 5.

2.2.2 Probability of Yielding

Logit modelling, also known as logistic regression modelling, is a statistical method to handle binary or dichotomous dependent variable that takes a value of either 0 (no) or 1 (yes). The advantage of employing this kind of modelling technique is that coefficient estimates for the significance of variables can be obtained utilising a sizable set of input variables. Hence, it is possible for us to determine whether or not a certain variable significantly affects the outcome using statistical inference. For this research, the logit model took the form of:

$$P(Y) = \frac{1}{1 + e^{-Y}} \quad (2)$$

where *P(Y)* is the probability of the driver yielding to pedestrians and *Y* is the yielding function.

2.3 Validation of Model

The model proposed is a discrete choice model, wherein drivers decide to yield or not, considering the specified predictor variables. 70% of the dataset was used in the logit model design to determine how each predictor variable affected a driver's decision to yield. The remaining 30% of the data that was gathered was then used to confirm that the created model was reliable and broadly applicable. The process of dividing the dataset into training and validation sets ensures a thorough evaluation of the model's predictive capabilities and enhances its reliability in real-world situations outside of the training set. This logit model validation test was conducted using SPSS statistical software.

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3. Results and Discussion

The five variables (gap, vehicle speed, position of pedestrians, number of waiting pedestrians, and position of vehicles) showed statistical significance (p-values less than 0.05), according to the output for the yielding function, Y, presented in Table 1. This suggests that each of these variables contributed to the overall explanatory power and relevance of the model in a statistically significant way. Based on the output, the yielding function, *Y* can therefore be expressed as Eq. (3), and the probability of yielding, *P(Y)* takes the form of Eq. (4) as follows:

$$Y = 0.067G + 0.024V - 0.395P_P - 0.171N_P + 0.146P_V - 1.604 \quad (3)$$

$$P(Y) = \frac{1}{1 + e^{-(0.067G + 0.024V - 0.395P_P - 0.171N_P + 0.146P_V - 1.604)}} \quad (4)$$

The odds ratio, represented by Exp(B) in Table 1, indicates the change in odds related to a predictor variable influencing the outcome variable. If the odds ratio is greater than 1, it means that there is a greater chance of the driver yielding to pedestrians at the raised crosswalk as the predictor rises. On the other hand, an odds ratio less than 1 indicates that the likelihood of the driver yielding decreases as the predictor rises.

Table 1 *Output for the yielding function and the probability of yielding*

Contributory Variable	B	Std. Error	Wald	Sig.	Exp(B)
Gap size	0.067	0.164	0.166	0.000	1.069
Vehicle speed	0.024	0.031	0.610	0.000	1.024
Position of the pedestrian	-0.395	0.523	0.570	0.000	0.674
Number of waiting pedestrians	-0.171	0.124	1.886	0.000	0.843
Position of vehicles	0.146	0.256	0.324	0.000	1.157
Constant	-1.604	1.559	1.058	0.000	0.201

From this study, gap size, vehicle speed and position of vehicles were found to have odds ratio values greater than 1, meaning that as these predictor variables increase, there is a higher likelihood that drivers will yield to pedestrians at the raised crosswalks. In other words, drivers are more likely to slow down, stop and give way to pedestrians when larger gaps are present in traffic, vehicle travelling speed is higher, and vehicles are either on the near lane or on both lanes. Larger gaps enable drivers to have more time to perceive, anticipate and react to the presence of pedestrians preparing to cross the road. They ultimately have more time to make decisions, thus they are more likely to yield to pedestrians.

It was interesting to find that higher speeds resulted in a higher probability of drivers yielding to pedestrians. This may be explained due to the nature of raised crosswalks, which mandate drivers to slow down. If they traverse the raised crosswalk at high speeds without slowing down, it will cause major discomfort to drivers and most likely cause damage to the vehicle. Therefore, drivers travelling at higher speeds would have to start slowing down from a further distance before reaching the raised crosswalk, which results in them having more time to make the right decision to yield to pedestrians.

Drivers of vehicles on the near lane and of vehicles present on both lanes have been found to have a higher likelihood of yielding to pedestrians. On the near lane, pedestrians are closest to the vehicle, thus making the driver more aware and cautious of the presence of pedestrians. When there are vehicles on both lanes (near and far lanes), drivers' awareness and cautiousness become more notable because they have to deal with interactions between themselves with pedestrians as well as the adjacent vehicle. Besides that, they may also be influenced by the action of the adjacent driver who yields to pedestrians.

A logit model validation using SPSS statistical software was carried out with 30% of the available data collected in the field. This validation process was aimed at determining the model's accuracy by comparing field-observed driver yielding occurrences with predicted driver yielding occurrences using the logit model developed from this study. A probability threshold of 0.5 or higher indicates success (yield), whereas values less than 0.5 indicate failure (did not yield). The overall findings, as shown in Table 2, indicated that the logit model performed commendably well, correctly predicting 90.83% of the total 120 sample observations. In particular, the model predicted driver yields with 93.10% accuracy (81 times) and non-yields with 84.85% accuracy (28 times). This validation method establishes the logit model's resilience and usefulness in capturing and forecasting driver yielding behaviour based on the input dataset.

Table 2 *Model validation*

	Observed	Predicted	Predicted Accurately	Percentage Accurate
Yield	87	102	81	93.10
Did Not Yield	33	18	28	84.85
Total	120	120	109	
Average Accuracy				90.83

While this study provides a good insight into pedestrian-driver interactions at raised crosswalks, there are a few limitations that may restrict the use of the model to university campuses only, since the data sampling was conducted on campus, which is a more controlled environment compared to urban locations such as central business districts where pedestrian and driver behaviour are more diverse, and their numbers are more pronounced. Furthermore, the study involved pedestrians who were mostly university students aged between 20 and 30 years. However, drivers involved in this study were more varied in terms of age and educational background. Different driving environments, particularly the type of streets, have a significant impact on driving behaviour due to varying infrastructure characteristics [14], while age plays a significant role in pedestrian crossing decisions and their vulnerability when interacting with motorised traffic [15], [16].

4. Conclusion

This in-depth study sheds light on the intricate dynamics of driver yielding behaviour at raised crosswalks, providing valuable insights that are challenging to comprehend without a detailed examination. The logit model developed from this research exhibited remarkable accuracy, reaching 90.83%, affirming its effectiveness in predicting and understanding drivers' actions.

The key role of gap size underscores the complexity of the relationship between available gaps and driver choices. Additionally, the observed behaviour of drivers slowing down near raised crosswalks after driving at higher speeds reflects a conscious effort to prioritise safety, showcasing the model's ability to capture real-world driving trends when approaching raised crosswalks. The study also emphasised the significant influence of the position of vehicles on a driver's likelihood to stop and give way, especially noting a substantial change when vehicles were travelling on the near lane or on both lanes. This accentuates the positive impact of vehicle and pedestrian presence in encouraging responsible driver behaviour. Furthermore, the research acknowledges the broader implications of drivers' decisions on road conditions and traffic, emphasising the need for a comprehensive approach. Sensitivity analysis proved instrumental in understanding the interconnected factors influencing driver choices. Ultimately, the study contributes to the ongoing global discourse on road safety, providing a foundation for future strategies and discussions aimed at enhancing safety measures and fostering responsible driving practices worldwide.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Basil David Daniel, Jason King Teck Qing;* ***data collection:*** *Jason King Teck Qing;* ***Analysis and interpretation of results:*** *Jason King Teck Qing, Basil David Daniel, Paikun, Sri Wiwoho Mudjanarko, Aleeya Erdyna Mohd Noor Azmi;* ***Draft manuscript preparation:*** *Jason King Teck Qing, Basil David Daniel, Paikun, Sri Wiwoho Mudjanarko, Aleeya Erdyna Mohd Noor Azmi. All authors reviewed the results and approved the final version of the manuscript.*

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