An Assessment of the Impact of Pedestrian Refuge Islands on Vehicle Speed Changes and Pedestrian Safety: Case Study in Tehran

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Received: 01.05.2014 Accepted: 01.07.2015

Abstract:

Pedestrians are among the most vulnerable road users. Speed of vehicles is considered as one of the major causes of danger for pedestrians crossing the street. Therefore, it is of utmost importance to devise suitable solutions to reduce speed of vehicles. One of these solutions is installation of Pedestrian Refuge Islands (PRI) in very wide midblocks. With regard to fluctuations in pedestrian and vehicle traffic volume in traffic hours, there are different variations in collisions between vehicle and pedestrian. In this article the effect of constructed PRI in Tehran on speed of vehicles and consequently their effects on probability fluctuations of fatal accidents are determined. Speed of vehicles in two phases of before and after arriving to the PRI is assessed. Additionally, speed of vehicles in non-observed volumes of vehicle and pedestrian are calculated using Aimsun.v6 simulation software. Paired T-test is applied to compare average speed of vehicles before and after the PRI. The results revealed that except for traffic volumes of 3000-4000 veh/h and 400-600 ped/h in other volumes reduction of average speed of vehicles as a result of PRI is significant. Also, the results show that in all volumes, these equipment reduce the probability of fatal accidents to under 10%. According to the results, it is recommended that PRI should be installed in mid blocks where traffic volume of vehicles in each lane is less than 750 veh/h.

Keywords: Pedestrian refuge island (PRI), before and after studies, fluctuations of speed of vehicles, probability of pedestrian fatal accidents

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1. Introduction

Vehicles have increased in numbers on a daily basis; in spite of the fact that they offer an improved convenience, they have brought about negative effects. For instance, losses of lives and properties are considered as one of the major consequences. Pedestrians as vulnerable road users are very important in analyzing traffic safety [Ashton,1982, Walz, Hoefliger and Fehlmann, 1983]. The most critical type of pedestrian movement is crossing the streets because of the high probability of collisions with moving vehicles [Beckwith and Hunter-Zaworski, 1998].

In accidents between vehicles and pedestrians there are a lot of variables which are able to influence severity of injuries. One of these variables is speed of vehicles [Richards, 2010]. According to the conducted researches, it was concluded that in accidents even as slow as 13 km/h, the accident turned out to be a fatal one [Antić et al. 2013]. As pedestrians are vulnerable road users, with small changes in speed of vehicles the probability of fatal accidents changes dramatically.

One of the solutions in reducing the probability of collision between vehicles and pedestrians is installation of traffic calming equipment in cross ways. One of this equipment is "pedestrian refuge island" (PRI) which is used in streets and intersections of cities. These islands are installed in the middle of the route and with the purpose of reducing the width in a direct route in one or two way streets (Figure1).

PRI have been installed in one way streets and intersections in Tehran since 2010. In this research the following questions are addressed:

1. Provided that there are PRI, how changes in volume of vehicles and pedestrians affect changes in speed of vehicles?
2. How effective are the PRI in Tehran in various volumes of vehicles and pedestrians?
3. How much do PRI improve safety of pedestrians?

2. Literature Review

There are a great number of studies conducted on pedestrian safety equipment. These studies include introduction of new equipment, studying the effect of the equipment on safety indexes, effect of the equipment on pedestrian satisfaction etc. Carsten (1998) studied some particular type of pedestrian safety equipment which identifies the presence of the pedestrian and affects timing of the traffic light [Carsten, Sherborne and Rothengatter, 1998]. He concluded that using these equipment result in safety and convenience improvement for pedestrians and does not negatively affect vehicle's movement. Pau and Angius (2001) studied the effect of humps in changes of vehicle speed at 23 locations where speed bumps were installed and found that 85th percentile of speed was above speed limit (50 km/h) [Pau and Angius, 2001]. Hakkert (2002) studied the effect of a particular type of pedestrian safety equipment which signals the drivers as the pedestrian reaches the crossing using flashing lights. He concluded that in the areas that these equipment are installed, drivers reduce their speed by 2 to 5 km/h and observance of the priority rights by the drivers increases [Hakkert, Gitelman and Ben-Shabat, 2002]. King (2003) studied the effects of PRI, intersections with traffic lights and sidewalks on pedestrian safety while crossing the street. He concluded that refuge construction has trivial effect on reducing the speed of vehicles. Also, the speed of vehicles is independent of vehicle volume [King, Carnegie

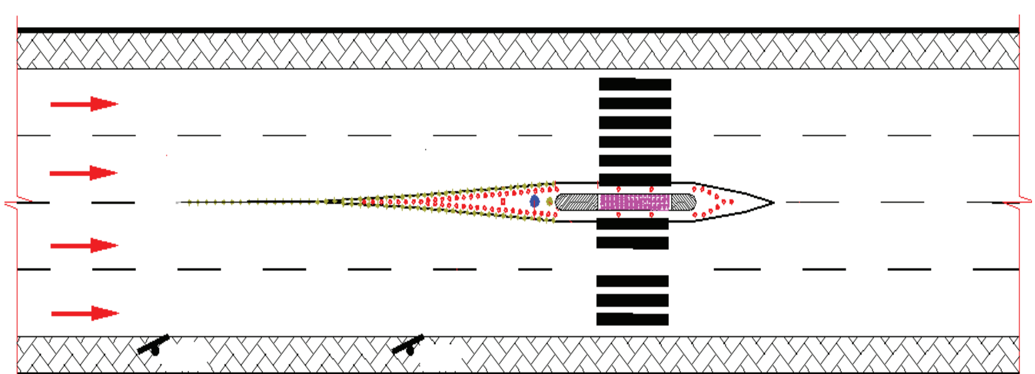

Figure 1. Components of pedestrian refuge island

and Ewing, 2003]. Li (2010) in a research studied the pedestrians' behavior to realize whether adverse weather conditions affects using PRI. Finally, he concluded that the pedestrians demonstrate riskier behavior in adverse weather conditions when using PRI [Li and Fernie, 2010]. Antic (2013) studied the effect of humps with different heights on reducing the speed of vehicles and concluded that the humps are very effective in reducing the speed of vehicles and where the vulnerable pedestrians cross the street it is recommended to make humps with heights of 5 to 7 cm [Antić et al. 2013].

There is also a particular focus on the relationship between impact speed and the risk of fatality for pedestrians in impacts with cars. In the 1970s, Ashton and Mackay led an in-depth accident study that collected information on pedestrian accidents. This was an on-the-scene investigation by a team based at the Accident Research Unit at the University of Birmingham [Ashton and Mackay, 1979] (Figure 2).

Pasanen (1992) calculated a relationship between driving speed and the risk of pedestrian fatality [Pasanen, 1992]. As part of this calculation, Pasanen calculated the relationship between impact speed and the risk of pedestrian fatality using the data from Ashton. Pasanen applied a non-linear regression model based on the least squared method, and calculated the following relationship between impact speed in meters per second (v) and the probability of fatality (P):

$$P = \frac{1.027}{1+37e^{-0.017\,v^2}} - 0.027 \quad (1)$$

Davis (2001) also used the data collected by Ashton and Mackay to calculate the relationship between the risk of pedestrian fatality and impact speed [Davis, 2001]. Davis used an ordered, discrete outcome model to calculate the relationship between impact speed and risk of pedestrian fatality, and did weight the data to the national proportion of fatal, serious and slight casualties. Davis performed these calculations separately for the three age groups included in the Ashton data: children (aged 0–14 years), adults (aged 15–59 years), and the elderly (60+ years). Davis found the following relationships between the probability of fatality (P) and impact speed (v) in kilometers per hour:

$$P_{\text{children}} = 1 - \frac{e^{8.85-0.12v}}{1+e^{8.85-0.12v}} \quad (2)$$

$$P_{\text{children}} = 1 - \frac{e^{8.87-0.13v}}{1+e^{8.87-0.13v}} \quad (3)$$

$$P_{\text{children}} = 1 - \frac{e^{9.73-0.2v}}{1+e^{9.73-0.2v}} \quad (4)$$

The German In-Depth Accident Study (GIDAS) is the largest in-depth accident study in Germany. Since mid-1999, the GIDAS project has collected on-scene accident cases in the areas of Hannover and Dresden. Rosen and Sander (2009) used GIDAS data to calculate the relationship between impact speed and the risk of pedestrian fatality [Rosén and Sander, 2009]. This sample included pedestrian impacts occurring between 1999 and 2007, where the pedestrian was hit by the front of the car and the impact speed was known. Pedestrians hit by sport utility vehicles, pedestrians who were lying down and pedestrians who were 'sideswiped' were removed from the sample. They used logistic regression to calculate the relationship between impact speed v (in kilometers per hour) and the risk of pedestrian fatality P. The relationship found was:

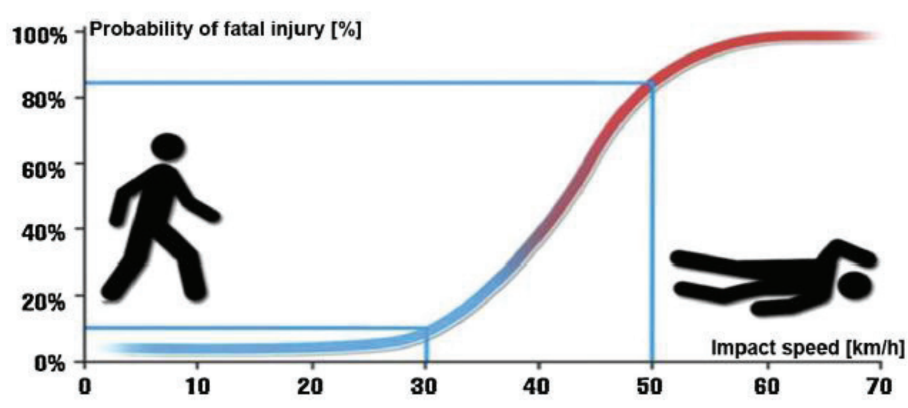

Figure 2. Probability of fatal injury in a pedestrian-vehicle crashes

$$P = \frac{1}{1+e^{6.9-0.090v}} \qquad (5)$$

Oh et al. (2008) developed a model for the risk of pedestrian fatality based on accident data collected in Korea from 2004 to 2005 [Oh, Kang and Kim, 2008]. The expression calculated for the risk of pedestrian fatality (P) with respect to impact speed (v) in kilometers per hour was as follows:

$$P = \frac{1}{1+e^{5.433-0.095v}} \qquad (6)$$

As it was explained before, various researches have been conducted on the effects of safety equipment. Antic studied the effect of humps with various heights in reducing speed of vehicles with a before-after study approach. It means changes in speed of vehicles were assessed in three phases of before arriving to the first hump, between the first and the second hump, and after the second hump. Pau and Angius also studied the effect of humps in changes of vehicle speed; however, their studies involved assessing the speed of vehicles in two phases of before arriving to the hump and the effective area of the hump. Hakkert in a before-after study approach and field study data collection, studied the changes in vehicle speed with classification of the vehicle type (public and private), line classification and in two phases of before (about 30 meters before arriving to the crosswalk) and reaching the crosswalk.

In this article, the effect of PRI on changes of vehicle speed is assessed using previous literature and before-after study approach. As to the limitations, it was not feasible to collect the data for two statuses of "before installing PRI" and "after installing PRI". According to the field studies, speed studies are conducted in two phases of before (before arriving to the PRI) and after (arriving to the PRI).

3. Methodology

Research methodology, characteristics of the case study and field observations will be discussed in the following. A summary of methodology is presented in figure 3.

3.1 Selection of the Area Understudy

As it was discussed previously, this article benefits from before-after study approach. One constrains in data collection was installation of PRI. It means it was not possible to collect the data before installation of the island.

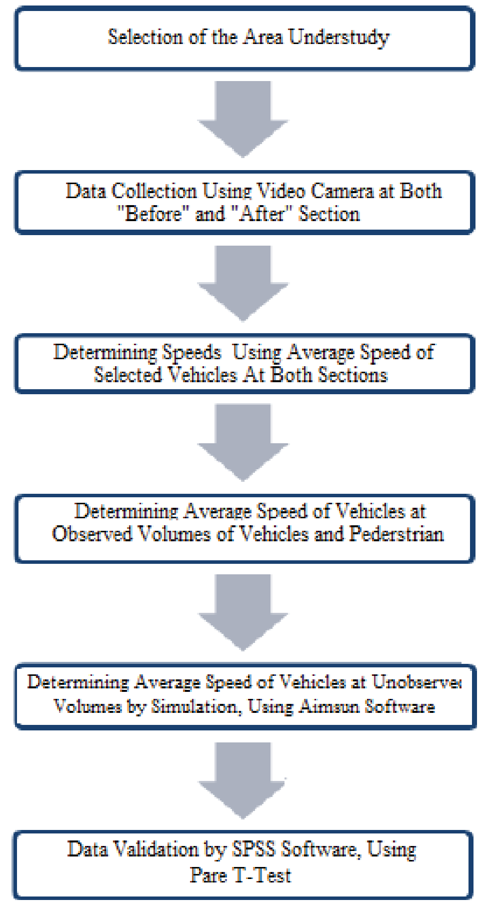

Figure 3. Methodology of the study

Therefore, in selection of the area understudy the following issues were addressed:

1) There mustn't be any interference in collection of speed and volume of the vehicles in the upstream area of the island (70-100 meters before arriving to the island)

2) The island must be located in an area where there are different volumes of vehicles and pedestrians.

Addressing the above concerns, the existing island in Motahari Street after Sohrevardi Street in Tehran was selected as area understudy (Figure 4). This midblock is located in area where there are a lot of offices; it is a one way street with the direction of west to east with four lanes, width of 3.5 meters and parking spaces in both sides of the street.

3.2 Data Collection Method

Data was collected using a video camera. In order to have a suitable viewing angle for registering speed in farther distances and avoiding vehicles overlaps, the camera was installed on a four floor building. Recording took place

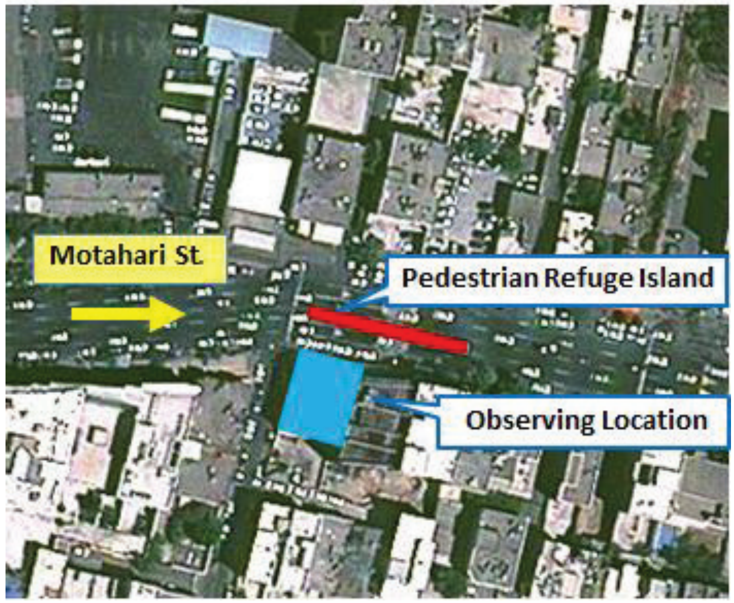

Figure 4. Location where pedestrian refuge island in currently installed

on Monday on August 19, 2013, at 8 am to 24 am. This period was selected because of favorable weather conditions (shiny, moderate weather). Also the selected day is in the middle of the week in Iran and the traffic condition is as normal. As in the area understudy the volume of motorcycle traffic was considerable, they were included in data collection. The number of motorcycles was collected and with the coefficient of 0.33 was added to the volume of light vehicles. Also, as heavy vehicle's rarely pass through the area, their number was overlooked.

3.3 Determining Speed of Vehicles

According to field studies in previous researches, speed of vehicles was collected in two phases:

1) Out of the effective area of the island: in a distance of 70 to 100 meters from the PRI (figure 5)

2) In proximity of PRI (figure 6)

Speed of vehicles was determined in periods of 15 minutes from traffic volume of different vehicles and pedestrians, vehicles were selected randomly and their speed before and after arriving to the PRI was registered. It is assumed that in area understudy, vehicles move with constant velocity. Speed of vehicles was calculated using equation 7 and 8:

$$V_{Vehicle} = 3.6 * \frac{L_{before}}{t_v} \quad (7)$$

$$V_{Vehicle} = 3.6 * \frac{L_{before}}{t_v} \quad (8)$$

Where:

L_{before}: Length of "Before" section = 55 meters,

L_{after}: Length of "After" section= 20 meters,

t_v =passing time of the vehicle from the area (seconds).

3.4 Research Scenario Design

According to distribution of traffic volume of pedestrians and vehicles, at first speed is calculated for the scenarios with the following conditions:

- Peak pedestrian volume, off-peak vehicles volume
- Peak pedestrian volume, Peak vehicle volume
- Off-peak pedestrian volume, Peak vehicle volume
- Off-peak pedestrian volume, off-peak vehicle volume

Additionally, in order to improve the accuracy of the presented model, other periods were selected for speed selection of vehicles. Finally, 60 % of the collected data were used for modeling and the remaining 40% were used for model validation. For every period of 15 minutes, 30 vehicles were selected randomly and speed data was collected from them. In this research 840 separate vehicles were selected randomly and speed was registered for the two phases.

According to the previously conducted field studies, volume of vehicles and volume of pedestrians are classified according to frequency in table 1. In order to determine speed of vehicles in various periods of travelling, cells of each column make pairs with each other.

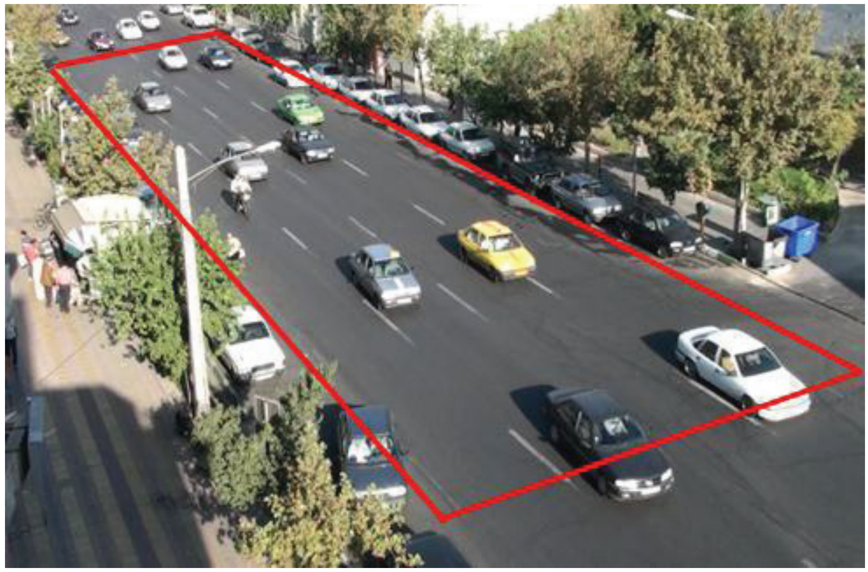

Figure 5. "Before" the area affected by island

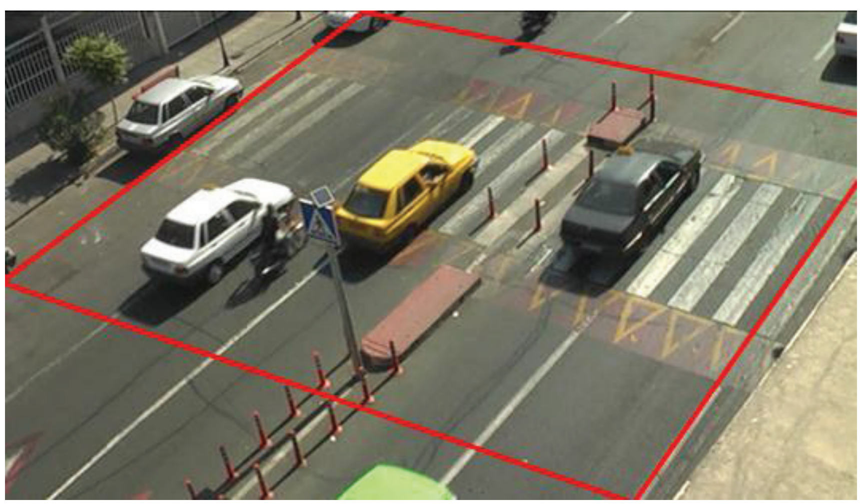

Figure 6. "After" the area affected by island

4. Results

In order to determine the results of the research, observed data collected on speed were used:

4.1 Results from Observations

Results gathered from observation of vehicle traffic volume and pedestrians are presented in figures 7 and 8. Also, table 2 presents the results from calculation of average speed in various periods of pedestrians and vehicles volumes

4.2 Simulation Results

In order to complete table 2 for values not observed, Aimsun.v6 simulation software was used. Using collected data, midblock model understudy was simulated and by changes of input volume for vehicle and pedestrians, speeds of vehicles were studied in two phases of before and after. The acceptance criteria are the speed difference of 5 km/h. Then, by inputting the volumes for data not collected, before and after speed for each vehicle is interpolated. For each pair volume, a number of 30 vehicles are selected randomly and the speed is registered for them.

4.3 Traffic Volume of Vehicles vs. Traffic Volume of Pedestrian

By registering the speed changes of vehicles in two phases in various volumes of pedestrian and vehicle

Table 1. Pedestrian and vehicle hourly volume classification

Vehicle Hourly Volume	Pedestrian Hourly Volume
1000-2000	0-200
2000-3000	200-400
3000-4000	400-600
4000-5000	600-800

Table 2. Speed changes observed and simulated at the site (Km/s)

			Vehicle Hourly Volume			
			1000-2000	2000-3000	3000-4000	4000-5000
Pedestrian Hourly Volume	0-200	Before	51.9	45.4	45.5	35.5
		After	34.4	33.6	37.7	30.0
		Difference	17.5	11.8	7.8	5.5
	200-400	Before	49.7	45.3	37.7	33.7
		After	32.7	30.4	25.7	22.1
		Difference	17	14.9	12	11.6
	400-600	Before	49.7	45.1	36.2	26.7
		After	30.0	27.2	26.7	22.7
		Difference	19.7	17.9	9.5	4.0
	600-800	Before	49.6	44.1	35.4	31.6
		After	30.0	22.5	27.3	21.5
		Difference	19.6	21.6	8.1	10.1

Observed Simulated

it is possible to study the relationship between the two variables in various levels. As table 3 shows, with changes of hourly volume of vehicles 1000 to 5000 Veh/h (75%), except for pedestrian volume 200-400, speed changes of vehicles in other volumes of pedestrian changes between 53- 60%. However, according to the results in table 4, with hourly volume changes of pedestrians 0 to 800 Ped/h (93%), speed changes of vehicles in various vehicle volume changes 25-56%. In short, vehicle speed changes in PRI are more sensitive to changes in vehicle volumes.

4.4 Effects of PRI on Probability of Fatal Accidents

Models conducting relation between speed of vehicles and probability of fatal accidents explained in literature reviews can be used in this study.

Due to reliability of the model developed by [Oh et al.] Eq.6, and also the significant results outcome from the model, it was decided to use this model in order to find the effect of PRI on probability of fatal accidents. While this significant result didn't come from other models. Table 5 shows the probability of fatal accidents in various volumes of vehicles and pedestrian affected by the PRI.

Table 3. Changes of pedestrian hourly volume vs. vehicle hourly volume changes

		Changes of hourly volume of vehicles:1000-5000		
		Before and After Speed Changes		
		Upper Speed (Km/s)	Lower Speed (Km/s)	Changes (%)
Hourly volume of pedestrian	0-200	39.1	15.5	60.4
	200-400	34.4	31.8	7.6
	400-600	39.7	15	62.2
	600-800	49	22.9	53.3

Table 4. Changes of vehicle hourly volume vs. pedestrian hourly volume changes

		Changes of hourly volume of pedestrian: 0-800		
		Before and After Speed Changes		
		Upper Speed (Km/s)	Lower Speed (Km/s)	Changes (%)
Hourly volume of vehicle	1000-2000	25.3	33.7	45.1
	2000-3000	46.9	26	49
	3000-4000	41.4	22.9	39.1
	4000-5000	56.4	15	34.4

5. Data Validation

For data validation in achieved results from simulation software and as the model understudy is processed before and after, Paired-Sample t-test and with accuracy level of 95% was used. Paired-Sample t-test is conducted when samples are selected independently and randomly and also data are normal or their difference is normally distributed. Vehicle speed distributions for collected samples in two phases of before and after are presented in figure 7.

As figure 7 shows, collected samples in the phase "before" has normal distribution with average of 38.70 and standard deviance of 12.19, and samples collected in phase "after" has normal distribution of 26.49 and standard deviance of 8.61. For each pair (vehicle hourly volume, pedestrian hourly volume), a number of 30 vehicles were selected randomly. Results from t-test are presented in table 6. Results from Paired t-test shows at the significance level of 0.05 with the exception of vehicle hourly volume 3000-4000 and pedestrian hourly volume 400-600, in other pairs the speed difference is significant (Sig. 2-tailed =0.000 < 0.05). Table 7 summaries average speed changes of vehicles in various traffic conditions in two phases of "before arriving to the PRI" and "after arriving to the PRI".

6. Conclusions and Recommendations

As it was discussed before, vehicle speed changes when arriving to the PRI was not constant which shows vehicle speed changes is influenced by vehicle volume and pedestrian volume. The results are benefi-

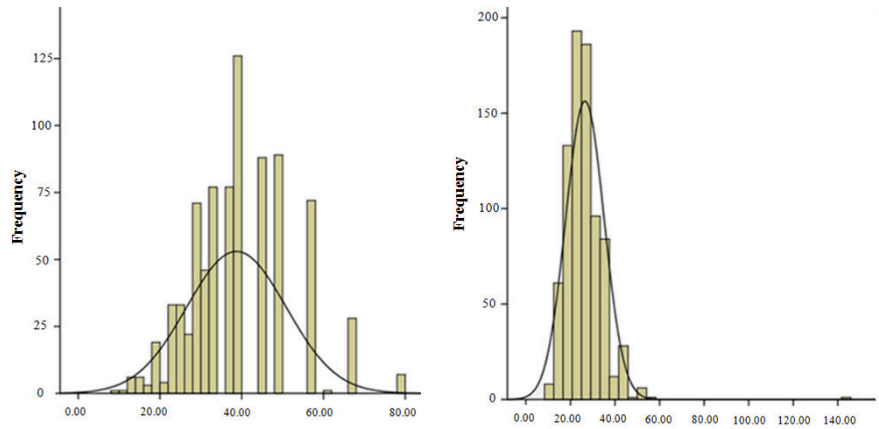

Figure 7. Average speed distributions at "Before" and "After" sections

Table 5. Probability of fatal accidents in various traffic conditions (Eq.6)

		Vehicle Hourly Volume											
		1000-2000			2000-3000			3000-4000			4000-5000		
Pedestrian Hourly Volume	0-200	37.7	10.3	27.4	24.6	9.6	15	24.8	5.7	19.1	11.3	7	4.3
	200-400	32.9	8.9	2.4	24.4	7.3	17.1	13.6	4.8	8.8	9.7	3.4	6.3
	400-600	32.9	7	25.9	24.1	5.5	18.6	12	5.2	6.8	5.2	3.6	1.6
	600-800	32.7	5.5	27.2	22.4	3.6	18.8	11.2	5.5	5.7	8.1	3.3	4.8

Changes in Probability of Fatal Before

Changes in Probability of Fatal After

Changes in Probability of Fatal (%)

cial for determining quantitative effects of pedestrian on speed of vehicles in various volumes of users and providing suggestions for suitable traffic conditions for using PRI.

6.1. Conclusion

According to table 5, the following results can be extracted from the effect of PRI on speed of vehicles in various volumes and pedestrians:

Table 6. Result of T-test on data collected

Pair Number	State	Std. Error Mean	Std. Deviation	N	Mean
1	Before	1.97	10.81	30	54.16
	after	1.54	8.43	30	35.44
2	before	1.14	6.27	30	53.31
	after	2.18	11.95	30	34.29
3	before	1.06	5.82	30	51.05
	after	1.94	10.64	30	29.93
4	before	1.00	5.49	30	52.98
	after	1.87	10.23	30	27.96
5	before	1.22	6.66	30	47.84
	after	1.47	8.05	30	34.30
6	before	1.21	6.65	30	49.21
	after	1.62	8.85	30	32.57
7	before	1.27	6.96	30	48.38
	after	1.95	10.69	30	27.84
8	before	1.27	6.98	30	46.30
	after	1.58	8.63	30	27.77
9	before	1.67	9.13	30	45.65
	after	1.07	5.89	30	28.30
10	before	1.55	8.46	30	39.79
	after	1.24	6.79	30	26.15
11	before	1.61	8.80	30	36.39
	after	4.12	22.59	30	29.32
12	before	1.73	9.45	30	33.81
	after	1.00	5.47	30	26.51
13	before	1.83	10.03	30	41.41
	after	1.45	7.95	30	31.07
14	before	3.01	16.47	30	35.75
	after	1.16	6.35	30	23.91
15	before	1.84	10.06	30	35.54
	after	1.91	10.44	30	24.37
16	before	1.62	8.87	30	31.78
	after	1.04	5.69	30	22.06

Table 7. Average speed changes of vehicles in various traffic conditions (Km/s)

		Vehicle Hourly Volume											
		1000-2000			2000-3000			3000-4000			4000-5000		
Pedestrian Hourly Volume	0-200	51.9	34.4	33.7	45.4	33.6	26	45.5	27.7	39.1	35.5	30	15.5
	200-	49.7	32.7	34.2	45.3	30.4	32.9	37.7	25.7	31.8	33.7	22.1	34.4
	400-	49.7	30	39.6	45.1	27.2	39.7	36.2	26.7	26.2	26.7	22.7	15
	600-	49.6	27.2	45.1	44.1	22.5	49	35.4	27.3	22.9	31.6	21.5	32

Average Speed Before   Average Speed After   Change of Speed(%)

1- According to the results from Paired sample t-test, in all pairs except for pair (vehicle volume: 3000-4000, pedestrian volume: 400-
600) average speed changes of vehicle because of the PRI is statistically significant.

2- In all pairs of pedestrian and vehicle volume, PRI results in reducing speed of the vehicles. Also, the island in all volume pairs results in reducing fatal accidents.

3- In general, in various volumes of vehicles, changes in pedestrian volume do not have any effects on reducing changes in probability of fatal accidents. Only in vehicle volume 3000-4000 and pedestrian volume 0-200, changes in probability of fatal accidents are different from other volumes of pedestrians. However, for the rest of conditions at most, changes in pedestrian volume are 5% effective in changes of fatal accidents.

4- In various volumes of pedestrians, by increasing vehicle volume the probability of fatal accidents decreases. In other words, the more is the vehicle volume, the less is the effectiveness of PRI.

5- From hourly vehicle volume of more than 3000, the fatal accident probability is low even at the absence of PRI (less than 13 % approximately). Therefore, it can be concluded that construction of PRI in one way streets with volumes more than 3000 veh/h is unnecessary. Additionally, PRI is more effective when the speed of vehicles before arriving to the island is more.

6- PRI in all traffic conditions such as vehicle volume, pedestrian volume and speed of vehicles before arriving to the island, reduces the probability of fatal accidents to less than 10%.

6.2 Recommendations

According to the conducted methodology and studies in this paper, there can be suggested some other fields of study:

1- Using the explained methodology in order to finding the effects of continues refuge islands in one midblock on vehicle's speed.

2- Because of the field conditions, pedestrian characteristics cannot be observed via camera. So it can be suggested to consider pedestrian's characteristics (such as gender, sex, education, purpose of the trip, etc.) on their behavior at different traffic conditions.

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