European Transport \ Trasporti Europei (2023) Issue 94, Paper n° 3, ISSN 1825-3997

https://doi.org/10.48295/ET.2023.94.3

Road Safety Criteria for Mid-Block Pedestrian Crossing Facility and Application of ITS Technologies

Sathya Prakash[1*], Krishnamurthy Karuppanagounder[2]

[1]*Research Scholar, Civil Department, National Institute of Technology Calicut, Kerala, India*
[2]*Professor, Civil Department, National Institute of Technology Calicut, Kerala, India*

Abstract

This paper describes an attempt made to evaluate the pedestrian's road crossing facility at midblock to relate with pedestrian road crossing behaviour and identify the variables influencing pedestrian road crossing decisions. The decision of pedestrians on road crossing depends on many other elements like yielding behaviour of a driver, vehicle speed, roadway width, traffic volume etc. Pedestrians road crossing data collected through videographic survey at Kozhikode city, Kerala, India were used to evaluate the pedestrian crossing facility. Regression model has been developed considering the pedestrian waiting time as dependent variable and vehicle speed and volume as independent variable. Further, a computational tool is developed to derive suitable criteria for regulating the number of pedestrian phases based on the percentage of vehicles in the queue formation for varying levels of interruptions and vehicle arrival rate. The criteria has been derived such that the negative force exerted by vehicles and drivers during pedestrian road crossing to a minimum level, through the implementation of signal control using Intelligent Transport System (ITS) technologies. Further, the queuing analysis results helps to identify the criteria for proposing grade-separated crossing based on the threshold value of the percentage of vehicles in the queue formation. From the queuing analysis, it was found that, the percentage of vehicle in queue has been increased from 19.44% to 38.89% for the arrival rate of 1200v/h when the number of pedestrian interruptions per hour is increased from 20 to 40. Also, it is observed that when the arrival rate increases from 1200 to 1800 v/h the percentage of vehicle in queue increases 19.44% to 77.78% for 20 number of pedestrian interruptions. The prediction tool developed may help the transportation policymakers and highway officials to evaluate the field conditions and to identify suitable control measures for the pedestrian facility with improved pedestrian safety and vehicular traffic efficiency.

Keywords: Pedestrian, Mid-block, Regression model, ITS, Queuing analysis, safety

1. Introduction

Pedestrians road crossing is one of the important elements in the urban traffic system; facing serious conflict with motorised vehicles while crossing. According to WHO (2022) statistics, more than half of all road traffic deaths are among vulnerable road users like pedestrians, cyclists and motorcyclists. Further, pedestrians must face safety risks when

* Corresponding author: Sathya Prakash (sathyaprakash.civil@gmail.com)

crossing at an uncontrolled section due to their unpredictable behaviour. Also, WHO (2022) finds that distracted driving, like using a mobile phone, increase crash by four times more than drivers not using mobile phones. Understanding vehicle and pedestrian behaviour is necessary to make the system work effectively with safety. But it is also known that the behaviour of humans is unpredictable and probabilistic. Also, the behaviour of pedestrians varies based on the associated activity during the crossing. The decision of a pedestrian will be influenced by several factors related to the nature of the trip they are associated at that moment. The earlier scenario shows traffic congestion is another problem that may lead to extra carbon emissions and reduce transport efficiency (M Fouladgar et al.,2017). Hence, the application of Intelligent Transport Systems (ITS) establishes communication between infrastructure and vehicles or among vehicles (S Sharma and S K Awasthi,2022) and improves the existing system's efficiency. Also, ITS technology could alert the drivers, pedestrian and other road users to improve safety. So there is a need to understand road user behaviour by applying social psychology theory to study pedestrians' interaction with vehicles at the crosswalk. So, the outcome of this research is to understand pedestrian behaviour and to frame a policy for pedestrian road crossing facilities. The rest of the article is structured as follows. Section 2 describes the literature study on vehicle and pedestrian interaction, followed by psychological factors that decide their road crossing decision and its application on ITS.

Further, the methodology steps and concept of field theory is briefed in section 3. Section 4 discusses results based on pedestrian-vehicle interaction and methods for improving the facility, which elaborates with findings and interpretation of results. Section 4.3 and 4.4 demonstrates queuing analysis and tool development. Finally, section 5 focuses on conclusive remarks with findings and future research.

2. Literature Study

The following section summarises the previous studies relating to pedestrian-vehicle interaction, field theory and ITS.

2.1 Pedestrian Vehicle Interaction at Crosswalk

The interaction of pedestrians with vehicles creates more conflict at crosswalks. Earlier research on pedestrian behaviour found that pedestrian delay due to pedestrian and vehicle interaction is less at crosswalks (Ling et al., 2012; Xie et al., 2012). Hamed (2001) studied and found that pedestrian expected waiting time has a greater influence on the number of attempts needed to cross the road. A finding by Leden (2002) shows pedestrian risk decreases with increased pedestrian flow and increases with an increase in vehicle flow. Earlier research shows that the pedestrian crossing choice was significantly affected by traffic flow and road type (Jamil et al.,2015). Another study by Ferenchak (2016), concentrates on the relationship between pedestrian behaviour and vehicles. The study found that waiting time increases as pedestrian gets older. Also, the elderly pedestrian has a lesser conflict with vehicles. Andrew HW (1991) identified that the crossing behaviour of pedestrians is affected by traffic volume and other conditions like weather and darkness. Based on these previous studies, pedestrian crossing behaviour is influenced by several factors like vehicle flow, age and weather conditions. So to further understand the effect of waiting time on pedestrians, traffic volume and vehicle speed are considered as the variables for predicting waiting time.

2.2 Field Theory

In psychology, there is a social behavioural theory called Field Theory. It is used to understand social situations to find how variation in decisions happens due to other influencing factors.

Based on Lewin's (Field Theory) theory, individual behaviour is not based on a past event or future expectations. Based on Burnes (2004), field theory is completely based on the interaction between the individual and the current environment. Field Theory of learning allows individuals to sort out and understand a complex environment (Lewin, 1947).

Based on the concept of field theory, the essential social interaction can be constructed considering individuals as a pedestrian involved in the road environment to perform road crossing. The field or environment has stimuli with different positive and negative forces; the effect of different forces guides the pedestrian to cross the road. Also, the impact of various forces diverts a person from performing the choice or neglecting the choice.

2.3 ITS application for pedestrian facilities

In the field of traffic management system, automation has played a broad role in making the system work effectively and increasing safety. The pedestrians' red light crossing increases the risk of road users' safety. It is found that the red light crossing is increased with a longer waiting time, particularly during the last few seconds before crossing (H. Guo et al., 2011) & (O. Keegan and M. O'Mahony, 2003). When compared with traditional traffic lights, countdown displays can improve pedestrian signal compliance (Lipovac et al., 2013). Further, the application of ITS includes a set of technological solutions designed to coordinate, improve and increase the safety of road users (Lewicki et al., 2019) & (Lozano et al., 2020). ITS technology reduces the number of incidents and increases the comfort and satisfaction of pedestrians (Šimunoviæ et al., 2009). Recent research shows Vehicle to Pedestrian (V2P) based protection system always requires pedestrians to carry handheld devices, which is practically impossible for children, ages and illiterate pedestrians. A Vehicle to Vehicle (V2V) communication system is recommended using ITS technology (Hamdani et al., 2020). Another road safety concept is employing detectors and sensors along the road to predict crashes based on instantaneous traffic dynamics (Hossain et al., 2019). Different warning systems using personal devices for a pedestrian in road traffic have been reviewed in recent research (Andrei et al.,2020).

Further, an intelligent vehicle based on Pedestrian Detection System (PDS) is equipped to support the driver's safety (Kołodziej et al.,2022). A roadside pedestrian warning system detects pedestrians crossing via roadside sensors and warns drivers with a flashlight embedded on the pavement near road crossings (Hakkert et al.,2002; Høye et al., 2019). Understanding the working principle of ITS can improve the manoeuvre of the existing system more safely.

3. Materials and Methods

The following section describes the methodological steps adopted in the study with a detailed description of the methods adopted, followed by psychological theory for road crossing activity.

3.1 Methodology

The study primarily investigates pedestrian and vehicle interaction at the crosswalk. Further, the challenges faced while implementing ITS technology are overcome by queuing analysis to formulate criteria for grade-separated crossing. The sequential steps followed in the methodology are described in the following sub-section.

3.1.1 Case Study Location

The selected location is near a bus terminal from Kozhikode city, Kerala, India. The state of Kerala in India is located in the southwestern end of the Indian subcontinent, which lies between the Arabian Sea in the West and the Western Ghats (Sahyadris) in the East with an area of 38863 sq. km (Government of Kerala, 2022). Kozhikode is also known as Calicut second largest metropolitan city State of Kerala (Government of Kerala, 2022). Since the study location is at the main bus terminal (Indira Gandhi Road), it has the characteristic of having regular pedestrian and vehicle volume. The selected study location map is shown in Fig.1.

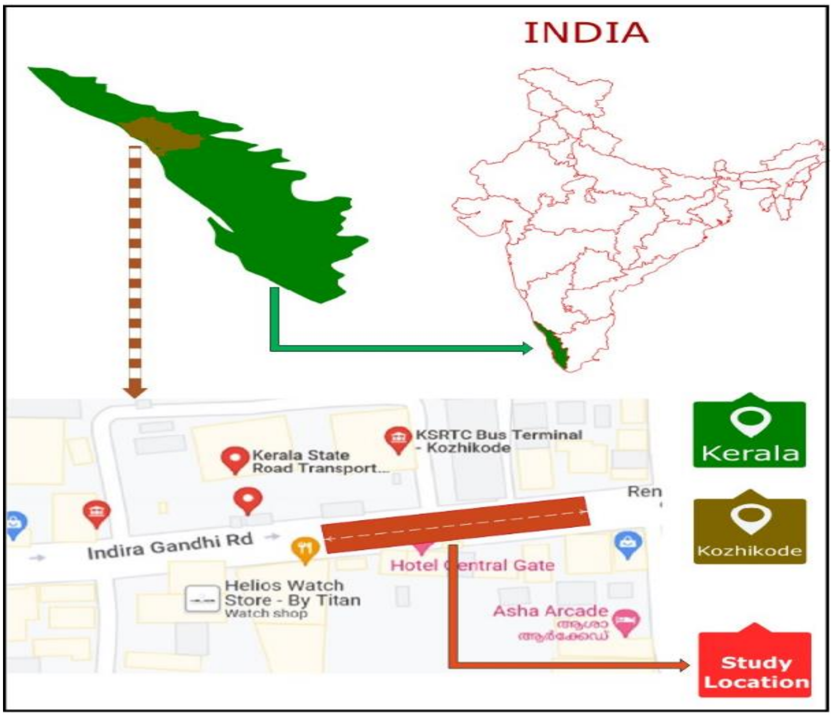

Figure 1: Survey Location in Kozhikode City

3.1.2 Data collection and extraction

Data collection is done using videographic survey by placing the camera at a suitable vantage point. Further, the video is recorded during the peak hours in the morning and evening for 3 hours. The total recorded duration, including morning and evening, is 6 hours, peak hour refers to the time at which more number of peoples are commuting for office or other purposes. Waiting time, speed and volume need to be extracted from the video to study the relationship between the pedestrian and vehicles. The data extraction process is accelerated by using a custom-made video player to save the data to excel format. The saved data contains pedestrian waiting time, vehicle speed and volume.

Further, the 5 minutes average value of each pedestrian and vehicle (speed and volume) is tabulated for further analysis.

3.1.3 Finding a relationship between vehicle and pedestrian

The consolidated 5 minutes set of data helps in understanding the vehicle and pedestrian interaction using a regression model. Further, the regression model results are used to perform sensitivity analysis by assuming a constant value for one variable and an incremental value for another variable. Sensitivity analysis derives relationships among the variables, which helps better interpret the regression model results.

3.1.4 Field Theory for Pedestrian Road Crossing

Field theory's conceptual idea is correlated to pedestrian road crossing decisions because the decision on pedestrian road crossing is influenced by several imaginary forces acting around them. The effect of positive and negative influencing forces on pedestrian road-crossing decisions is studied.

3.1.5 Evaluating the existing traffic control system and ITS-based improvement

The working principle of the existing traffic control system is studied, and the need for an automated system using ITS is studied by considering the interruptions encountered by pedestrians and vehicles at crosswalks.

3.1.6 Queuing system for formulating recommendations

If the encountered interruption is continuous at the traffic control system, there will be a constant queue which interrupts the traffic flow. Further, queuing analysis is performed using the regression model's output to formulate criteria for grade-separated crossing, which effectively regulate the ITS-based control system.

3.1.7 Tool for policymakers

The developed criteria for grade-separated crossing is made into a windows-based tool for policymakers. To analyse the output of the working tool, variables with fixed and varying inputs are given as input in the software tool for evaluating the performance.

3.2 Field Theory for identifying variable influencing Pedestrian Road Crossing decision

The field theory study shows that the behaviour of the individual's decision is based on the environment associated with the current situation. Hence, field theory can be correlated with the pedestrian road-crossing decision. Several factors influence the road crossing decision by the pedestrian at the crosswalk is initiated based on the imaginary force acting around. These imaginary forces are generated based on the interaction between the vehicle and the road-crossing environment. This imaginary force can be a positive force or a negative force, i.e., a positive force can encourage the pedestrian to cross the road through creating a favourable environment for safe crossing of the road. But the negative force may prevent the pedestrian from crossing the road through making an unfavourable condition for the pedestrian for safe crossing. Table 1 shows an example of positive and negative forces which influence the crossing decision. The examples of positive force can be driver yielding behaviour, the presence of fewer vehicles in the road, the presence of a signal, and the presence of zebra markings. An example of negative force can be an increase in speed of the vehicle, higher vehicle volume, no yielding behaviour of drivers, and increase in width of the road. The combination of forces influences the decision on the road crossing positively or negatively. When the road width is higher but there is a median available, the combination of positive force can influence the pedestrian to make a crossing decision. In general, when a pedestrian tries to cross the road, these negative and positive forces combinations act virtually on them, resulting in deciding to cross the road or make a decision to prevent road crossings. The influence of choosing to crossroad depends on the positive and negative forces acting around the pedestrian. Fig.2. shows the imaginary forces acting around pedestrians and vehicles for a mid-block location. The force can be positive or negative, depending on the pedestrian's environmental factors.

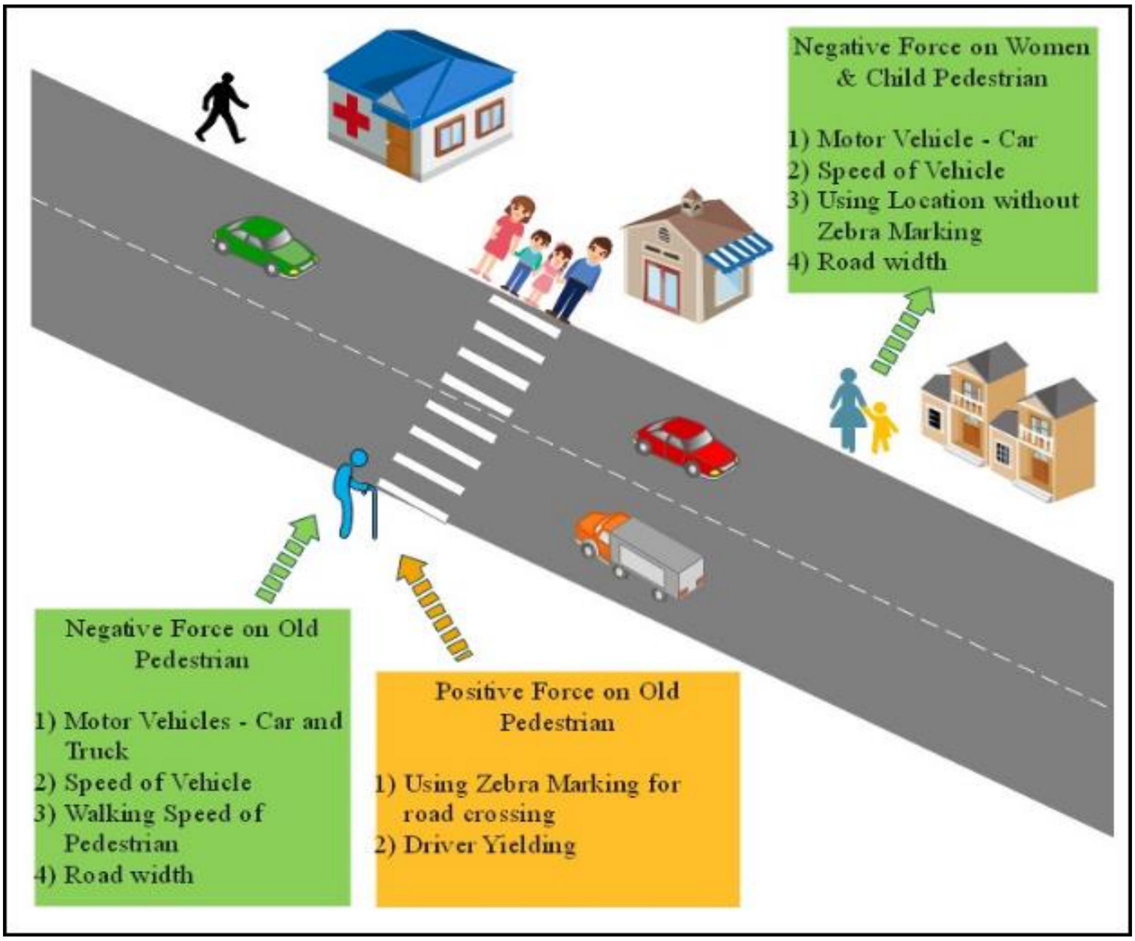

Figure 2: Forces around pedestrian at the midblock crossing.

However, the decision of a pedestrian depends on the number of vehicles and their speed on the road. If hindering forces dominate, the pedestrian decides to wait or sometimes decides to cross up to the median and then further decides to cross based on the road traffic. The concept of field theory is framed as a model by adding a complex situation with the effect of forces around them.

Table 1 Forces acting around road crossing pedestrians

Pedestrian Road Crossing Decision	*Positive influencing forces*	*Negative influencing forces*
Road Geometrics	Road width is lesser	Road width is higher
	Presence of median	Absence of median
	Straight Road	Presence of Sharp curves
Environmental Factors	Day, presence of street light	Fog, Rain, Night
	City Roads	Highways
Traffic Controls	Presence of Zebra Marking	Absence of Zebra Marking
	Presence of Signal	Absence of Signal
Vehicles	Speed is lesser	Vehicle crossing with high speed
	Volume is lesser	High volume
	Driver yielding yes	Driver Non-Yielding
Pedestrian Characteristics	Higher walking speed, Crossing in a group	Old, Poor vision, with luggage

4. Results and Discussions

The results of the developed model with the methods to improve existing facilities are discussed in the following section.

4.1 Analysing vehicle-pedestrian interaction

A multiple linear regression model was developed to analyse pedestrian interaction with the vehicle. From the extracted data, the pedestrian volume is found to be 618, and the corresponding average waiting time is 2.78 seconds. The volume of the vehicle for six hours is 10,955, and the average vehicle speed is 5.3 m/s. From the 5 minutes average data, a regression model has been developed to predict the waiting time for the pedestrian as the dependent variable, with vehicle speed and volume as the independent variable. The outliers that create extreme variation in values are removed from the dataset to improve the model's predictability. A regression equation was developed with ($F(2,64) = 114.87$, $p<0.05$) and an R square of 0.782. Pedestrian waiting time predict equal to 0.253 + 0.013 (Traffic Volume) + 0.076 (Vehicle speed) in seconds when traffic volume count average is calculated for 5 minutes, and vehicle speed (average for 5minutes) is measured in m/s. The model summary and prediction results are shown in Table 2 and Table 3. A similar trend was observed from a previous study with increasing waiting time for increasing traffic volume (Avinash et. al,2020). Further, the regression model result is used for sensitivity analysis by assuming a suitable base condition.

Table 2 Model summary

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*
1	.884[a]	.782	.775	.60788

a. Predictors: (Constant), SPEED (m/s), TRAFFIC VOL

Table 3 Regression model

Model		*Unstandardised Coefficients*		*Standardised Coefficients*		
		B	*Std. Error*	*Beta*	*t*	*Sig.*
1	(Constant)	0.253	.413		.613	.542
	Traffic Volume	0.013	.001	.846	11.603	.000
	Speed (m/s)	0.076	.091	.061	.837	.406

Dependent Variable: Waiting Time

Fig.3. shows the prediction of pedestrian waiting time for fixed vehicle speed and incremented vehicle volume. The vehicle volume is increased by ten units from 60, and for each vehicle's speed, the waiting time of pedestrians is predicted. Also, Fig.4. shows the prediction of pedestrian waiting time for increasing vehicle speed. From the analysis, it is observed that waiting time has a positive trend over vehicle volume. A similar increasing trend was observed for pedestrians waiting time and vehicle speed.

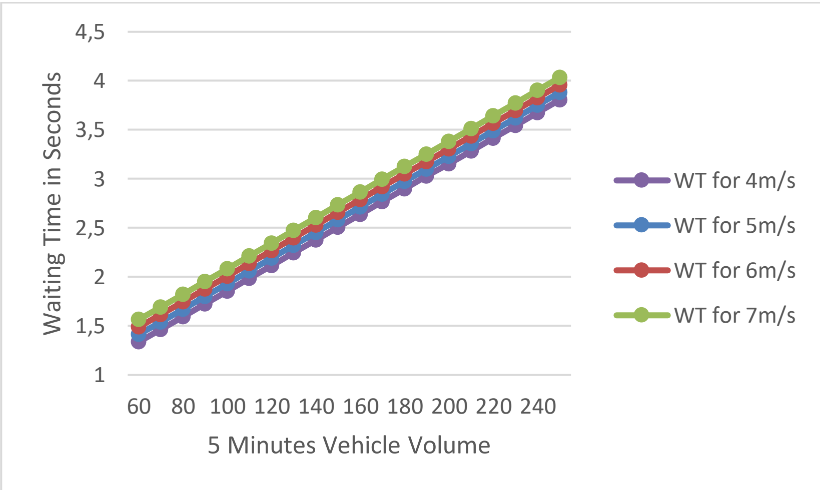

Figure 3. Relationship between vehicle volume and waiting time for different arrival speed

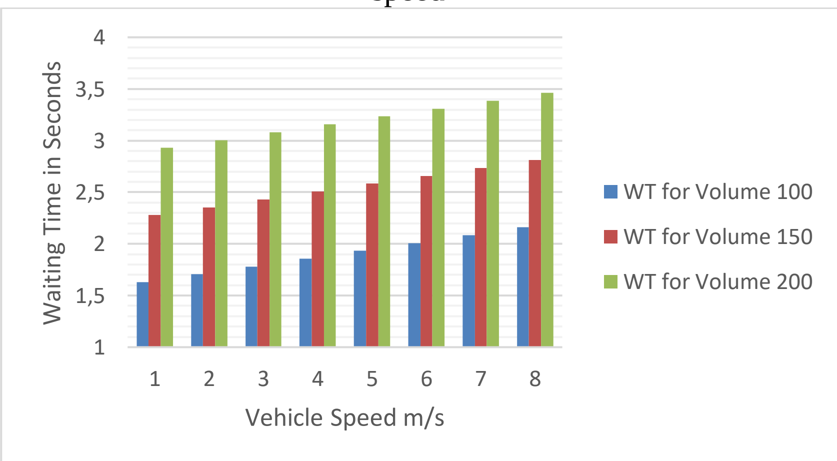

Figure 4. Relationship between vehicle speed and waiting time

4.2 Improving existing traffic control systems using ITS technology

The conceptual idea of field theory helps us understand the influence of different imaginary force that acts during pedestrian crossing activity. The existing traffic control systems, like signals and signboards, are the primary elements that control road traffic movement. The existing system is not automated and operates continuously with a specified interval of time. This system considerably impacts on driver's workload to scan every time while passing on the road section to make safe travel. About 64% of drivers in India on average, have regretted missing road traffic sign boards during their driving. Also, 24% of drivers in India follow google maps applications without making attention to the on-road traffic sign boards (Hatolkar,et al,2017). So the safety of every road user depends on the attention of driver on the road. The safety of pedestrians also depends on the decision by drivers. A driver approaching the zebra marking area should search for signboard, signal and pedestrian movement. When there is a chance of pedestrian movement, the driver should reduce speed and yield to pedestrians. Since the system has many elements, the driver approaching a crossing location should be very cautious. Also, the signal is operated at a regular interval of time which stops the vehicle drivers even when there is no pedestrian. Also, the pedestrian may tend to cross the road with high risk while motor vehicle drivers are not yielding. This scenario can be effectively regulated by converting the manual system to an automated system (ITS application) to help regulate the positive and negative forces acting around the pedestrian. The automated system will create an easy way for pedestrians to cross the road. The hindering forces which prevent the pedestrian's decision to cross can be channelised by the application of ITS. The current system of road crossing is operated with a fixed interval of signal timing, i.e., operated with a regular interval of time. The disadvantage of the system is that the signal will be operated without considering the variation in pedestrian and traffic volume. The system can be redesigned using ITS technologies called vehicle-actuated signals, which are operated based on pedestrian and vehicle demand. Designing a pedestrian signal on demand will make the system automated; the signal will be red for vehicle drivers only when there are pedestrians. Also, this eliminates the need for the installation of signboards, and drivers do not have to search for zebra marking signboards; vehicle drivers should yield only when there is a red signal. This automated signal prevents the driver from scanning for pedestrians on the road every time. Earlier research works are performed to study how the automated signal system can improve the working of the existing system (Zhao et al., 2012). When the system has an automated signal, the number of interruptions per hour will be greater, when the volume of pedestrians are high during peak hours. Due to this reason, the vehicle may be interrupted many numbers of times in the given duration with an increase in pedestrian volume. This increase in interruptions will also lead to the formation of a queue in road traffic. To avoid queue formation in the traffic system, the automated system is programmed with a fixed number of interruptions per hour based on the threshold values of pedestrian interruptions and vehicle volumes. The following section explores the design of an automated signal for a defined signal interval. This also helps to develop a criterion for grade separation based on vehicle percentage in a queue.

4.3 Development of criteria for a grade-separated pedestrian crossing facility

When the pedestrians and traffic volume exceeds the threshold values, queue formation arises for motor vehicles, resulting in a greater delay for pedestrians and motor vehicles. There is a need to redesign the signal control to avoid the formation of a queue on the road. Due to the increased number of interruptions by pedestrians because of the automated signal, the queue will be continuous. Grade-separated crossing eliminates the conflict between drivers and pedestrians. Also, grade-separated crossing can be provided when there are more positive forces (more pedestrians trying to cross the road, forcing the driver to yield), interrupting the regular traffic flow.

Further, a criterion has been framed using Queuing system to redesign a crossing facility to elevated or subway. The criteria create a threshold value for the pedestrian interruption and vehicle volume using queuing performance equations for signalised intersections (May, 1990). To use the queuing technique, the signal green time for pedestrians has to be calculated based on the assumption that the pedestrians are crossing at an average speed of 1m/s. So the time taken by the pedestrian to cross the 14m road width is 14 seconds.

Based on the assumption of a crossing time of 14 seconds, the number of interruptions per hour is considered as 20 to 60 with an increment of 2 for further analysis. A sample calculation is performed to estimate each interruption with an assumed arrival and service rate. The analysis results will show that the percentage of the vehicle will be in the queue for the given vehicle arrival rate and the number of interruptions, as shown in Table 4.

Table 4. Queuing analysis for varying vehicle arrival rate and number of interruptions

Interruption	*Pedestrian Green Time (s)*	*Time per interruption (s)*	*Vehicle Green per interruption (s)*	*Arrival Rate v/h*	*Service Rate v/h*	*A.R/ S.R*	*No of vehicle per cycle*	*% of vehicles queued*
20	14	180.0	166.0	500	2000	0.25	25	10.3
22	14	163.6	149.6	500	2000	0.25	22	11.4
24	14	150.0	136.0	500	2000	0.25	20	12.4
26	14	138.4	124.4	500	2000	0.25	19	13.4
28	14	128.5	114.5	500	2000	0.25	17	14.5
30	14	120.0	106.0	500	2000	0.25	16	15.5
32	14	112.5	98.5	500	2000	0.25	15	16.5
34	14	105.8	91.8	500	2000	0.25	14	17.6
36	14	100.0	86.0	500	2000	0.25	13	18.6
38	14	94.7	80.7	500	2000	0.25	13	19.7
40	14	90.0	76.0	500	2000	0.25	12	20.7
42	14	85.7	71.7	500	2000	0.25	11	21.7
44	14	81.8	67.8	500	2000	0.25	11	22.8
46	14	78.2	64.2	500	2000	0.25	10	23.8
48	14	75.0	61.0	500	2000	0.25	10	24.8
50	14	72.0	58.0	500	2000	0.25	10	25.9
52	14	69.2	55.2	500	2000	0.25	9	26.9
54	14	66.6	52.6	500	2000	0.25	9	28.0
56	14	64.2	50.2	500	2000	0.25	8	29.0
58	14	62.0	48.0	500	2000	0.25	8	30.1
60	14	60.0	46.0	500	2000	0.25	8	31.1

Fig. 5 shows the percentage of vehicles queued when there is a variation in the arrival rate (500 v/h to 1500 v/h) with a fixed service rate of 2000 v/h. It shows that the percentage of vehicles in the queue increases with an increment in the number of interruptions and vehicle arrival rate.

From queuing analysis (Mannering and Washburn, 2012),

$\frac{Arrival\ Rate}{Service\ Rate} > 1$, the queue will be continuous.

The queue will be formed when the arrival rate is higher than the service rate. The criterion can be formulated for different arrival and service rate with pedestrian green time. Development of such criteria will be helpful for policymakers and traffic management officials in deciding to provide appropriate pedestrian crossing facility with due consideration for pedestrian safety and traffic efficiency.

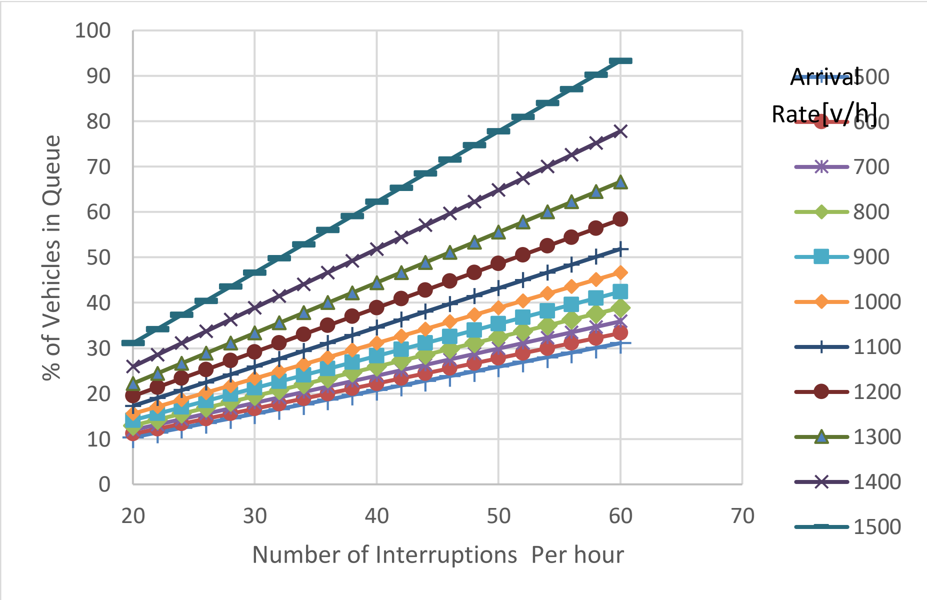

Figure.5. Percentage of vehicles in the queue for the varying interruption and arrival rates.

4.4 Tool to predict the vehicle queue formation at Midblock

A windows-based tool has been developed to use vehicle speed, volume, pedestrian speed, road widths, and service rate as input to find the criteria for grade-separated crossing. The image of the developed tool is shown in Fig.6 and Fig.7. The tool was developed based on the concepts used in the previous sections, 4.1 and 4.3. The combined result of both sections helps in identifying the criteria for grade-separated crossing. The prediction tool is designed with vb.net by the authors, and it can be used with any windows operating system. The application is a portable version that can be used without installation by transferring and using any copying device. This application can be used only at midblock sections, with the presence and absence of a signal. An example analysis using the prediction tool for varying input data (Fig.7) gives output on the percentage of the vehicles in the queue based on proposed road width, arrival rate, service rate and other pedestrian variables. Also, the tool uses the regression model equation from Table 3 as an input to find the waiting time of pedestrians.

Further traffic volume input from the regression model is used to predict the vehicle queue formation for various interruptions and other variables. Also, the Fig.8. shows an output of different variables with the vehicle arrival rate ranging from 50 to 200 Vehicles/5 minutes. The above range of vehicle arrival rate results in the maximum hourly flow of 2400 v/h. When the service rate is 2000v/h, the ratio of arrival rate to service rate results in an output of 1.2, which is greater than 1. This result shows that there will be the formation of a continuous queue at the midblock. Policymakers can use this tool to decide on grade-separated crossing or signalised crossing. If the tool shows the queue is continuous, the decision is to use grade-separated crossing for the pedestrian to avoid congestion in the road network. In the next section, the input value for different variables is changed to analyse the output of the software tool.

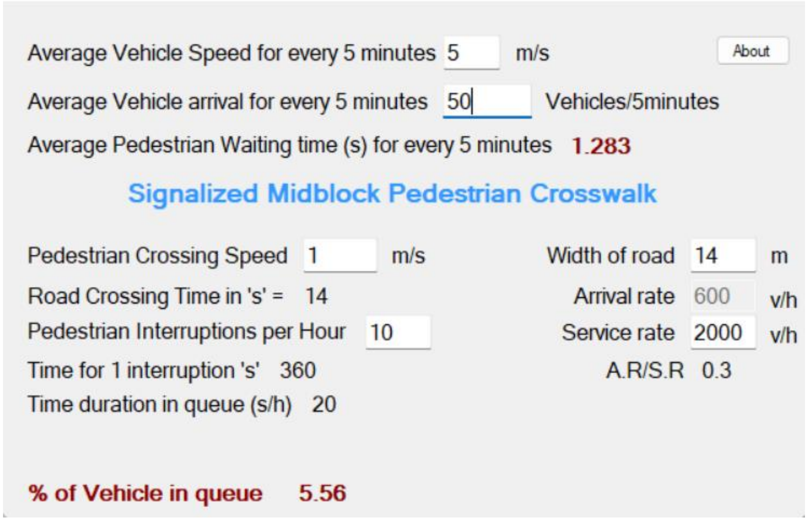

Figure.6. Application to predict the vehicle queue formation at midblock

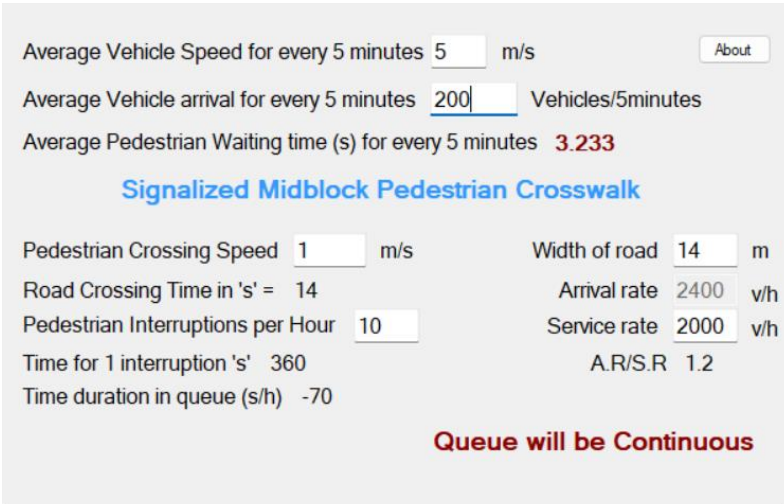

Figure.7. Vehicle queue status at higher arrival rate

4.5 Analysing the output from Queue formation software

An analysis is done to study the predicted output from the tool using different input values. The details of fixed input variables is shown in Table 5. Vehicle arrival for every 5 minutes is given as varying input with starting value of 10 vehicles per 5 minutes with a fixed increase of 10 counts on preceding inputs shown in Table 6.

Table 5 Variables with fixed values for queuing analysis

Variables	*Values*
Vehicle speed	5 m/s
Pedestrian speed	1 m/s
Road width	14 m
Pedestrian Interruption per hour	10
Service rate	2000 v/h

The output of the percentage of vehicles in the queue is calculated for different vehicle arrival rates. The results' details are shown in Table 6, and the graphical representation is shown in Fig.8. The analysis shows an increasing trend in the percentage of vehicles in the queue with an increasing arrival rate. Since the arrival rate is increasing for the fixed service rate, the percentage of the vehicle in the queue is observed to increase with an incremental arrival rate. When the vehicle arrival rate for every five minutes is more than 160, it will result in giving a continuous queue formation. The decision to redesign the existing facility or design a new facility can be made based on the output from the criteria for a grade-separated crossing facility.

Table 6 Sample input and output from the prediction tool

Vehicle speed m/s	*Vehicle arrival every 5 minutes*	*Pedestrian Speed m/s*	*Road width m*	*Pedestrian Interruptions*	*A.R v/h*	*S.R v/h*	*% Vehicle in Queue*
5	10	1	14	10	120	2000	4.14
5	20	1	14	10	240	2000	4.42
5	30	1	14	10	360	2000	4.74
5	40	1	14	10	480	2000	5.12
5	50	1	14	10	600	2000	5.56
5	60	1	14	10	720	2000	6.08
5	70	1	14	10	840	2000	6.71
5	80	1	14	10	960	2000	7.48
5	90	1	14	10	1080	2000	8.45
5	100	1	14	10	1200	2000	9.72
5	110	1	14	10	1320	2000	11.44
5	120	1	14	10	1440	2000	13.89
5	130	1	14	10	1560	2000	17.68
5	140	1	14	10	1680	2000	24.31
5	150	1	14	10	1800	2000	38.89
5	160	1	14	10	1920	2000	97.22
5	170	1	14	10	2040	2000	Queue is continuous
5	180	1	14	10	2160	2000	

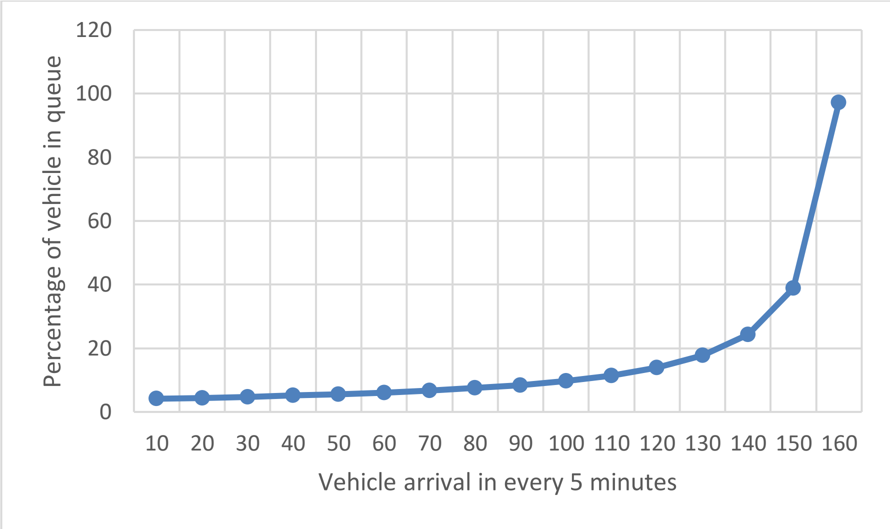

Figure.8. Prediction on percentage of vehicles in the queue at midblock

4.6 Discussion

Pedestrians are among the vulnerable road users as their behaviour is unpredictable in different circumstances. The discussion of results and their outcomes are presented in this section.

4.6.1 Pedestrian vehicle interaction

The regression model result identifies that the waiting time of pedestrians positively influences vehicle volume. Also, the waiting time positively influences the speed of the vehicle. This model helps in understanding the factors that influence the waiting time of pedestrians based on a motor vehicles on the roads. This waiting time prediction is used as an input for queuing analysis tool to predict the vehicle queue formation at midblock.

4.6.2 Application of ITS for traffic control system

During a travel activity, drivers need continuous attention on the road for various signboards and signals for decision-making. This prolonged continuous attention makes the driver get fatigued and frustrated, leading to traffic incidents. But this can be overcome by ITS technologies, which reduce the driver scanning time on the road for signs or signals. ITS application reduces the impact of imaginary positive and negative forces acting on vehicles and pedestrians. It is also observed the interruption will be continuous as the number of pedestrians and vehicle volume increases.

4.6.3 Queuing analysis for vehicle-pedestrian interaction

The fixed-time pedestrian crossing signals provided at the mid-block create frequent interruptions to the vehicular traffic leading to the formation of queue. The frequency and duration of the pedestrian signal decide the queue length and delay of the vehicles. Providing an automatic signal system with the required number of pedestrian interruptions based on traffic volume and number of pedestrians per unit time minimises the delay for both pedestrians and motor vehicles. A queuing analysis tool is developed to predict the vehicle queue formation on the road with a different number of pedestrian interruptions. This tool can be used as a guiding tool for policymakers in designing the automation system at a midblock. Further, if this tool predicts a continuous queue, it is recommended to have a grade-separated crossing.

5. Conclusion

This study analyses pedestrians' road crossing behaviour by identifying positive and negative forces exerted by vehicles, driver behaviour, and environmental factors. The nature of influence by the significant variables are evaluated through the regression model. Further, the vehicular traffic movement efficiency and pedestrian safety of the crossing facilities can be enhanced through the implementation of ITS technology-enabled traffic control systems by reducing the negative force acting on the environment. Based on the technology, vehicular traffic movement will be interrupted only when pedestrians try to cross the road. Otherwise, the signal indication allows the continuous movement of vehicular traffic. When the pedestrian volume increases, the number of interruptions to the vehicles also increases, leading to increased delay and queue formation. Hence, queuing system analysis is carried out to calculate the threshold value for the percentage of vehicles queued for different number of interruptions and vehicle volumes. From the above analysis, it is observed that the percentage of the vehicle in queue increases from 19.44% to 38.89% when the number of interruptions per hour is increased from 20 to 40 for the arrival rate of 1200v/h. Also, it is noted that the percentage of vehicles in queue increases from 19.44 % to 77.78% when the arrival rate increases from 1200 to 1800v/h with the 20 number of interruptions per hour . Based on queuing analysis, the percentage of vehicles in the queue varies based on pedestrian interruptions and vehicle arrival rate. The increase in pedestrian interruption per hour and the ratio of vehicle arrival and service rates will increase the percentage of vehicle queues.Developing similar criteria for varying road width and traffic volume can facilitate policymakers and highway officials to decide on the appropriate crossing facility required for the given situation. Also, this will help in prioritising the up-gradation of at grade crossing facility to a grade-separated one under limited resource scenario. The developed prediction tool can be used as a guiding resource for policymakers to choose grade-separated crossing based on the prevailing field conditions. The earlier studies shows that pedestrians are reluctant to use grade-separated crossing due to longer road crossing time (Ribbens, Hubrecht ,1996). But, when the grade separated pedestrian crossing facility is proposed based on the field conditions which mandate, the grade-separated pedestrian facility usage will be more and also improve the vehicular traffic movement with minimum delay and queue formation. The work can be extended in the future by studying pedestrian behaviour at crosswalks due to changes in weather conditions, i.e. rain and night time road crossing movement. The difference in environmental conditions has a considerable effect on the hindering force acting on the pedestrians.

References

Lewin, K. (1947) “Group decisions and social change”, In T. M. Newcomb, E. L. Hartley, T. M. Newcomb, & E. L. Hartley (Eds.), *Readings in social psychology*. New York: Henry Holt.

Burnes, B. (2004) “Kurt Lewin and the planned approach to change: A re-appraisal”, *Journal of Management Studies,* 41(6), pp.977–1002.

H. Guo, Z. Gao, X. Yang, and X. Jiang,(2011) “Modeling pedestrian violation behavior at signalised crosswalks in China: A hazards-based duration approach,” *Traffic Injury*

Prevention, vol. 12, no. 1, pp. 96–103.

O. Keegan and M. O'Mahony,(2003) "Modifying pedestrian behaviour,"*Transp. Res. A, Policy Pract.,* vol. 37, no. 10, pp. 889–901.

K. Lipovac, M. Vujanic, B. Maric, and M. Nesic,(2013) "The influence of a pedestrian countdown display on pedestrian behavior at signalised pedestrian crossings," *Transp. Res. F, Traffic Psychol. Behav*., vol. 20,pp. 121–134.

Ling, Z.; Ni, Y.; Li, K. (2012). "Modeling interactions between pedestrians and right-turn vehicles at signalised intersections", *CICTP 2012: Multimodal Transportation Systems*: Convenient, Safe, Cost-Effective, Efficient, 3–6 August 2012, Beijing, China, 2072–2084.

Hamed, M. M. (2001). "Analysis of pedestrian's behavior at pedestrian crossings". *Safety Science,* 38, pp.63–82.

S Hamdani, N Benamar and M Younis (2020) "Pedestrian Support in Intelligent Transportation Systems: Challenges, Solutions and Open issues", *Transportation Research Part C*.

Hossaina,M. Abdel-Aty, M. Quddusc,M.A, Muromachi,Y and Sadeeke, S.N (2019) "Real-time crash prediction models: State-of-the-art, design pathways and ubiquitous requirements", *Accident Analysis & Prevention*, pp. 66-84.

Andrei, V, Vasiliy, E, Gleb, R (2020) "Method of early pedestrian waring in developing intelligent transportation system infrastructure", *Transportation Research Procedia*, pp. 708-715.

Hakkert, A.S., Gitelman, V.; Ben-Shabat, E.(2002) "An evaluation of crosswalk warning systems: Effects on pedestrian and vehicle behaviour". *Transp. Res. Part F Traffic Psychol. Behav.* 5, pp.275–292.

Høye, A., Laureshyn, A. (2019) "SeeMe at the crosswalk: Before-after study of a pedestrian crosswalk warning system". *Transp. Res. Part F Traffic Psychol. Behav*, 60, pp.723–733.

Kołodziej, J., Hopmann, C., Coppa, G., Grzonka, D., Widłak, A. (2022). Intelligent Transportation Systems – Models, Challenges, Security Aspects. In: Kołodziej, J., Repetto, M., Duzha, A. (eds) Cybersecurity of Digital Service Chains. *Lecture Notes in Computer Science*, vol 13300.

Jamil, R., Xiong, S., Kong, X., Zheng, S. and Fang, Z. (2015). "Pedestrian crossing patterns preference at a non-signalised crosswalk." *Procedia Manufacturing*, 3, pp.3353-3359.

Andrew HW (1991). "Factor's influencing pedestrian cautiousness in crossing streets". J *Soc Psychol* 131(3) pp.367–372

Avinash Chaudhari, Shriniwas Arkatkar, Gaurang Joshi & Manoranjan Parida (2020), "Exploring stage-wise pedestrian-crossing behavioral patterns at vulnerable urban midblocks: a perspective under heterogeneous traffic conditions", *Journal of Transportation Safety & Security*, 12:7, pp.863-891.

Leden, L. (2002). "Pedestrian risk decrease with pedestrian flow. A case study based on data from signalised intersections in Hamilton, Ontario". *Accident Analysis and Prevention,* 34, pp.457–464

Lewicki. W, Stankiewicz. B, Olejarz-Wahba,(2019) " The role of intelligent transport system in the development of the idea of smart city". In *Proceedings of the 16th Scientific and Technical Conference on Transport Systems Theory and Practice*, Katowice, Poland,pp. 26–36.

Lozano Domínguez, J.M., Al-Tam, F. Mateo Sanguino, T.J., Correia, N.(2020)

"Analysis of machine learning techniques Applied to sensory detection of vehicles on intelligent crosswalks". *Sensors*.

Lj. Šimunoviæ, I. Bošnjak, S. Mandãuka(2009) "Intelligent Transport Systems and Pedestrian Traffic". *Promet – Traffic&Transportation*, Vol. 21, 2009, No. 2, pp.141-152.

Mannering, F.L., Washburn, S.S., (2012) *Principles of Highway Engineering and Traffic Analysis*, Fifth Edit. ed. John Wiley & Sons, Inc.

May, A.D., (1990) *Traffic Flow Fundamentals*. Prentice Hall, Inc, New Jersey.

Zhao, D., Dai, Y., Zhang, Z., (2012) "Computational intelligence in urban traffic signal control: A survey IEEE Transactions on Systems", *Man and Cybernetics Part C: Applications and Reviews* 42, pp. 485–494.

Ribbens, Hubrecht (1996). "Pedestrian Facilities in South Africa: Research and Practice". *Transportation Research Record: Journal of the Transportation Research Board*, 1538(1), pp.10–18.

Xie, D.-F.; Gao, Z.-Y.; Zhao, X.-M.; Wang, D. Z. W. (2012). "Cellular automaton modeling of the interaction between vehicles and pedestrians at signalised crosswalk", *Journal of Transportation Engineering* 138(12)pp.1442–1452.

Y Hatolkar, P Agarwal and S Patil. (2018). "A Survey on Road Traffic Sign Recognition System using Convolution Neural Network", *International Journal of Current Engineering and Technology* Vol.8, No.1.

M Fouladgar, M Parchami, R Elmasri, and A Ghaderi. (2017)." Scalable deep traffic flow neural networks for urban traffic congestion prediction", *International Joint Conference on Neural Networks* (IJCNN): 2251–2258. IEEE, 2017.

S Sharma and S Kumar Awasthi. (2022)." Introduction to intelligent transportation system: overview, classification based on physical architecture, and challenges", *International Journal of Sensor Networks*: Vol. 38, No. 4.

"About Kerala", *Government of Kerala (2022). https://kerala.gov.in/subdetail/NTM1ODMxNzQuNDg=/MjA0ODc2ODQuMzY=*.

"Road Traffic Injuries," *World Health Organization* (2022). https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries.

"Kozhikode", *Government of Kerala* (2022). https://kerala.gov.in/subsubdetail/MTg5MTE3MDguNjQ=/NTQ2MzM4MjQuOTY=

Acknowledgements

The authors sincerely thank the support received from the Centre for Transportation Research, Department of Civil Engineering, National Institute of Technology Calicut, a Centre of Excellence setup under FAST Scheme of MHRD, Govt. of India.