Estimation of Capacity Decrease and Delay Caused by Mid-block Crossing Pedestrians

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Crosswalks are designed to help people cross the street safely and help the traffic operate properly. However, in Vietnam, people habitually cross at mid-block locations and there are not many crosswalks designed on streets, which imposes negative impacts on the traffic performance. This research focuses on estimating the capacity decrease and traffic delay caused by mid-block crossing pedestrians. The capacity decrease is calculated in four cases based on the number of groups of pedestrians crossing the street in one minute. The traffic delay (temporal effect) is estimated for the cases of motorcycles (nearly 70 percent of all vehicles) and cars under a certain traffic volume condition in a certain period of time. The results of the research will help the city planners and traffic engineers solve the current problems and predict the future problems relating to crossing pedestrians.

Key Words *: mid-block crossing, pedestrians, capacity, delay*

1. INTRODUCTION

Traffic designers often suppose that pedestrians will cross roadways at designated crosswalks. However, observation of pedestrian behavior clearly indicates that people habitually cross at mid-block locations. Very few pedestrians choose to go out of their way to cross at an intersection. Most of them prefer to take the most direct route possible to get to their destination, even if this means crossing several lanes of high-speed traffic.

Especially in Vietnam, most of the pedestrians do not have the habit of crossing the road at crosswalks. They are likely to do it only when the place they want to approach is accidentally near a crosswalk. It is because to most people, crossing the street where they want to and when they want to is easier than waiting until they get all the way to the crosswalk and the little green man lights up. Though it is a fact that there are not many crosswalks designed on streets in Vietnam, it does not mean pedestrians can allow themselves to cross the road anywhere they want. It is no doubt that sudden street crossing imposes negative impacts on the traffic performance, let alone traffic accidents.

The interaction of pedestrians and drivers at unsignalized crosswalks was explored in the report of "*A Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalks*" (Schroeder, 2008). Through logistic regression techniques, the microscopic data were used to derive predictive models for driver yielding and pedestrian crossing behavior. The analysis found that pedestrian and driver decision-making processes are sensitive to the dynamic profile of the vehicle, pedestrian characteristics and other concurrent events at the crosswalk. By relating the yield outcome to the dynamic state of the vehicle, a region of vehicle dynamics constraints was defined where virtually no yields are observed. Pedestrian assertiveness was found to be a key variable for promoting yielding behavior and increasing the likelihood of a pedestrian crossing. A contrast of the behavioral models for driver yielding and pedestrian crossing found a generally better model fit for the latter category. It is reasoned that the pedestrian decision is strongly influenced by the temporal duration to the point of conflict and the consequences of a poor decision. With a lack of enforcement, a driver is more easily swayed in the decision of whether or not to yield. The pedestrian crossing data are thus more consistent than the yielding data, resulting in models with greater statistical power. The evaluation of two pedestrian crossing treatments found that the treatments resulted in expected increases in the likelihood of drivers yielding, but also promoted more aggressive pedestrian behavior. For a pedestrian-actuated treatment, the effect on yielding was found to be greater following activation.

Regarding the impacts of crossing pedestrians create on the traffic flow, this matter was discussed by Meneguzzer *et al* (2011) in their article of "*Evaluating the impact of pedestrian crossings on roundabout entry capacity*". In the study, an empirical approach to the estimation of roundabout entry capacity in the presence of significant levels of pedestrian crossing volumes was developed on the basis of experimental observations. Impedance caused by pedestrians to approaching traffic is quantified using crosswalk occupancy time, rather than pedestrian volume.

Gao *et al* (2012) paid their attentions to the pedestrian and vehicle conflict system as whole. The different conflicts between pedestrians and vehicles induce traffic delay and decrease urban the efficiency of road traffic at a certain extent. Based on characteristics and conflict scenes analysis of pedestrian and vehicle behaviors at isolated signalized intersection, 4 types of pedestrian and vehicle behavior rules were described, the pedestrian - vehicle inference courses by once and twice pedestrian crossing are expatiated, then, 3 delay models of pedestrian - vehicle system were established. The authors took a big intersection in Beijing as an example, a simulation case was calculated. Data showed that: due to twice pedestrian crossing, the system delays are 14.3% and 7.4% less than once one at a.m. and p.m. peak time separately.

This paper consists of 5 main parts; each part deals with its relevant aspects. This research's overview and literature review are presented in this section, Section1 – Introduction. The research objectives are presented and elaborated in Section 2. Section 3 describes in detail the methodology used in this paper. The results are scrutinized in Section 4. Finally, the paper ends with several conclusions presented in Section 5.

2. OBJECTIVES

The paper is meant to find out the impacts of pedestrian crossings at mid-block locations on the traffic flow. Two main factors are taken into consideration, namely, traffic capacity and traffic delay, which means that the study aims at two main objectives as below:

(1) To estimate the decrease of capacity caused by crossing pedestrians;

(2) To find out the temporal effect (delay) of crossing pedestrians on vehicles under a certain traffic condition during a certain period of time.

3. MODEL DEVELOPMENT

Pedestrian crossing activities and the movements of the affected vehicles are studied through the analysis of the field data collected by a direct observation of pedestrian activities using two video cameras placed at two different positions as follows:

- One camera was set up overhead at the study site, right angles to the direction of vehicle traffic to record the movements of vehicles and pedestrians;
- Another camera was placed on the pavement beside the street to record the characteristics of affected drivers including gender and number of people on the vehicles.

Recording time is about 7 hours. The study site is located in Hanoi downtown, which is a two-way street with the road width of 11 meters. There is an elementary school on one side of the street and two bus stops on two sides of the street.

(1) Estimation of the decrease of capacity

According to the observation made from viewing the videos, in 1 minute, there are at most 3 groups of pedestrians crossing at the road segment. It is supposed that the traffic capacity varies and is commensurate with the number of pedestrian groups.

The objective of this part is to present the methodology to find out the relationship between traffic flow and mean stream speed in 4 cases of no pedestrians, 1, 2, and 3 groups of pedestrians; whereby the capacity change can be estimated.

As a matter of fact, it is difficult to estimate the traffic volume under heterogeneous traffic flow unless different vehicle types are converted into a common unit. Since motorcycles cover the biggest proportion among all transportation modes in Vietnam, it is better to use motorcycle unit (MCU) instead of passenger car unit (PCU) to calculate traffic volume.

The traffic volume data were collected for every 1 minute then were converted to an equivalent flow rate with the unit of motorcycle per hour (MCU/h). In addition, to satisfy the requirement of dimensional analysis in the computation, the speed unit of meter per second was also converted to kilometer per hour (km/h).

Table 1 Recommended MCU's factors for vehicles by the conversion of Indian Roads Congress (IRC)

No.	Type	MCU
1	Cycle	0.80
2	Motorcycle	1.00
3	Car	2.00
4	Minibus	4.40
5	Bus	8.00

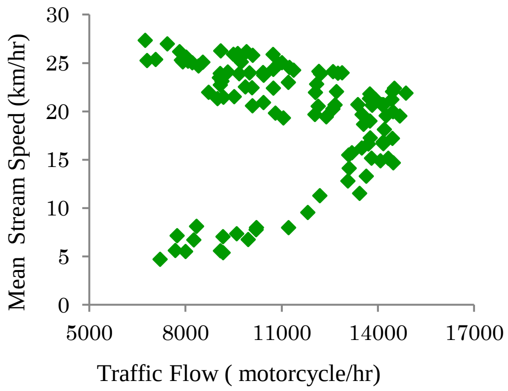

Fig.1 Example of scatter plot diagram showing the relationship between traffic flow and mean stream speed
Source: Adopted from Nguyen *et al* (2011)

The relationship between traffic flow (Q) and mean stream speed (V) is described as an exponential function as follows:

$$Q = a\,V \exp(-V/b) \qquad (1)$$

Where, Q: traffic flow (MCU/h)
V: mean stream speed (km/h)

For different cases of different numbers of pedestrian groups, the flow – speed functions are shown as below:

In case of
$N = 0$: $Q_0 = a_0\, V_0 \exp(-V_0/b_0)$
$N = 1$: $Q_1 = a_1\, V_1 \exp(-V_1/b_1)$
$N = 2$: $Q_2 = a_2\, V_2 \exp(-V_2/b_2)$
$N = 3$: $Q_3 = a_3\, V_3 \exp(-V_3/b_3)$

In which, N is the number of pedestrian groups in 1 minute.

In order to identify the parameters, non-linear regression analysis was conducted. In this research, the non-linear regression analysis process was performed by using SPSS (Statistic Package for Social Sciences) program.

The program performed the non-linear regression analysis and provided the author with the results of estimated parameters, R^2 value, etc.

The traffic capacity can be determined by calculating the maximum point of the flow – speed curve, whose function format is y = a.x.exp(-x/b).

To find the maximum value of the above function, its derivative was obtained as below:

$$y' = a\, e^{\frac{-x}{b}}\,(1 - \frac{x}{b})$$

Let y' = 0, we have 1 – x/b = 0; therefore, x = b, y = a b exp(-1)

Applying the results to equation (1), the capacity and critical speed can be calculated easily.

(2) Estimation of the delay of affected vehicles

Delay is the additional travel time experienced by a driver, passenger or pedestrian due to circumstances that impede the desirable movement of traffic. This research studies the temporal effect of crossing pedestrians on individual affected vehicles. Since the impacts crossing pedestrians cause to motorcycles and cars are different from each other, it is necessary to divide the affected vehicles into two groups of motorcycles and cars, which were then dealt with separately in the research.

a) Estimation of the delay of affected motorcycles

The objective of this part is to present the methodology to estimate the effects of specific factors on the travel time of the affected motorcycles.

SEV program was utilized to extract the data for the calculation of vehicles' speed. To capture the change of speed of the vehicle with time, the interval was set at 0.5 seconds.

It is assumed that if there are no pedestrians, vehicles will keep running at the initial speed (v_0).

The assumed factors are as follows:
- The initial speed of the vehicle (v_o)
- Traffic volume during the time the pedestrians are - crossing the street (Q)
- Pedestrian group size (N)
- Gender of the driver (G)
- Number of people on the vehicle (P)

Function for Δt is assumed to be linear, which means, $\Delta t = a_1.\, v_o + a_2.Q + a_3.N + a_4.G + a_5.P + a_6$

Delay Δt can be calculated as below:

$\Delta t = t_p - t_0$

$$t_0 = \frac{S}{v_0} \qquad t_p = \frac{S}{\bar{v}_t}$$

$$\bar{v}_t = \frac{\sum_{j=1}^{k} \frac{\sqrt{(x_j - x_{j-1})^2 + (y_j - y_{j-1})^2}}{0.5}}{k}$$

Where,
Δt: delay (s)
t_0 : imaginary time the vehicle spend to travel distance S at initial speed v_0 (s)

t_p: real time the vehicle spend to travel distance S (s)
v_0: initial speed of the vehicle (m/s)
$\bar{v}_t$: average speed of the vehicle (m/s)
S: affected distance of the vehicle (m)
x_j, y_j: coordinates of the vehicle at time step j
k: total number of intervals

As a matter of fact, when facing a crossing person, in most of the cases, drivers will decrease the speed to avoid collision. The unconditioned reaction of people when their movement is obstructed by some hindrance can also account for the drivers' behavior of decreasing their speed. However, there are still some cases, though very few, in which the drivers increase their speed when seeing a crossing pedestrian so that they can get through the road segment where the crossing person may affect their movement before the pedestrian reaches that place.

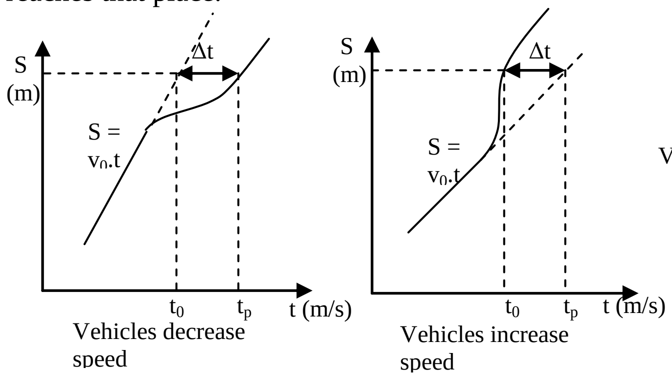

Fig.2 Temporal effect in two cases of vehicles decreasing and increasing speed

Because the function for Δt is assumed to be linear, the LINEST function of Microsoft Excel was employed to find the parameters of the function. With the returned output, the funtion of the dependent variable Δt can be obtained.

b) Estimation of the delay of affected cars

The objective of this part is to present the methodology to estimate the effects of specific factors on the travel time of the affected cars.

SEV program was employed to extract the data for the calculation of cars' speed. To capture the change of speed of the vehicle with time, the interval was set at 0.5 seconds.

It is assumed that if there are no pedestrians, vehicles will keep running at the initial speed (v_0).

The assumed factors are as follows:

- The initial speed of the vehicles (v_o)
- Traffic volume during the time the pedestrians are crossing the street (Q)
- Pedestrian group size (N)

Therefore, delay (Δt) is a function of v_o, Q, and N or $\Delta t = f(v_o, Q, N)$.

Function for Δt is assumed to be linear, which means, $\Delta t = a_1.v_o + a_2.Q + a_3.N + a_4$

Delay Δt can be calculated by the same formulas as shown in the previous part. Then, because the function for Δt is assumed to be linear, the LINEST function of Microsoft Excel was employed to find the parameters of the function. With the returned output, the funtion of the dependent variable Δt can be obtained.

4. RESULTS AND ANALYSIS

(1) Estimation of the decrease of capacity

This part presents the findings from the calculation of the relationship between traffic flow and speed, as a result of which, the comparison of capacity among the 4 situations of no pedestrians, 1, 2, and 3 groups of pedestrians crossing at the road segment can be obtained.

A visual image showing the relationship between traffic flow and mean stream speed was presented in the form of a scatter diagram as shown in Figure 3.

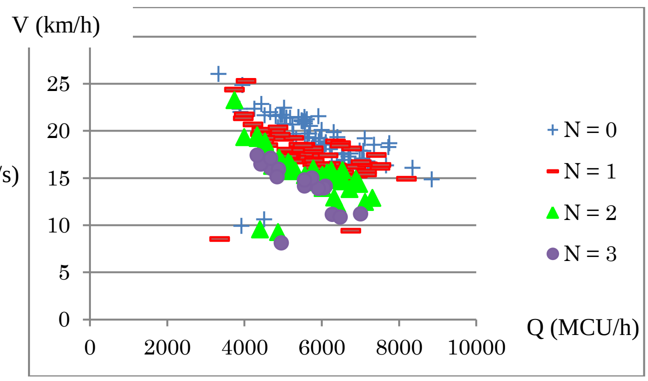

Fig.3 Scatter diagram of the relationship between Traffic flow and Speed

The data of traffic volume and speed were input into SPSS program for regression analysis process.

The following table shows the results of parameter estimation returned by the non-linear regression analysis for the function format of Q = a*V*exp(-V/b) (Eq.1) for the 4 cases of no pedestrians, 1, 2, and 3 groups of pedestrians crossing at the roadway section.

Table 2 Estimated parameters

Parameter / No of pedestrian groups	a	b
N = 0	1785.929	10.966
N = 1	1786.806	10.363
N = 2	1826.191	9.583
N = 3	1921.520	8.875

Replace a and b of Eq. 1 with corresponding values, the functions for each case were obtained as follows:

N = 0: $Q_0 = 1785.929\ V_0\ e^{\frac{-V_0}{10.966}}$

N = 1: $Q_1 = 1786.806\ V_1\ e^{\frac{-V_1}{10.363}}$

N = 2: $Q_2 = 1826.191\ V_2\ e^{\frac{-V_2}{9.583}}$

N = 3: $Q_3 = 1921.520\ V_3\ e^{\frac{-V_3}{8.875}}$

For each case of N = 0, N = 1, N = 2, and N = 3, the R^2 scores are 0.424, 0.390, 0.447, and 0.559, respectively.

The R^2 score of 0.424 means that 42.4 percent of the variance of the dependent variable can be explained by the model. Because R^2 scores ranging between 0.30 and 0.60 generally denote a good model fit, the model of flow-speed relationship function for the case of N = 0 can be verified and considered good. The same goes for the other flow-speed functions in the cases of N = 1, N = 2, and N = 3. Therefore, the relationship of traffic flow and mean stream speed at the study site under various conditions relating to the number of crossing pedestrian groups can be explained by corresponding functions as stated above.

In order to find the traffic capacity, a.k.a. maximum flow, it is necessary to identify the maximum point of the curve expressing the flow-speed relationship (May, A. D., 1990).

Based on the derivative derived from function (1), which is

$y' = a\ e^{\frac{-x}{b}}(1 - \frac{x}{b})$, the maximum flow and optimum speed in each case were obtained as shown in Table 3.

Table 3 Capacity and Optimum speed

	Q_{max} (MCU/h)	V_{opt} (km/h)
N = 0	7204.734	10.966
N = 1	6811.902	10.363
N = 2	6438.033	9.583
N = 3	6273.628	8.875

The table shows the capacity and optimum speed in different cases of different numbers of groups of pedestrians crossing at the road segment. The differences in capacity and optimum speed can be clearly described in 2 figures 4 and 5:

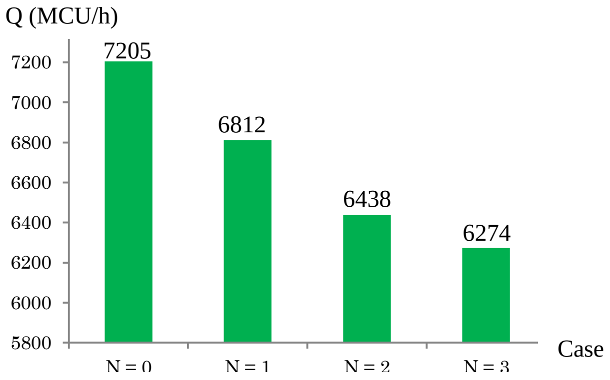

Fig.4 Comparison of traffic capacity among different cases

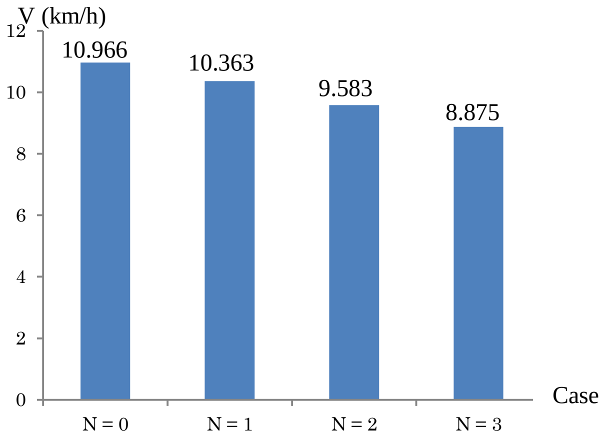

Fig.5 Comparison of speed among different cases

Figure 4 and Figure 5 clearly show that the capacity and optimum speed are inversely proportional to the number of crossing pedestrian groups. The more people cross the street, the lower the capacity and the optimum speed are.

(2) Estimation of the delay of affected vehicles

a) Delay of motorcycles

After all data were extracted from the videos, useable data were selected to be analyzed. There were several cases in which data became useless. For example, sometimes when there was a presence of a crossing person and a vehicle slowed down, but it was because the driver wanted to make a turn to reach a nearby store, not because of the pedestrian reason. In another case, sometimes a vehicle speeded up when a pedestrian was managing to cross the street, it was not because the driver had noticed that the distance from their position to the pedestrian was safe enough for him/her to speed up and get around, it was because he/she had been distracted and had not been aware of a crossing person. Those were some typical reasons why many data were considered unusable. To recognize and eliminate such kind of unreliable and misleading data, there was no other way but observation from videos. After the extraction and filtration of data, the number of motorcycle samples selected to be analyzed was 554.

As presented in the previous part, delay Δt can be expressed as a function of v_o, Q, N, G, and P as follows: $\Delta t = a_1 . v_o + a_2.Q + a_3.N + a_4.G + a_5.P + a_6$

Where, Δt: traffic delay (s)

v_o: the initial speed of the vehicle (m/s)

Q: traffic volume during the time the pedestrians are crossing the street (veh.)

N: pedestrian group size

G: gender of the driver

P: number of people on the vehicle

Table 4 Estimated parameters for the delay function of motorcycles

	P	G	N	V_0 (m/s)	Q (10^{-5}veh/m)	Int.
Para.	0.22	-0.15	0.021	0.01	-5.56	-0.1
Std. error	0.01	0.013	0.006	0.003	1.85	0.033
T value	13.3	-11.6	3.58	3.44	-3.01	-3.3

R-Squared = 0.45

Table 4 presents the results of parameter estimates for the delay function of motorcycles.

According to the results presented in Table 4, it can be concluded that number of people on the motorcycle (P), gender (G), and pedestrian group size (N) are the factors that have a great influence on the delay of motorcycles; while the initial speed of the motorcycle (Vo) and the traffic volume (Q) at the time pedestrians cross the street create less influence on the delay of a motorcycle.

The R^2 score of 0.45 means that 45 percent of the variance of the dependent variable can be explained by the model. Because R^2 scores ranging between 0.30 and 0.60 generally denote a good model fit, this model of delay function can be verified and considered good.

b) Delay of cars

According to the observation from viewing the videos and primary analysis of extracted data, most of the cars decrease their speed when facing a crossing pedestrian. It is easy to understand because a car needs more space than a motorcycle to make a trajectory change, thus, in most of the cases, slowing down is the only way for cars to avoid any conflict when there is a presence of anything blocking their way and vision.

After the extraction and filtration of data, the number of car samples selected to be analyzed was 41.

As presented in the previous part, delay Δt can be expressed as a function of v_o, Q, and N as below:

$$\Delta t = a_1 . v_o + a_2.Q + a_3.N + a_4$$

Where, Δt: traffic delay (s)

v_o: the initial speed of the vehicles (m/s)

Q: traffic volume during the time the pedestrians are crossing the street (veh.)

N: pedestrian group size

Table 5 Estimated parameters for the delay function of cars

	N	V_0 (m/s)	Q (10^{-5}veh/m)	Int.
Para.	-0.12	0.05	30	-0.05
Std. error	0.07	0.02	6.25	0.15
T value	-1.62	3.23	4.76	-0.33

R-Squared = 0.53

Table 5 presents the results of parameter estimates for the delay function of cars.

According to the results presented in Table 5, it can be concluded that the initial speed of the vehicle (v_o) and traffic volume (Q) have a great influence on the delay of cars; while the pedestrian group size creates less influence on the delay a car.

The R^2 score of 0.53 means that 53 percent of the variance of the dependent variable can be explained by the model. Because R^2 scores ranging between 0.30 and 0.60 generally denote a good model fit, this model of delay function can be verified and considered good.

5. CONCLUSIONS

Although there have been a number studies concerning the interaction of crossing pedestrians and vehicular traffic as mentioned in part 1, there has not been any research studying the impacts of crossing pedestrians at mid-block locations on the traffic flow in terms of capacity decrease and delay.

Therefore, this research was conducted to find out the impacts of pedestrian crossings at mid-block locations on the traffic flow. Two main factors were taken into consideration, namely, traffic capacity and traffic delay. The results of the study has answered the two main questions as follows: (1) how much the capacity decrease is due to crossing pedestrians and (2) how much the temporal effect (delay) crossing pedestrians create on vehicles under a certain traffic condition during a certain period of time.

Regarding capacity decrease, the study has provided the models showing the flow – speed relationship of the four cases of no crossing pedestrian, 1, 2, and 3 groups of crossing pedestrians. The results helped the author come to the conclusion that the capacity and optimum speed are inversely proportional to the number of crossing pedestrian groups. The more people cross the street, the lower the capacity and the optimum speed are.

On the subject of the delay crossing pedestrians create on vehicles, the study has given the models showing the effects of specific factors on the travel time of the affected motorcycles and cars.

According to the models developed in the study and the primary results of the study, some conclusions could be drawn as follows:

- Number of people on the vehicle, gender, and pedestrian group size are the factors that have a great influence on the delay of motorbikes.
- Initial speed of the vehicle and traffic volume have a great influence on the delay of cars.
- Number of people crossing the street in a period of time has a great influence on the delay of the traffic flow.
- 25% of the vehicles increase their speed when facing a crossing pedestrian.
- 70% of the speed-increasing drivers are male.

The results of the research will hopefully help the city planners and traffic engineers solve current problems and predict the future problems relating to crossing pedestrians.

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