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Agent-based Modeling of Pedestrian Behavior at an Unmarked Midblock Crossing

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Abstract

Illegal pedestrian behavior is considered one of the main reasons for pedestrian-related crashes. This paper provides a detailed outlook of the gap acceptance behavior of pedestrians illegally crossing at an urban midblock section of a six-lane road. A simulation model was developed to capture the illegal crossing behavior for the pedestrians using agent-based modeling techniques and implemented in Anylogic. Once calibrated to study the crossing behavior, several distributions were fed into the model to determine the best distribution that mimics the pedestrians' movements. It was found that the normal distribution is the closest fit. The results suggest that the pedestrians add a factor ranging from 1.25-1.5 to vehicle speeds before anticipating the gap, then determine whether to cross or not. The simulation tool was found useful for replicating the illegal crossing behavior. The results from this study can be helpful in assessing the pedestrian safety and providing better crossing facilities for pedestrians in urban areas.

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Keywords: gap acceptance; jaywalking, crossing behavior; illegal pedestrian crossing

1. Introduction

Illegal crossing occurs when pedestrians cross a road where the laws and regulations do not allow them to do so. There are many forms of illegal crossing including a pedestrian crossing at an area not prepared for pedestrian crossing or at an area prepared for pedestrian crossing without waiting for the pedestrian phase. In urban areas, while

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illegal crossing, the pedestrians are at a high risk as this is undertaken on higher traffic volume roads. The decision to start crossing not only depends on upon the pedestrian characteristics, but it is also governed by traffic flow characteristics. On multilane urban roads, pedestrian perceives the traffic condition on different lanes, analyze them simultaneously and choose to accept a specific gap before starting to cross. During this maneuver, pedestrian gap acceptance behavior and pedestrian speeds are vital for safe crossing movement. The main objective of this research is to study the gap acceptance behavior of pedestrians illegally crossing on a midblock multilane section in an urban area and develop models to predict accepted gaps for these pedestrians. A section of a six-lane divided road, located in Doha, was selected for the purpose of this study.

2. Background

A limited number of studies was found predicting the size of accepted gaps for pedestrians jaywalking at a midblock section. A study in Qatar analyzed of the gap acceptance behavior of pedestrians jaywalking at an urban midblock section. The effective accepted gap was determined as a function of the pedestrian characteristics, crossing behavioral attributes, and vehicular traffic related attributes. Waiting time was identified as a significant parameter affecting the size of the accepted gaps. In the same study, two regression models were developed to predict the size of the accepted gap in the case of the pedestrian waiting or not waiting before crossing[1]. The gap acceptance behavior of pedestrians was studied at an uncontrolled mid-block section in Athens, Greece using videotaping. A lognormal regression model was developed for accepted gaps. This model included distance, vehicle size, accompanied, the presence of illegal parking, and gender as independent variables[2]. A study modeled the crossing behavior of pedestrians on nine uncontrolled midblock roads in three cities in Egypt. Specifically, the size of accepted gaps and pedestrians' decision to cross the street were studied. The minimum accepted gap was predicted using a lognormal regression model which included vehicle speed, street width, the frequency of an attempt, rolling gap, and age as significant variables[3].

Another study in India examined a midblock section using video graphic technique to study pedestrians' gap acceptance behavior. Data for accepted gaps were used for developing regression model. The model was comprised of gender, age, the number of attempts, rolling gap, vehicle speed, pedestrian speed and pedestrian direction as independent variables[4]. By considering additional observations, same authors presented another model for the same site considered above to estimate the size of minimum accepted gap for pedestrians using a lognormal regression model. The new model included the driver yielding behavior, rolling gap, the frequency of attempts, accepted lag or gap, the number of observations while crossing, the frequency of disturbance, and vehicle speed as statistically significant independent variables[5]. Further, the authors compared the earlier multiple regression models with another site located in Mumbai with an uncontrolled marked midblock crosswalk. The regression model for marked crosswalk included driver yielding behavior, rolling gap, vehicle speed, pedestrian platoon, waiting time, movement of pedestrian, gap type and pedestrian crossing condition as independent statistically significant variables. The results of regression and logit models showed that the potential of a conflict is much lower in the case of crossing at a marked crosswalk compared to an unmarked crosswalk. Also, pedestrians at unmarked crosswalk rolling gap acceptance are more significant[6].

Other studies investigated the probability of a pedestrian accepting an available gap based on the pedestrians crossing behavior and traffic characteristics using logit or probit models[7,8]. It can be seen that very few studies have considered unmarked midblock section used for crossing; further, most of the studies have used a section of two-lane roads. The main objective of this study is to provide a comprehensive understanding of the gap acceptance behavior of pedestrians on a wider midblock section located in an urban area using agent-based modeling (ABM).

3. Data Collection

Field data were collected at a midblock section located in downtown Doha, Qatar. Qatar is a fast-growing country with unique characteristics located in the Arabian Gulf region. The country mainly witnesses extremely hot weather in particularly during the summer season (nearly 50º Celsius). The weather has a significant impact on the pedestrian volumes. People are hardly seen outdoor during these extreme conditions. People with higher incomes depend on their personal vehicle or the taxi service. Buses are mainly used by workers and people with low income who do not afford to use a taxi or to buy their personal cars. More people are willing to pay for parking versus free parking in order to walk less to their final destination[9-14]. The traffic law in Qatar has many similarities with the traffic laws in the other countries in the region and Western countries[15,16]. According to the traffic law in Qatar, pedestrians can cross only at intersections during the pedestrian walk phase. However, pedestrians can be seen jaywalking to avoid walking to existing crosswalks. This behavior is illegal according to the traffic law in Qatar but not strictly enforced due to limited enforcement resources[17].

The length of the selected section is 390 m and has two signalized junctions with pedestrian crosswalks on upstream and downstream of the section. The section of the road has six through lanes (three in each direction) separated by a wide median. To prevent illegal crossing, a high fencing is provided with openings at a certain distance for maintenance purposes. Service roads are provided on both sides and are separated from the main street by a traffic separator. The service roads to cater for the extensive commercial facilities present, specifically banks and parks. Both sides of the road also have parking facilities, which generate more need for crossing the street. The data was collected on two typical weekdays using four video cameras. The view from the camera was selected to have some overlaps. Only the pedestrian movement on the main section was captured, and movement on the service roads was not considered. The video recording was done for twelve consecutive hours from 6:00 am to 6:00 pm on both days. Data for accepted gaps were extracted for complete recorded time to get 972 observations. This study focused only on accepted gaps by the pedestrians. Various attributes related to pedestrian characteristics, pedestrians' behavioral characteristics, and traffic-related attributes were extracted for accepted gap by each pedestrian.

The pedestrian crossing behavior was recorded using several categorical and continuous variables. The accepted gap was calculated as the time gap for the critical vehicle to reach the pedestrian crossing point. The critical vehicle is defined as the vehicle which is closest to the pedestrian or requires a minimum amount of time in reaching the pedestrian crossing point. The position of the critical vehicle was noted at the time when a pedestrian makes the decision to cross. The critical vehicle can be located in any of the lanes depending on the situation during the crossing. The critical distance is the distance between the critical vehicle and the pedestrian crossing point. The lane number of the critical vehicle was also noted. The speed of the critical vehicle was obtained by dividing critical distance by time (accepted gap). The number of rejected gaps was also obtained by taking into account vehicles on all lanes. Also, waiting time of pedestrian was counted, this was the time from a pedestrian arrives at the curb or median till the pedestrian starts crossing.

The time required by a pedestrian to cross the road was noted with the distance traveled (either perpendicular or oblique)to get the pedestrian crossing speed. As the midblock section was divided with a wide median, separate observations were recorded for crossing from the curb to the median and median to curb. It was observed whether the pedestrian was running, accelerating, or decelerating while crossing. While illegally crossing on a multi-lane wider section, the pedestrians need to check gap availability in all lanes simultaneously before making the decision to cross. Some pedestrians assess a gap in the near lane only and start crossing, and further expect that the gaps in farther lanes will become available as they approach these lanes, these crossings were termed as rolling gaps.

Some vehicle-related attributes were noted to find out the effect of surrounding traffic conditions on crossing, specifically gap acceptance behavior. Two vehicle-related attributes were noted, one observing the vehicle acceleration or deceleration and another looking at the lane change of the critical vehicle, after sighting the pedestrian. Some specific cases were excluded from the analysis a) pedestrian stopping completely in the middle of the road and waiting for the available gap, b) pedestrian crossing when the traffic was queuing up to the crossing point, c) pedestrian crossing on a bicycle or with a bicycle in hand, d) pedestrian started crossing and returning back after sighting a large or a high-speed vehicle, e) pedestrian jumping over the fence while jaywalking, and g) pedestrians crossing on a zigzag path.

4. Simulation Model

A simulation model was developed to capture the illegal crossing behavior for the pedestrians. Due to the random arrival of vehicles and pedestrians, the gap between pedestrians and the closest vehicle is, in most cases, much larger than the actual critical gap. For this reason, only a simulation technique can be used to mimic the pedestrians' behavior. The simulation model was developed using ABM techniques and implemented on Anylogic version 6.6.0. AnyLogic a simulation tool that supports all common simulation methodologies: system dynamics, discrete event, and ABM. ABM is a bottom-up technique in which the building blocks of the simulation are created and interact in a virtual environment given a set of rules. Agents are autonomous entities within the model that are capable of making decisions given an external stimulus. This type of simulation has proven to be successful in modeling different activities for pedestrians. Anylogic has been used successfully in modeling different activities for vehicles and pedestrians, including pedestrian movements[18], self-organized pedestrian movements[19], pedestrian emergency evacuation[20], pedestrian activities in subway stations[21], and vehicle's schedules[22]. The agent-based model used for this study is object oriented and modular. The following is a description of the model components:

5. Model Logic

The model consists of four modules, environment module, agent module (pedestrians and vehicles), critical gap computing module, and graphic output. These modules follow the model logic shown in Fig. 1.

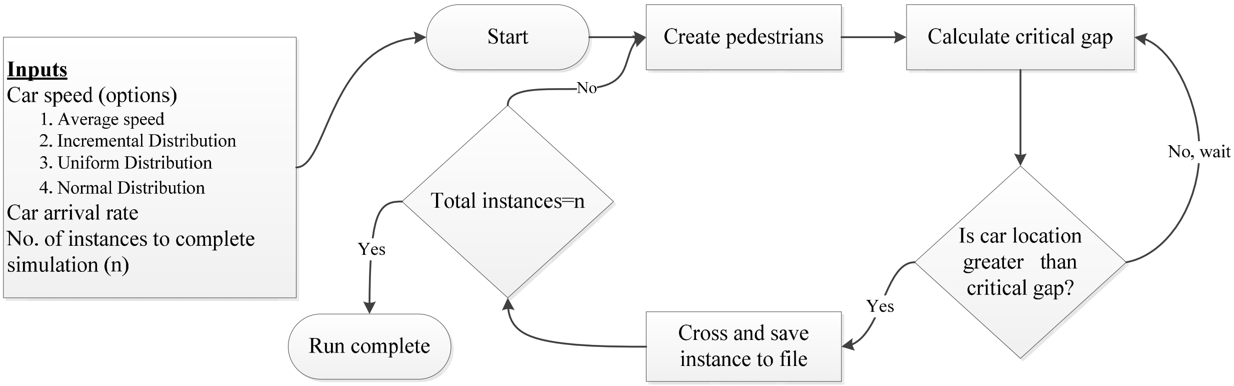

Fig. 1 Model Logic

5.1. The Environment Module

The environment created within this model is a 2D continuous environment. In addition to the agent, the environment contains a 3-lane road that is identical in dimension to the road in the experimental setup. It should be noted that the length of the road in the environment was set to 120m only to mimic the camera coverage distance in the experimental setup. As mentioned earlier, pedestrians crossing with zero vehicles on the lanes could have in reality seen vehicles further than 120m when crossing. Thus, only instances, where crossing took place with vehicles at distances less than 120m, are considered both in the real data and the simulated data.

5.2. The Agent Module

5.2.1. Vehicles

The vehicles are a class of agents that mimic vehicles on the road. For this model, the only parameter that changes for these agents is the speed. The vehicle speed was extracted from the data collected. In the analysis, it was assumed that the vehicles neither change lane nor change speed once placed in the environment. The vehicle arrival rate was set to replicate the traffic volumes obtained from the field. Vehicles arrive at random times within the hour. All vehicles have a standard length of 3.5m and width of 2m. The speed of the vehicle can be a single input or a function in itself. In this study, the authors used several distributions to simulate the vehicle speeds.

5.2.2. Pedestrian

The pedestrian agent is a core agent in the model. The pedestrian agent appears at random times at a rate of arrival similar to the rate obtained in the field but in the same location, on the right side of the road. Only a single pedestrian is allowed to appear at any given time. Once the pedestrians cross, they disappear from the model, and a second pedestrian can appear. In order to get crossing speed for the pedestrians, the details of the pedestrians crossing the road using perpendicular path were extracted from the video data. The pedestrians who crossed on an oblique path were neglected in this study. The recorded video was used to find out the pedestrian crossing time from the curb to the median and vice versa. The pedestrian crossing speed was derived using the distance traveled by each pedestrian. The extracted data was divided into two categories:

Pedestrian crossing without a conflict:

In this case, there were no vehicles on the road when a pedestrian crossed the road. For this category, 1,094 cases were observed. The minimum observed speed was 0.73m/s, and maximum observed speed was 2.77m/s. The overall average speed was 1.40m/s and a standard deviation of 0.20m/s. This case was ignored in this study since it does not provide the true crossing speed of the pedestrians, which is different in the case of a conflict.

Pedestrian crossing with a conflict:

In this case, there were some vehicles on the road when a pedestrian crossed. This condition was used to obtain the crossing speed of the pedestrians for this study. For this case, 602 cases were found. The minimum and maximum speeds were 0.96m/s and 4.73m/s respectively. The overall average speed was 1.73m/s with a standard deviation of 0.47m/s. Overall, the speed values for the second case were much higher than the first case.

5.2.3. Critical Gap Computation Module

The pedestrians have the ability to determine the number of vehicles on the lane and the speed of each vehicle. The pedestrians determine whether they may pass and 'clear' the road or not based on the following equation;

$$D_m = \frac{D_l S_v}{S_p} \tag{1}$$

Where, D_m is the minimum critical gap distance needed for the pedestrian to cross safely,
D_l is the width needed to cross (3.6 if the critical vehicle is in the first lane, 7.2 in the second lane and 10.9 in the third lane,
S_v is the vehicle speed,
S_p is the crossing speed of the pedestrian set at 1.73 m/s as obtained from pedestrian speed analysis.

If the vehicle location is further from D_m for all three lanes, the pedestrian will pass. Otherwise, the pedestrian will wait. However, as will be explained under the results section, this precise calculation did not mimic the experimental results accurately, for this reason, an error term was introduced in some cases such that the pedestrian will 'think' the vehicle is faster than it actually is.

6. Model Results

Various simulation runs were performed in order to test and calibrate the model. Table 1 provides a summary of the results as compared to the real data. The simulation runs differed in the distribution of the vehicle speed, which can impact the minimum critical gap. Four different distributions were tested:

1. Average Speed: All vehicles have a set speed of 48km/hr, which is the average speed obtained from the actual data.
2. Incremental Speed: Vehicles' speeds are increased by 1km starting at 30km/hr and ending at 72km/hr. This is the same speed range obtained from the actual data.
3. Uniform Speed Distribution: Vehicles' speeds are varied according to a rectangular distribution. That is to say, all speeds between the minimum and maximum vehicle speeds carry the same probability.

4. Normal Distribution: Vehicles' speeds are set according to a truncated normal distribution. The truncation sets the minimum and maximum speeds to match the actual data. The truncation is to safeguard for unreasonable values. The average and variance of the distribution are 48 km/hr and 8.8 km/hr respectively.

It is worth noting that the results of each category (average, incremental, uniform & normal) illustrated in Table 1 are the average of three simulation runs.

Table 1 Simulation Results for Different Distributions

	Gap Distance (m)			
	Mean	Standard Deviation	Min	Max
Actual Data	70.9	17.22	30.50	119.55
Model Data				
Average Speed (48kph) Run	60.0	23.47	30.10	118.74
Incremental Speed (30-72kph)	63.4	23.51	28.44	118.58
Uniform Speed Distribution (30-72kph)	66.0	24.41	23.43	118.50
Truncated Normal Speed Distribution (Avg. 48kph, Var 8.8, min 30kph, max 72kph)	66.4	24.22	26.45	118.61

The mean gap distance for all runs is less than that of the actual data. This result suggests that the model is underestimating the gap. Furthermore, the standard deviation of the simulation runs is larger than that of the actual data suggesting the simulation run data is more spread out than the actual data. This outcome suggests the fit between the simulation data, and actual data is not accurate. The data range, however, is similar to actual data for most simulation runs. To determine which simulation runs closely fits actual data; gap data from simulation runs was ranked from highest to lowest and plotted against the actual data. Fig. 2 illustrates the results. Table 2 shows the analysis of the error between the actual data and each simulation category. The charts illustrate that most of the simulation runs are underestimating the actual data. Visual inspection suggests that the normal distribution is the closest fit. Table 2 confirms this observation and illustrates the average error across all points, absolute error (modulus of average errors) and the confidence interval of the average error.

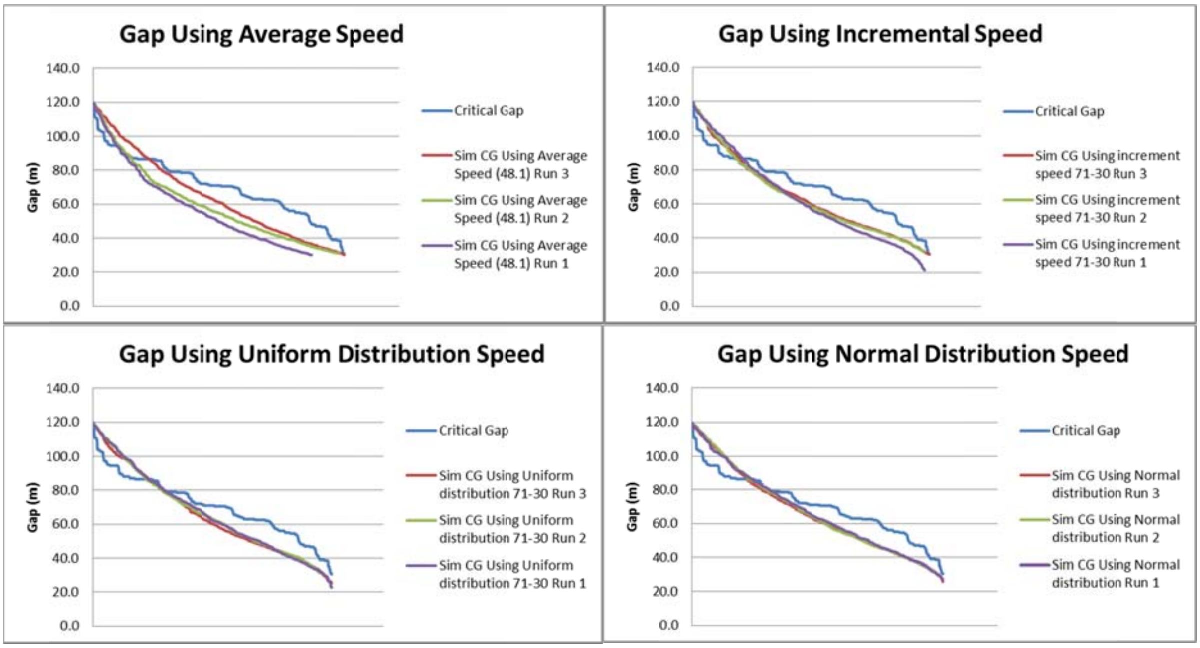

Fig. 2 Simulation Data Versus Actual data

Table 2 Error Analysis of Simulation Runs

Simulation Run	Average Error %	Absolute Error %	Error Confidence Interval (90%)
Average Run	-17.7	19.8	8.1 to -34.4
Incremental	-12.9	15.8	9.6 to -26.8
Uniform	-9.6	13.8	12.4 to -24.6
Normal	-8.9	13.2	13 to -24.3

To enhance the fit, the speed in the normal distribution runs was multiplied by a positive factor. This factor would account for the underestimation of the simulation. Fig. 3 illustrates the results of introducing different factors of 1, 1.25, 1.5 and 1.75 respectively. In reality, the factored runs simulate a pedestrian who is overestimating the vehicle speed as it approaches. This is expected as a pedestrian will always be more conservative than a precise simulation. Table 3 illustrates the error of the factored simulations.

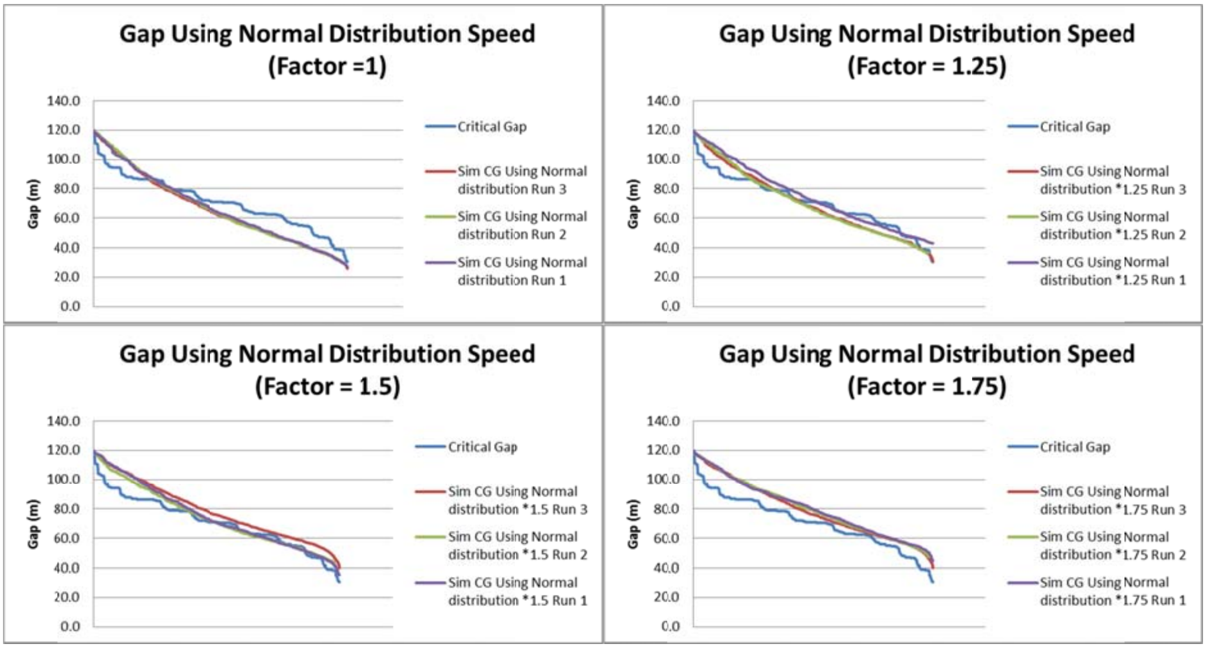

Fig. 3 Simulation Data for Different Factors Versus Actual data

Table 3 Error Analysis of Factored Simulation Runs

Normal Distribution Simulation Run	Average Error %	Absolute Error %	Error Confidence Interval (90%)
Factor 1	-8.9	13.2	13 to -24.3
Factor 1.25	-0.4	7.9	14.7 to -12.2
Factor 1.5	4.8	6.4	16 to -4.1
Factor 1.75	13.0	13.0	28 to 5.76

From the absolute error, the normal distribution runs with a factor of 1.5 gave the best results followed by a factor 1.25. The results suggest that the pedestrians add a factor ranging from 1.25-1.5 to vehicle speeds before anticipating the gap, then determine whether to cross or not.

7. Conclusions and Recommendations

An agent-based passenger movement model was established to model the illegal crossing behavior on a six-lane urban road in Doha, Qatar using ABM techniques and implemented in Anylogic. Once calibrated to study the crossing behavior, several distributions, including average speed, incremental speed, uniform speed distribution, and truncated normal speed distribution were fed into the model to determine the best distribution that mimics the pedestrians' movements. The normal distribution resulted in the lowest errors. Different factors were applied to this distribution in order to enhance the results and improve the error. It was found that applying a factor ranging from 1.25-1.5 reduced the errors significantly. This result is an indication that the pedestrians add a factor to the vehicle speed before anticipating the gap, and then determine whether to cross or not. The tool has demonstrated that it is useful for replicating the illegal crossing behavior. This tool can be helpful in assessing the pedestrian safety and providing better crossing facilities for pedestrians in urban areas.

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