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Assessment of pedestrian-vehicular interaction at un-signalized intersections to measure the delay caused by crossing pedestrian on platoon vehicles

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Abstract

Purpose – This study aims to validate a model for estimating platoon delay due to pedestrian crossing for use in Kuwait City.

Design/methodology/approach – The model was modified slightly for the scenario used in Kuwait, in which the presence of raised crosswalk meant that all incoming traffic would slow down automatically. Using video footage to observe the site, several variables were collected, and a model was used to calculate the delays suffered by the vehicles because of pedestrian crossing. The model was validated using the actual footage and manual observation to measure the delays.

Findings – The model showed a good match fit to the observed data, as the average delays differed by 22.5% between the two methods. Following the comparison, a sensitivity analysis was made on three variables: the acceleration rate, deceleration rate, as well as the pedestrian walking time. The analysis has shown that deceleration rate has approximately twice the effect on the model than the acceleration rate has. It has also shown that the pedestrian walking time has a major effect on the model, in an almost one-to-one correlation. A 50% change of the pedestrian walking time is associated with approximately 50% change in the model's output delay.

Originality/value – A model for estimating platoon delay because of pedestrian crossing was validated for use in Kuwait City. The model was modified slightly for the scenario used in Kuwait, in which the presence of raised crosswalk meant that all incoming traffic would slow down automatically.

Keywords Crosswalk, Pedestrian, Platoon, Delay, Kuwait

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1. Introduction

Crosswalks are common urban elements found in all cities around the world. Not only are they significant to the safety of the crossing pedestrians, but they also play a significant role in both the vehicle's and pedestrian's traffic flow. Among the various types of crosswalks, unsignalized crosswalks are the most common because of their low installation costs, which makes them a flexible solution to improve pedestrian crossing. They are also considered a safer setting in comparison to the hazardous jaywalks, which would occur in locations where crosswalks are not provided (Feliciani *et al.*, 2020). Thus, this study will focus its area of research on unsignalized crosswalks.

Crosswalk installations are mostly located near the junctions connecting bus stops and close to land use facilities and services such as buildings, leisure regions and stores (Gitelman *et al.*, 2017). Crosswalk crossing pedestrians are the most vulnerable among other highway consumers, as they are exposed to the environment, thus are at risk of being involved in a pedestrian–vehicular conflict (Wang *et al.*, 2019). In case of such scenario, the hazard is mostly on the pedestrian's side rather than the vehicle. While the only hazard on the vehicle might occurs if the vehicle driver follows a swerving movement pattern to avoid crashing the pedestrian, thus strikes other vehicles or items (Nasernejad *et al.*, 2021).

Traffic conflict is a very mature field, from simulation to trajectory data extraction has been very good application. Conflicts between pedestrians and vehicles mostly occur because of misunderstanding the behaviors of both parties, or because of distractions caused from either side (Feliciani *et al.*, 2020).

Previous studies were performed to investigate pedestrian–vehicular conflict cases. Alhajyaseen and Iryo-Asano (2017) found that one of the most unpredictable pedestrian behaviors leading to a higher conflict occurrence rate are sudden maneuver speed changes, whereas Chen *et al.* (2017) found that a higher exposure to pedestrian–vehicle conflicts occur with the presence of right-turn vehicles. It was also found that as the waiting time for pedestrians to cross increases, they start getting impatient and cross under hazardous conditions, which increases the risk of conflicts to occur (Tiwari *et al.*, 2007). This relates to the concept of the gap-acceptance theory, in which each pedestrian has a specific critical gap value. If the pedestrian deems that the gap in traffic is greater than the critical gap value, they will to cross the street (Golakiya and Dhamaniya, 2020).

Previous experimental investigations were also performed to understand the factors affecting pedestrian's and vehicle driver's behaviors, and how they perceive each other. In general, it was concluded that the behavior of pedestrian crossing has a significant impact on pedestrian–vehicle interaction, especially at unprotected crosswalk places (Zhang *et al.*, 2018). Factors such as pedestrian's gender and age were studied in terms of their impact on the pedestrian's crossing velocity. It was found that males run quicker than females and youthful people stroll quicker than adults (Bowman and Vecellio, 1994; Coffin and Morrall, 1995; Fitzpatrick *et al.*, 2006a, 2006b; Holland and Hill, 2007; Koushki, 1988), whereas older people's perception of the danger associated with crossing behavior during street traffic is greater than that of younger pedestrians (Lord *et al.*, 2018). Behavioral studies also showed that that choice of gap acceptance is primarily based on the approaching vehicle's speed, the distance between the vehicle and pedestrian, size of pedestrian groups and waiting time before crossing (Sheykhfard and Haghighi, 2020). Soares *et al.* (2021) also concluded that the pedestrian's crossing velocity was influenced by both their visual perception ability and speed anticipation ability. It was also found that pedestrians tend to adjust their crossing velocity at crosswalks, based on multiple factors such as highway and environmental and traffic circumstances. Pedestrian velocity is also influenced by different variables such as the traffic quantity, pedestrian platoon, road sort and parked cars (Knoblauch *et al.*, 1996).

Furthermore, it was concluded that numerous traffic paths and intersection phases have a significant impact on pedestrian's crossing velocity, with the running velocity being independent of the number of routes (Almodfer *et al.*, 2017). The type of vehicle was also found to influence crossing behavior, with faster crossing speed associated with heavier vehicles rather than smaller ones, which is again higher than the crossing speeds associated with two wheelers (Kadali and Vedagiri, 2020). According to the previous literature, there is an inverse relationship between pedestrian velocity and traffic delay. Reducing the crossing time of pedestrian through proper design of traffic light signals and geometric parameters of crossing areas will decrease dramatically the vehicle delays.

A model assessing pedestrian safety at unsignalized crosswalks showed that high reaction time of drivers, small safety margin time, and visual obstacles near crosswalks increase the probability of serious pedestrian–vehicle conflicts (Zhu *et al.*, 2021). Several factors, such as vehicle diversity, undisciplined road users, lack of infrastructure facilities and weak enforcement of traffic laws, increase the difficulty of road use for nonmotorized users. In India, a study to understand pedestrian gap acceptance behavior at unsignalized intersections, under heterogeneous traffic conditions, was performed. The study showed that because of the lack of discipline among drivers, pedestrians were forced to accept short vehicular gaps, which increase the risk of pedestrian–vehicle conflicts (Vasudevan *et al.*, 2020).

The pedestrians' crossing at unsignalized crosswalks cause vehicular delay, forming a platoon. A model estimating the delay incurred by platoon vehicles because of pedestrian activity at crosswalks showed that pedestrian's walking time was the variable to significant impacts on vehicular delays (Forde and Maina, 2017). While Bonneson and Fitts (1999) predicted the delay in vehicles through the development of four models: a lane flow-rate model, a merge capacity model, a merge-delay model and an overflow probability model.

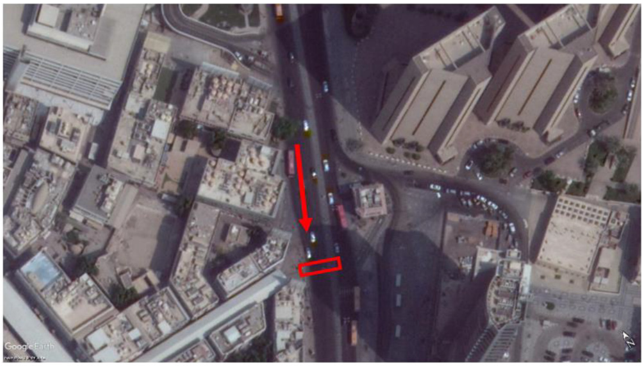
2. Objectives

This research aims to study the pedestrian–vehicular interaction at unsignalized intersections, in terms of the delay suffered by vehicles because of pedestrian crossing. To do so, a model for estimating platoon delay due to pedestrian crossing was validated for use in Kuwait City. The model performed by Forde and Maina (2017) was modified to suit the actual scenario found in Kuwait. That scenario being, that the presence of raised crosswalks caused all incoming traffic to slow down automatically. Using video footage to observe the crossing pedestrians at the crosswalk site, several variables were collected. The model was then validated using the actual footage to measure the delays. Following the comparison, a sensitivity analysis was performed on three variables: the acceleration rate, deceleration rate, as well as the pedestrian walking time.

3. Data collection

The site chosen for the study was a raised crosswalk in Ahmad Al-Jaber Street as indicated in Figure 1. The crosswalk extends across a two-way, four-lane street, with a median separating the two directions. It is also approximately 200 m downstream from a four-way intersection and 154 m upstream from the following intersection, allowing vehicles to approach it from all directions.

Video footage of the intersection was collected on April 2, 2019. All necessary permits from the Kuwait's Ministry of Interior were acquired beforehand. A COUNTcam mini, mounted on a tripod, was placed on site and set to focus on the crosswalk as shown in Figure 2. The camera could record up to 50 h of continuous footage. The tripod was raised



Source: Authors' own work

Figure 1. Study site with the direction of study shown

Source: Authors' own work

Figure 2. Sample of video footage

over 3 m from the ground to obtain the optimum view of pedestrians as well as incoming traffic.

In total, 6½ h of footage were collected during prime-time traffic, which was found to be between 8:45 a.m. and 3:15 p.m. Also, the footage was taken during suitable weather conditions (Max. 26°), prompting more pedestrian flow. Footage was then viewed and analyzed to obtain the necessary information for the model development. Not all vehicle platoon cases, nor all pedestrians crossing cases were taken as inputs for the model. The criteria for choosing the cases were pedestrian(s) crossing causing the vehicles to stop and free-flowing traffic with no congestion.

Three variables were collected from the recordings to be used in the model. The first was the pedestrian walking time, defined as the time from when the first pedestrian enters the crosswalk until the time the last pedestrian leaves it. The second variable was the time spent by the leading vehicle in full stop. Because the raised crosswalks cause all vehicles to automatically decrease their speed, whether pedestrians are present or not, therefore only the cases where the leading vehicle came to a full stop were considered in this study. The third variable was the time each subsequent vehicle in the platoon took to cross a certain reference point, taken in this study as the beginning of the raised crosswalk. Following the observation of the footage as well as performing on-site trials, it was determined that the average speed of vehicles was 40 km/h. It was also determined that the leading vehicles require 6 s to decelerate their speed from the upstream until the raised crosswalk, while requiring 3 s to reaccelerate their speed after passing the crosswalk, to return to their normal speed.

In total, 74 cases of vehicular delay caused by pedestrian crossing were recorded, with the platoon size ranging from one to six vehicles.

4. Methodology

4.1 Observed and model methods

Two different methods were performed in this study for comparison and validation. The first method was based on the observed average delay of the vehicles, which was found through observing and analyzing the recordings. The delay of the leading vehicle was calculated by adding the vehicle's stopping time to the deceleration and acceleration time (6 and 3 s, respectively). Based on the finding that the average vehicle speed at the location is 40 km/h, it was determined that the vehicles need an average of 6.75 s to cross the study distance, which was approximately 75 m in length. That time was subtracted from the total delay time to find the delay caused by the pedestrians crossing alone. The delay of the subsequent vehicles, on the contrary, was calculated by adding the leading vehicle's delay time to the time the following vehicle needed to cross the beginning of the raised crosswalk, which as stated previously, was chosen a reference point in this study.

The second method was based on modifying the model found by Forde and Maina (2017) which estimates the delay incurred by platoon vehicles because of pedestrian activity at crosswalks. The modification was performed in a way to suit the scenario found in Kuwait City. Therefore, equation (1) was created to estimate the delay of the leading vehicle in a two-lane crossing:

$$D = \frac{0.28\ S_f}{2}\left(\frac{1}{R_d} + \frac{1}{R_a}\right) + \left(\frac{3L_{cw}}{4S_{ped}} - \frac{0.28S_f}{R_d}\right) \tag{1}$$

where:

S_f = is the free flow speed (km/h);

R_d = is the deceleration rate (m/s^2);

R_a = is the acceleration rate (m/s^2);

L_{cw} = is the length of the crosswalk (m); and

S_{ped} = is the walking speed of pedestrians (m/s).

All subsequent vehicles' delays were calculated using the following equation (2):

$$D_i = D_{i-1} - \phi \tag{2}$$

where ϕ is the headway between vehicles, which is assumed to be 1 s based on our observations of the bunched vehicles.

5. Results

A summary of the results found using Microsoft Excel to calculate all delays through both methods is shown in Table 1. The second method (model method) differed from the first (observed method) by an average of 22.5%, with the maximum average delay in seconds/vehicle being 31.625 and 28.63 for the model and observed method, respectively, whereas the minimum average delay was found to be 4.09 and 4.25 s/vehicle for the model and observed methods, respectively.

Figure 3 indicates the trend line of the observed method used as validation of the model method. The coefficient of determination R^2 of the baseline is 0.65, which indicates how closely each data point fits the regression line, meaning that the model accounts for 65% of the variation between the observed and predicted values.

5.1 Sensitivity analysis

The results of the model show a close matching fit between the model and observed methods. Yet, it does not explain the variables most likely affecting the results of the model. Therefore, a sensitivity analysis was performed on three variables: the acceleration rate, the deceleration rate and the pedestrian walking time. By increasing and decreasing the base values of one of these variables by 50%, and maintaining the remaining variables the same, we can obtain a clear picture of what affects the model the most. Figure 4 shows the model results associated with increasing the acceleration rate, whereas Figure 5 indicates the results associated with decreasing the acceleration rate.

The data shows that increasing the acceleration rate by 50% decreases the average vehicle delay by 5.1% as opposed to the baseline method, while increasing the R^2 to 0.666. While decreasing the acceleration rate by 50% increases the average vehicle delay by 15.3% compared with the baseline method, however this leads to a decrease in R^2 to 0.648. As for the deceleration rate, the data shows that increasing it by 50% from that used in the baseline

Table 1. Summary of observed and model results

Comparison	Observed method	Model method
Average delay (s/veh)	10.75	9.46
Standard deviation	5.104	4.230

Source: Authors' own work

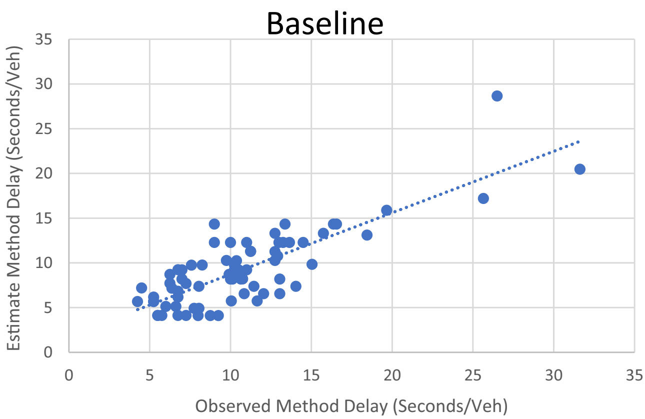


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Figure 3. Baseline model method versus observed method

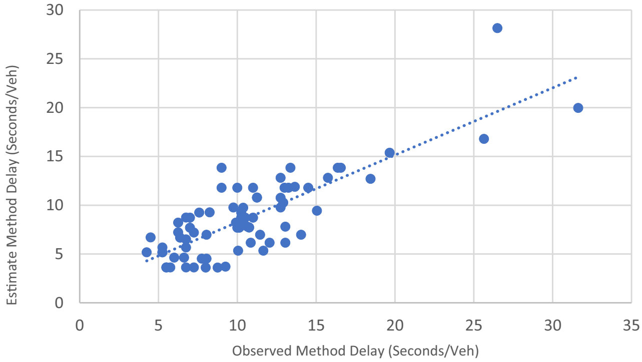

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Figure 4.
A 50% increase in acceleration rate versus observed method

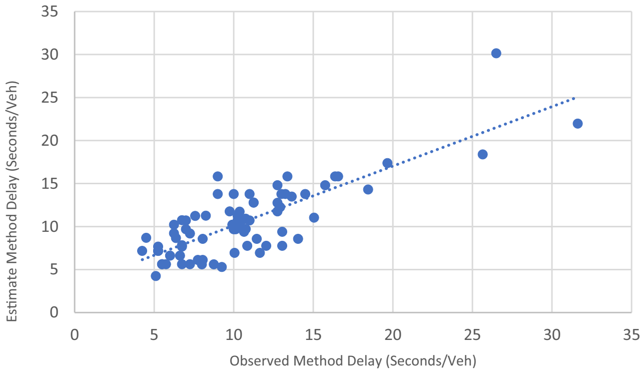

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Figure 5.
A 50% decrease in acceleration rate versus observed method

method showed a 10.3% increase in the average vehicular delay, but leading to a decrease in R^2 to 0.648, whereas decreasing the deceleration rate by 50% was proven to decrease the average vehicular delay by 30.5% and lead to a better fit with R^2 at 0.687.

Figures 6 and 7 indicate the results of increasing and decreasing the deceleration rate, respectively. Table 2 compares between the results of the sensitivity analysis, where it shows that decreasing the deceleration rate has the most significant impact on the model, while increasing the acceleration rate has the least significant impact.

Performing the sensitivity analysis on the pedestrian's walking time showed that increasing the pedestrian's walking time by 50% as opposed to the baseline method increases the average vehicular delay by 52.27% and changing the R^2 to 0.65. While decreasing the pedestrian's walking time by 50% from the baseline method decreases the average vehicular delay by 52.17%. Those numbers indicate how extremely sensitive the model is to changes occurring in the pedestrian's walking time. Figures 8 and 9 indicate the results of increasing and decreasing the pedestrian's walking time, respectively. Table 3 compares between the results of the sensitivity analysis in terms of the pedestrian's walking time, indicating how significantly the variable effects the model.

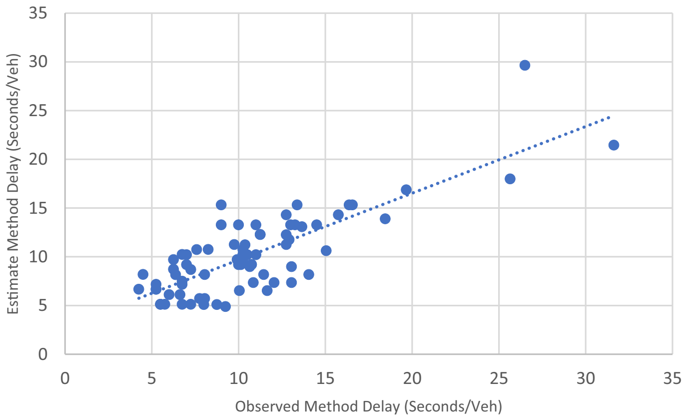

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Figure 6.
A 50% increase in deceleration rate versus observed method

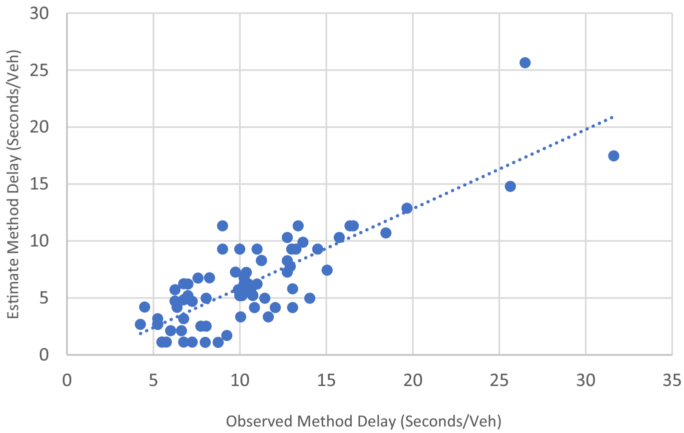

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Figure 7.
A 50% decrease in deceleration rate versus observed method

Comparison	Baseline method	50% increase in acc. rate	50% decrease in acc. rate	50% increase in dec. rate	50% decrease in dec. rate
Average delay (s/veh)	9.46	8.97	10.9	10.42	6.57
Standard deviation	4.23	4.22	4.24	4.24	4.21
Min. delay (s/veh)	4.09	3.59	5.29	4.89	1.09
Max. delay (s/veh)	28.63	28.14	30.14	29.64	25.64

Source: Authors' own work

Table 2.
Sensitivity analysis on acceleration and deceleration rates

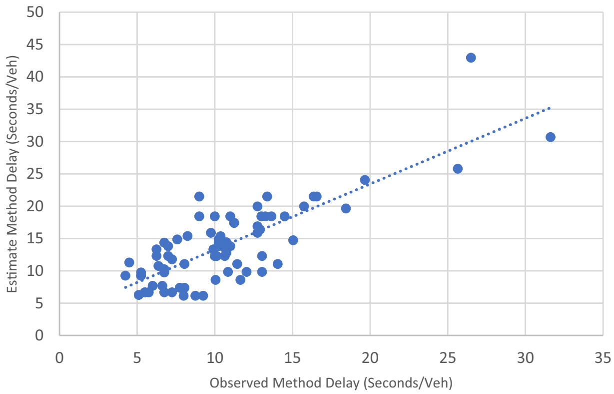

Figure 8.
A 50% increase in pedestrian walking time versus observed method

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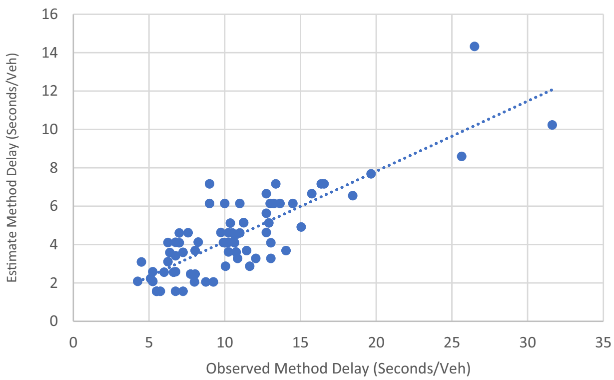

Figure 9.
A 50% decrease in pedestrian walking time versus observed method

Source: Authors' own work

Table 3.
Sensitivity analysis on pedestrian walking time

Comparison	Baseline method	50% increase in ped. time	50% decrease in ped. time
Average delay (s/veh)	9.46	14.36	4.52
Standard deviation	4.23	6.25	2.22
Min. delay (s/veh)	4.09	6.14	1.55
Max. delay (s/veh)	28.63	42.95	14.32

Source: Authors' own work

6. Conclusions

Kuwait City is a predominately a metropolitan city with wide asphalt roads designed for accommodating vehicular traffic. Pedestrians are relegated to the curbs and crosswalks while traversing the city. It is in these crosswalks that pedestrian/vehicle interactions are to occur. While crossing the streets in unmarked locations – sometimes referred to as jaywalking – is a usual phenomenon in Kuwait City, it is not the focus of the study. This study is instead focused on the pedestrian/vehicles interaction at unsignalized intersections, where pedestrians make judgment calls as to when to cross, and vehicles have to stop to give way. The aim of the study is to measure the delay caused by pedestrian crossing on platoon vehicles, as the interruption of one pedestrian crossing can cause a cascading effect on vehicles stopping.

A model for estimating platoon delay because of pedestrian crossing was validated for use in Kuwait City. The model performed by Forde and Maina (2017) was modified slightly for the scenario found in Kuwait, in which the presence of raised crosswalks meant that all incoming traffic would slow down automatically. Using video footage to observe the site, several variables were collected, and a model was used to calculate the delays suffered by the vehicles because of pedestrian crossing. The model was validated using the actual footage and manual observation to measure the delays. The model showed a good match fit to the observed data, as the average delays differed by 22.5% between the two methods.

Following the comparison, a sensitivity analysis was made on three variables: the acceleration rate, deceleration rate, as well as the pedestrian walking time. The analysis showed that the pedestrian walking time had the most effect on the model, in an almost one-to-one correlation. A 50% change of the pedestrian walking time is associated with approximately 50% change in the model's output delay. It also showed that the deceleration rate had approximately twice the effect on the model than the acceleration rate has.

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