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4 authors:

Shenura Jayatilleke
Sri Lanka Institute of Information Technology

Vasantha Wickramasinghe
University of Peradeniya

Harsha Madushani
University of Peradeniya

Sunanda Dissanayake
Kansas State University

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Shenura Jayatilleke[1], Vasantha Wickramasinghe, Ph.D[2], Harsha Madushani[3], Sunanda Dissanayake, Ph.D. P.E[4]

[1]Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, 10115, Sri Lanka. Email: shenura.stefan@gmail.com
[2]Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, 10115, Sri Lanka. Email: vasantha.w@sliit.lk
[3]Department of Statistics and Computer Science, Faculty of Science, Univ. of Peradeniya, Peradeniya, Sri Lanka. Email: maduharsha1993@gmail.com
[4]Department of Civil Engineering, Kansas State Univ, USA. Email: sunanda@k-state.edu

ABSTRACT

Growth of road users in urban areas results in consequential higher interactions between pedestrians and vehicles causing delay to the mainstream traffic flow. The delay caused by pedestrians who make random jaywalking along the carriageway is substantial when such behavior exists. Thus, the prime objective of this research was to study the interaction and develop a delay model to estimate the collective delay caused to the mainstream traffic which encounters jaywalking pedestrians. This delay is influenced by the characteristics of the crossing pedestrians and the behavior of on-coming vehicles. The data collection was done in a suburban city near Colombo, Sri Lanka. The data were extracted from video footages taken using a drone camera. Both the movement of the vehicles and crossing pedestrians on the subject lane were tracked using automated software in order to enhance the accuracy of the results. The delay caused to mainstream vehicle was derived using the deceleration and acceleration behavior. The proposed delay model exemplifies that the pedestrian-vehicle gap and the pedestrian speed along with other relevant pedestrian characteristics such as age, pedestrian speed at the start of the vehicle speed drop and vehicle related characteristics such as vehicle speed at the start and end, veh-ped gap at the vehicle speed drop, subject lane and vehicle type are highly significant to the delay of the subject vehicle on the mainstream. The overall R value of 0.63 was observed from the regression analysis of the proposed delay model. The applicability of the proposed model for each pedestrian and vehicle characteristic has been determined and evaluated based on their level of significance.

Keywords: Delay model, Jaywalking pedestrians, Heterogeneous traffic

INTRODUCTION

The vehicle-pedestrian interaction is often observed on roads in various aspects consequentially resulting in delaying the mainstream traffic flow when yielding for jaywalking. The main objective of this research was to study the interaction between the jaywalking pedestrians and the subjected vehicle on the mainstream traffic and thereby develop a delay model for the vehicle with relevant influential characteristics and identify the relevant deceleration patterns of the mainstream traffic. Many previous studies were carried out to develop speed models to determine the delay, however those have been conducted under homogeneous conditions. As the conditions are much different in many developing countries, these methodologies are not applicable in heterogeneous traffic conditions. The study of influential pedestrian characteristics is vital as it contingents on the driver yielding behavior. Yielding to the jaywalkers causes delay to the subjected vehicle on the traffic flow, resulting in a high sustained delay to the mainstream traffic. This study therefore focused on developing a straightforward delay model for the subjected vehicle on the mainstream with contrast to the governing pedestrian and vehicle characteristics.

LITERATURE REVIEW

Many studies were conducted taking gender and age into consideration as these are potential factors that influence the gap acceptance behavior. Kadali and Vedagiri (2013) conducted a study, considering age and gender. They ended up finding that neither age nor gender is critical on the gap acceptance behavior. However, this result has many conflicts with other studies. Sun et al. (2003) and Das et al. (2005) showed that the age and gender have a substantial effect on the gap acceptance behavior. They also studied the pedestrian crossing patterns and found that pedestrians are more likely to cross in a staggered manner especially in a divided road where there is a higher traffic density on the median lane. Bassani et.al. (2013) found that an average speed reduction of 7.23 km/h is caused by the pedestrians sharing the right of way due to absence of side walk specifically on urban roads. Advani and Nisha (2013) found that high volumes of pedestrians walking beside the roadway leads to a lower speed on urban streets.

Shukla et al. (2016) established a speed prediction model for urban roads that are having considerable pedestrian engagements along the carriageway and found that a 0.35 km/h speed reduction occurs to the mainstream traffic flow for each and every pedestrian waking beside the side way. Varhelyi (1996) found that the average speed reduction of the mainstream traffic flow is 2 km/hr when a single pedestrian is present and about to cross the road on one side. The speed reduction increases to an average of 5 km/hr when there are multiple pedestrians present and about to cross from both sides of the road. Thiessen et al. (2017) found that pedestrian movements across the road cause an operating speed reduction of 2 km/hr.

Nevertheless, there are some studies which explains the traffic movement in contrast with empirical models or other adjustment factors. Bang (2006) conducted many studies in relation to the speed characteristics on urban roads with reference to the different factors that governs with different driver and pedestrian attributes. Hence a speed model was introduced, which is;

$$V_{average} = 48.7 - 0.011Y_1 - 0.015Y_2 \quad (1)$$

Where:

Y_1 = Vehicle volume on both directions (veh/h)

Y_2 = Pedestrian volume (ped/h/km)

Golakiya and Dhamaniya (2019) conducted a study in heterogeneous traffic conditions and proposed a regression model to find a speed of a specific vehicle under the influence of other vehicles. This model emphasizes more on the selected vehicular categorical speed given by;

$$V_j = a_0 - (£\ (a_i' \text{ x } n_i/V_i)-(a_k'\text{x } n_{ped}/V_j)) \quad (2)$$

Where:

n_i , n_{ped} = Coefficients for the i^{th} vehicle and pedestrians.

V_j = Vehicle speed of j^{th} vehicle (m/s)

V_i = Vehicle speed of i^{th} vehicle (m/s)

a_o = Regression coefficient representing the free flow speed of vehicle type j

a_j = Regression coefficient relevance to the impact of density on the free flow speed of the j^{th} vehicle category.

However, it was observed that, all of the previous studies which had evaluated the delay of the mainstream had only considered speed models, in finding the delay as to compare the actual speed with a standard base speed. Hence it is imperative to introduce a straightforward delay model by considering the governing pedestrian and vehicle characteristics in the form of a linear regression equation. Therefore, this study focused on the subjected pedestrian characteristics of the jaywalker such as pedestrian speed, gap and other related characteristics with contrast to the subjected vehicle characteristics such as the vehicle speed, type etc.

METHODOLOGY

Data Collection

Initially the locations were selected considering the vehicle and pedestrian densities during peak and off-peak hours. Given that the selected location resided with optimum pedestrian and vehicle densities and minimal road undulations yet with heterogeneous traffic conditions. Data were collected in a suburban area in Sri Lanka as shown in Figure 1. Figure 2 shows the aerial view of the selected site location. The considered road section is an A class two-way two lane divided dual carriageway section with a center median. This road section had a clear center median without barriers for a length of 142m. Data collection was carried out on Tuesday and Saturday from 4.00 pm to 6.00 pm after considering the vehicle and pedestrian densities of the selected section.

The considered space mean speed was around 40km/hr which is the urban speed limit. The vehicle headway consideration was done so that a minimum headway of 10m was to be maintained. However, the vehicle speed and headway were of minor deviations from the considered values due to the vehicle density variations in the upstream and the downstream of the main traffic flow. The selected road section was a flexible pavement having a uniform surface and negligible undulations. The selected road section of the location did not have any road humps, barriers or any potential disturbance for the subjected vehicles or pedestrians. The selected location did not have any curve or bent road sections and there was no detected longitudinal slopes on the road section.

Figure 1: Site location

Figure 2: Aerial view of the location

Data extraction

Data extraction was done in two stages. In the first stage, manual extraction of categorical variables and in the second stage, automated extraction of other variables with related to speed and distance.

Manual extraction of categorical variables of pedestrian related characteristics such as gender, age, body type, carrying bags or not, attire, leg status, crossing pattern, group size were carried out and the categorizations used are shown in Table 1. Manual extraction of vehicle related characteristics such as subjected lane and vehicle type are shown in Table 2. The extracted characteristics were categorized numerically as 0,1,2,3 with considering the ascending delay order of each characteristic respectively.

Table 1: Pedestrian related characteristic categorization

Gender		Age		Body type		Bag		Leg status		Attire		Crossing pattern			Group size	
Male 0	Female 1	45 Below 0	45 Above 1	Skinny 0	Fat 1	No Bag 0	With Bag 1	No limp 0	Limp 1	Trouser 0	Skirt/Sarong 1	Away 0	Straight 1	Towards 2	Single 0	Dual 1

Table 2: Vehicle related characteristic categorization

Subjected lane		Vehicle type			
0	1	0	1	2	3
First lane (Near)	Second lane (Far)	Motor Bike	Three wheeler	Car/ Van/ Jeep	Truck/ Lorry/ Bus

Automated data extraction was carried out using the tracking software "TRACKER-4.11.0"as the interface shown in Figure 3. Therefore, pedestrian speed, vehicle-pedestrian gap, vehicle speed, vehicle acceleration and deceleration, distance travelled by the subjected vehicle, actual time for vehicle speed recovery were taken.

Figure 3: Tracker analysis

The theoretical time for the vehicle speed recovery was calculated with respect to the recovery rates. Recovery rates were identified with three scenarios as (1) complete recovery, (2) over recovery and (3) under recovery.

Complete recovery as shown in Figure 4 was identified when the constant speed travelled by the vehicle before the jaywalking impact happened is completely recovered and the recovery process of the speed drop is only influenced by the jaywalking scenario.

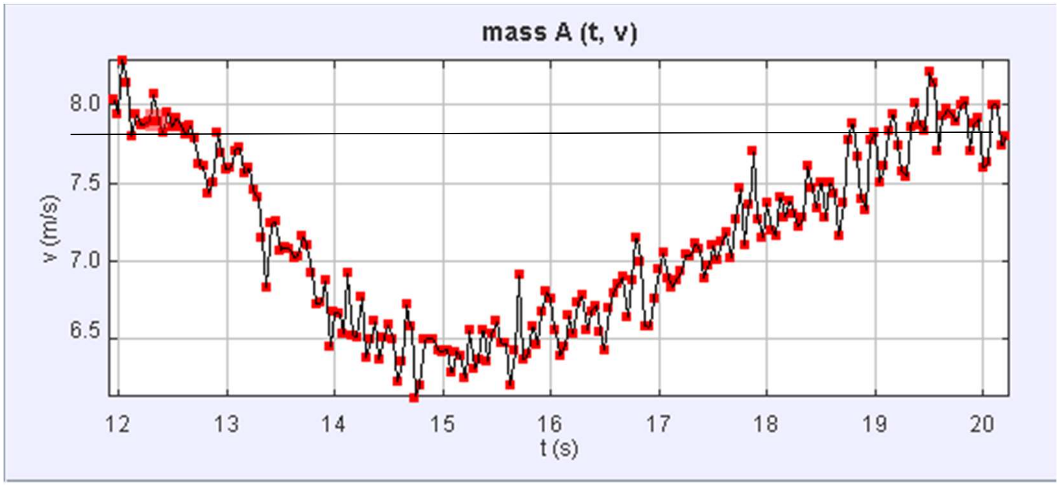

Figure 4: Complete recovery

Over recovery as shown in Figure 5 was identified when the constant speed travelled by the vehicle before the jaywalking impact happened is over recovered and the vehicle attains a higher speed than the drop at the start. The higher speed is attained due to the low vehicle density in the downstream. The recovery was considered as a complete recovery and only the speed until the drop happened at the start was considered as the influential jaywalking scenario.

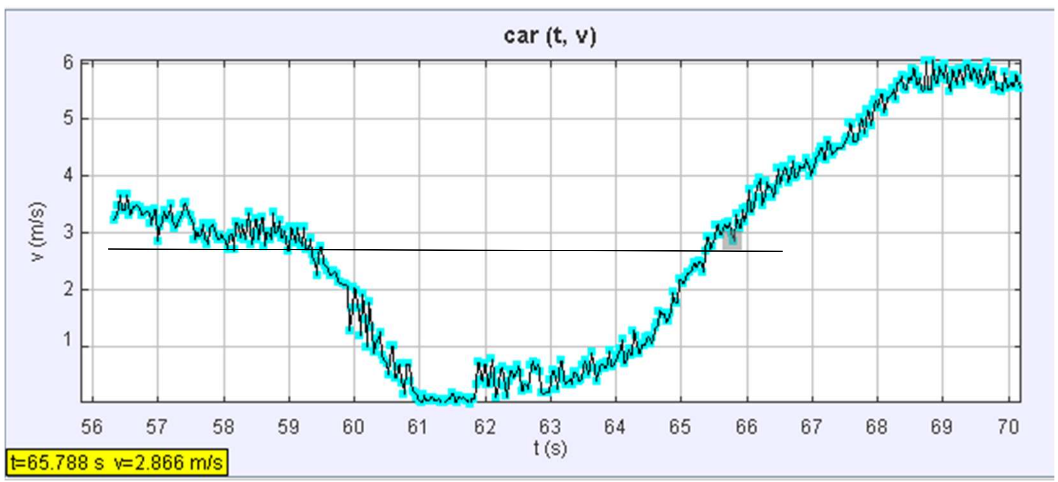

Figure 5: -Over recovery

Under recovery as shown in Figure 6 was identified when the constant speed travelled by the vehicle before the jaywalking impact happened is not recovered and the vehicle attains a lower speed than the drop at the start. The lower speed is attained due to the higher vehicle density in the downstream. The recovery was considered until a constant speed is attained and the extraction was done considering the vehicle is decelerating.

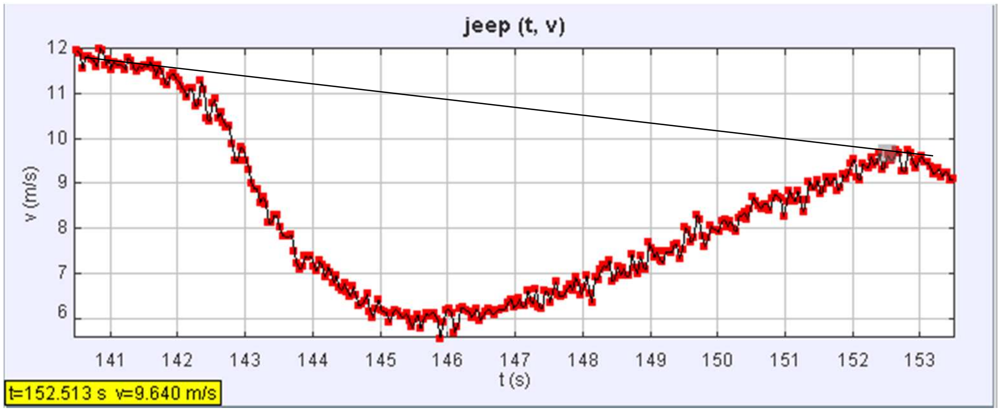

Figure 6: Under recovery

Theoretical time calculation for complete and over recovery was obtained from Equation 3 and under recovery was obtained from Equation 4.

$$T = \frac{\text{Distance travelled by the subjected vehicle}}{\text{Vehicle speed at the start}} \quad (3)$$

$$T = \sqrt{\frac{\text{Vehicle speed at the end} - \text{Vehicle speed at the start}}{\left(\frac{(\text{Vehicle speed at the end})^2 - (\text{Vehicle speed at the start})^2}{2 \times \text{Distance travelled by the subjected vehicle}}\right)}} \quad (4)$$

The delay caused to the subjected vehicle on the mainstream by jaywalking was computed from Equation 5.

$$\text{Delay} = \text{Actual time} - \text{Theoretical time} \quad (5)$$

Analysis method

Regression analysis was conducted to produce the linear delay model in the form of the multiple linear regression equation as shown in Equation 6.

$$Y = a_0 + a_1X_1 + \ldots + a_nX_n \quad (6)$$

Given that,
Y = Dependent variable (Delay of the subjected vehicle on the mainstream)
X = Independent variables from the pedestrian and vehicle characteristics
$a_0, a_1, \ldots a_n$ = Variable coefficients

The analysis was done in two processes as model fitting and model validation. The complete analysis was done with using the R-STUDIO software.

Model fitting was done for the training data set which was taken as 70% of the complete data set. Regression analysis was then performed with stepwise regression to identify the most significant variables in the delay model. The hypothesis is as below.

H_0 – There is no relationship between the dependent variable and the independent variable

H_1 – There is a relationship between the dependent variable and the independent variable

Model validation was performed for the test data set which was taken as 30% of the data set. Serial correlation was checked using Durbin-Watson test. The hypothesis is as below.
H_0 – There is no correlation in the residuals Vs. H_1 – There is a correlation in the residuals
Normality was checked using Anderson – Darling test. The hypothesis is as below.
H_0 – Data normally distributed Vs. H_1 – Data not normally distributed

The correlation between the test data and the training data were checked so that there is a minimal variation between the two data sets.

RESULTS AND DISCUSSION

Stepwise regression was done with having the vehicle delay as the dependent variable and other variables as independent variables. The stepwise regression was performed until all the individual variables attained a 95% confidence level of significance Such that the complete model obtains a R^2 value of 0.6388.

Results obtained from model fitting are shown in Table 3. The coefficient of each variable along with the individual significance and the relevant significance level is shown.

It was observed that the vehicle speeds and vehicle – pedestrian gap are highly significant towards the delay of the vehicle while the vehicle type, subjected lane, pedestrian age and speed are moderately significant towards the delay of the subjected vehicle. Nevertheless the complete delay model indicates a P value of 2.937×10^{-7} with a high R^2 value of 0.6388 which are satisfactory for practically obtained data. Thus, it was concluded that the model is acceptable as its relevant values are in the acceptable range.

Table 3: Individual variable significance

Parameter	Coefficient	Std. Error	t value	P value	Significance
Intercept	2.23649	0.71651	3.121	0.00325	***
Subjected lane	1.16780	0.43736	2.670	0.01074	*
Vehicle speed at the start	0.8421	0.17486	4.816	1.93×10^{-5}	***
Vehicle speed at the end	-0.08583	0.17070	-5.029	9.7×10^{-6}	***
Veh-Ped gap at the vehicle speed drop	-0.04292	0.01465	-2.931	0.00545	**
Pedestrian speed at the start	-0.08948	0.41336	-2.165	0.03613	*
Age	1.16649	0.63651	1.833	0.07395	.
Vehicle type	0.39856	0.18268	2.182	0.03478	*

*** Extremely significant, ** Very significant, * Moderately significant, · Less significant

As the main intention of the research was to find the delay of the subjected vehicle on the mainstream traffic due to the impact of illegal crossing pedestrians on suburban roads, the proposed delay model introduces the absolute delay of the subjected vehicle due to jaywalking. This delay is interpreted in seconds per vehicle (s/veh) as the jaywalking impacts directly to the subjected vehicle.

It was observed that the coefficient of the subjected lane is a positive value which can be interpreted that if the vehicle is travelling on the first lane and if the pedestrian is also at the start of the first lane and moving towards the second lane, then the delay is less. But if the vehicle is travelling on the second lane and pedestrian crossing direction is from the first lane towards the second lane then the delay of the vehicle is high. This delay difference due to the vehicle travelling lane is happened because of the yielding effect of the driver of the vehicle. In the first event the yielding effect is less whereas in the second event the yielding effect is high as the perception reaction time of the driver is high in the second event. A delay comparison of the subjected lane is shown in Table 4.

Table 4: Delay comparison of the subjected lane

Parameter	Event 1	Event 2
Vehicle position	On the first lane	On the second lane
Pedestrian position	At the start of the first lane	At the start of the first lane
Pedestrian crossing direction	From the first lane to the second lane	From the first lane to the second lane
Delay	LOW	HIGH

The coefficient of the vehicle speed at the start is a positive value, which means that if the speed of the subjected vehicle is high at the upstream then the delay caused due to jaywalking is also high as the speed drop could be potentially high and thereby the recovery is also potentially high. But if the upstream vehicle speed is low then the speed drop and the recovery is comparatively low.

The coefficient of the vehicle speed at the end is a negative value which can be interpreted that if the end speed of the vehicle is high then it is over recovered or complete recovered and the delay occurring due to jaywalking is less due to the acceleration event in the recovery phase. And if the end speed is low then it is less recovered and the delay occurrence is high due to the deceleration event in the recovery phase. A delay comparison of the vehicle speed at end is shown in Table 5.

Table 5: Delay comparison of the vehicle speed at the end

Parameter	Over recovered	Complete recovered	Under recovered
Downstream vehicle density	Low	Normal	High
Vehicle speed at the end	High (High acceleration and recovery)	Normal (Normal acceleration and recovery)	Low (Low acceleration and recovery)
Delay	LOW	NORMAL	HIGH

The coefficient of the vehicle and pedestrian gap at the vehicle speed drop is a negative value inferring that if the gap is low then the delay is high as there is a higher speed drop with small gaps. But if the gap is high then the speed drop is less and the delay is less due to the yielding effect and the perception reaction of the driver.

The coefficient of the pedestrian speed at the start of the vehicle speed drop is a negative value implying that if the pedestrian crosses the road with a high speed then the speed drop of the vehicle is low and if the pedestrian crosses the road with a lower speed then the vehicle speed drop and the recovery is high due to the yielding effect and the perception reaction of the driver.

The coefficient of the age is a high positive value which implies that if the age of the pedestrian is high the yielding by the driver is high which causes a higher delay.

The considered sample for vehicle type comprised of 31.4% of bikes, 14.3% of three wheelers, 47.1% of car/van/jeeps and 7.2% of truck/lorry/busses. The coefficient of the vehicle type is a positive value which suggests that for smaller vehicles such as bikes and three wheelers the delay caused is less and for heavy vehicles it is comparatively high.

Model validation results of Autocorrelation and normality are shown in Table 6.

Table 6: Model validation results

Name of the test	Result	
Durbin Watson Autocorrelation test	DW value = 1.716 (Between 1.5 and 2.5)	P value = 0.0888 > 0.05
Anderson Darling Normality test	AD value = 0.1624	P value = 0.9451 > 0.05

Therefore there is no serial correlation between the residuals and the residuals are normally distributed. The correlation coefficient was obtained as 0.45 which is an acceptable value for practically tested data. So, the model was completely validated thereby with satisfying all the relevant statistical checks and assumption in regression analysis. The delay model obtained from the stepwise regression for the subjected vehicle on the mainstream traffic flow is shown in Equation 7. The delay model attained an adequate fit for the linear regression.

$$\text{Delay} = 2.23649 + 1.16780A + 0.8421B - 0.08583C - 0.04292D - 0.08948E + 1.16649F + 0.39856G \quad (7)$$

Where,

A = Subjected lane of the vehicle (near/far)
B = Vehicle speed at the start of the drop (m/s)
C = Vehicle speed at the end after the recovery (m/s)
D = Vehicle-Pedestrian gap at the vehicle speed drop (m)
E = Pedestrian speed at the start of the vehicle speed drop (m/s)
F = Age of the pedestrian
G = Vehicle type

The obtained model is applicable in the context of the road parameters of the selected location. The accuracy can be further enhanced with the consideration of multiple locations with different road parameters.

CONCLUSIONS

In this research, regression modelling technique was used to introduce a delay model for the delay occurring to the subjected vehicle on the mainstream traffic due to illegal crossing by pedestrians on urban and suburban areas on road sections without center median barriers. The collective pedestrian and vehicle characteristics in a jaywalking situation, influencing to the delay were identified and analyzed in this study.

The delay of the subjected vehicle on the mainstream mainly depend on the variables such as the subjected lane, vehicle speed at the start, vehicle speed after the recovery of the speed drop, vehicle and pedestrian gap at the start of the vehicle speed drop, age of the pedestrian and the vehicle type. The analysis shows that the vehicle speed at the start and at the end are extremely significant whereas the vehicle pedestrian gap at the start is very significant and the subjected lane, pedestrian speed at the start of the vehicle speed drop and the vehicle type are moderately significant and the age of the pedestrian is less significant towards the collective delay of the subjected vehicle on the mainstream traffic flow.

This study is the first study that has been carried out considering the pedestrian characteristics such as speed and gaps while introducing a straightforward delay model in heterogeneous traffic conditions. Accordingly, this study will be useful to estimate the collective delay from such pedestrian characteristics in straight road sections.

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