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

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***Abstract*—Pedestrians are among one of the most vulnerable road users. Speed of vehicles is considered as one of the major causes of danger for pedestrians crossing the street (making cross movements). Therefore, it is of almost importance to devise suitable solutions for reducing speed of vehicles. One of these solutions is Pedestrian Refuge Islands (PRI). 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 3000-4000veh/hand 400-600 ped/h in other volumes reduction of average speed of vehicles as a result of PRI is significant. According to the results, it is recommended that PRI should be installed in midblock where traffic volume of vehicles in each lane is less than 750 veh/h.**

***Index Terms*—Pedestrian Refuge Island (PRI), before and after studies, fluctuations of speed of vehicles, probability of pedestrian fatal accidents**

I. 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 [1], [2]. The most critical type of pedestrian movement is crossing the streets because of the high probability of collisions with moving vehicles [3]. 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 [4].

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 [5]. 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 (Fig. 1). PRI have been installed in one way streets and intersections in Tehran since 2010. In this research the following questions are addressed:

- Provided that there are PRI, how changes in volume of vehicles and pedestrians affect changes in speed of vehicles?
- How effective are the PRI in Tehran in various volumes of vehicles and pedestrians?

How much do PRI improve safety of pedestrians?

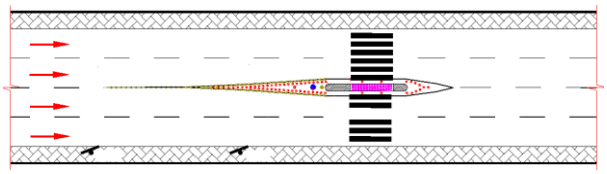


Figure 1. Components of pedestrian refuge island

II. 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 [6]. He concluded that using these equipment results 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) [7]. Hakkert (2002) studied the effect of a

Manuscript received January 1, 2015; revised August 15, 2015.

doi: 10.18178/jtle.4.1.41-46

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 driver's increases [8]. 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 [9]. 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 [5].

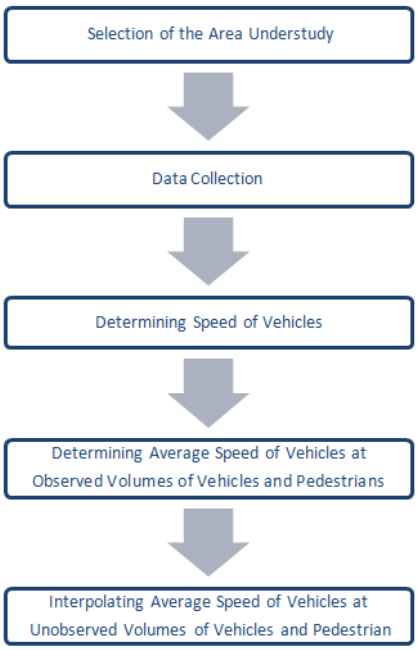


Figure 2. Methodology of the study

III. Methodology

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).Research methodology, characteristics of the case study and field observations will be discussed in the following. A summary of methodology is presented in Fig. 2

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

- 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)
- 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 (Fig 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. Data was collected using a video camera. In order to have a suitable viewing angel for registering speed in farther distances and avoiding vehicles overlaps, the camera was installed on a four floor building. Recording took place at 8 to 24 on Monday, which is in the middle of the week in Iran, on August 19, 2013 in favorable weather conditions. According to field studies in previous researches, speed of vehicles was collected in two phases:

- Out of the effective area of the island: in a distance of 70 to 100 meters from the PRI,
- In proximity of PRI (Fig. 3).

Figure 3. "Before" and "After" sections

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.

B. 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 pedestrians 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 I. Also, in order to determine speed of vehicles in various periods of travelling, pair (vehicle hourly volume, pedestrian hourly volume)is determined according to Table II.

IV. Results

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

TABLE I. Pedestrianand 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 II. Grouping Pedestrian and Vehicle Hourly Volume Two BY

Pair Number	Vehicle Hourly Volume	Pedestrian Hourly Volume	Pair Number	Vehicle Hourly Volume	Pedestrian Hourly Volume
Pair 1	1000-2000	400-600	Pair 9	1000-2000	0-200
Pair 2	2000-3000	400-600	Pair 10	2000-3000	0-200
Pair 3	3000-4000	400-600	Pair 11	3000-4000	0-200
Pair 4	4000-5000	400-600	Pair 12	4000-5000	0-200
Pair 5	1000-2000	600-800	Pair 13	1000-2000	200-400
Pair 6	2000-3000	600-800	Pair 14	2000-3000	200-400
Pair 7	3000-4000	600-800	Pair 15	3000-4000	200-400
Pair 8	4000-5000	600-800	Pair 16	4000-5000	200-400

A. Results Outcome from Observations

Results gathered from observation of vehicle traffic volume and pedestrians are presented in Fig. 4 and Fig. 5. Also, Table III presents the results from calculation of average speed in various periods of pedestrians and vehicles volumes.

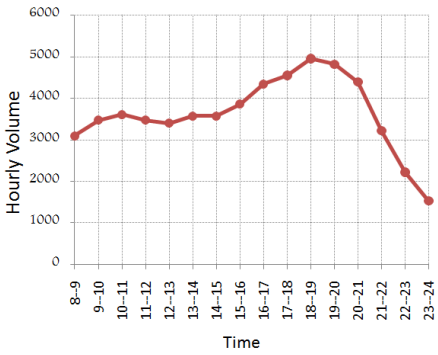


Figure 4. Vehicle volume distribution at the site

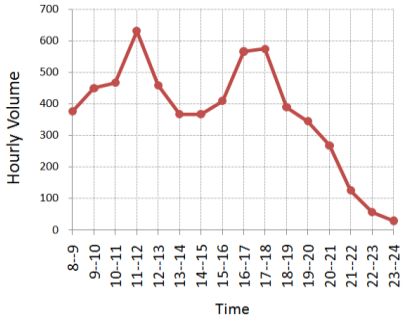


Figure 5. Pedestrian volume distribution at the site

TABLE III. Result from Observation

Pedestrian Hourly Volume	Vehicle Hourly Volume: 1000-2000	2000-3000	3000-4000	4000-5000
0-200		45.4		35.5
		33.6		30.0
		11.8		5.5
200-400	49.7	45.3		
	32.7	30.4		
	17	14.9		
400-600	49.7	45.1		26.7
	30.0	27.2		22.7
	19.7	17.9		4.0
600-800	49.6	44.1		
	30.0	22.5		
	19.6	21.6		

Unobserved Speed Before Speed After Speed Changes

TABLE IV. Result from Simulation

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

Observed Speed Before Speed After Speed Changes

B. Simulation Results

In order to complete Table III 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. The results from simulation are presented in Table IV.

TABLE V. CHANGES OF PEDESTRIAN VOLUME VS. VEHICLE VOLUME CHANGES

		Changes of hourly volume of vehicles		
		Before and After Speed Changes		
		Upper Speed	Lower Speed	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 VI. CHANGES OF VEHICLE VOLUME VS. PEDESTRIAN VOLUME CHANGES

		Changes of hourly volume of pedestrian: 0-800 (93%)		
		Before and After Speed Changes		
		Changes (%)	Lower Speed	Upper Speed
1000-2000	Hourly volume of vehicle	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

C. 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 it is possible to study the relationship between the two variables in various levels. As Table V 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 VI, 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.

V. 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 in two phases of before and after are presented in Fig. 6 for collected samples.

As Fig. 6 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 VII and Table VIII. 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).

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 beneficial 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.

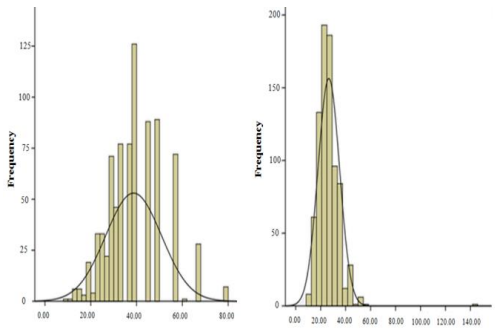


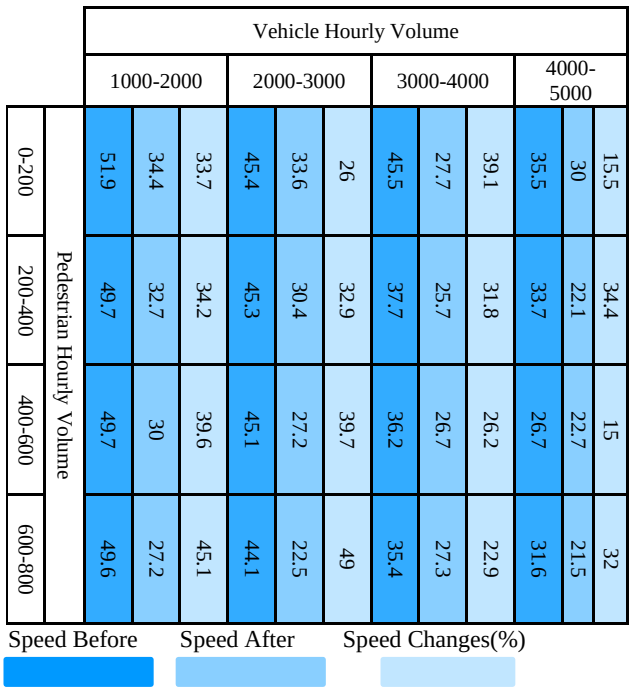
Figure 6. Average speed distributions at "After" section

TABLE VII. 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 VIII. RESULT OF SPEED CHANGES AT DEFERENT PEDESTRIAN AND VEHICLE VOLUMES



VI. CONCLUSION

Table VI 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". According to Table VI, the following results can be extracted from the effect of PRI on speed of vehicles in various volumes and pedestrians:

- 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.
- 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.
- PRI is more effective when the speed of vehicles before arriving to the island is more.
- 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%.

REFERENCES

[1] S. J. Ashton, "Vehicle design and pedestrian injuries: I. pedestrian accidents," in *Chapman*, A. J. Wade, F. M. Foot, *et al*., Eds., John Wiley & Sons Ltd, 1982.

[2] F. H. Waltz, M. Hoefliger, and W. Fehlmann, "Speed limit reduction from 60 to 50 km/h and pedestrian injuries," in *Proc. Twenty-Seventh Step Car Crash Conf. International Research Council on Biokinetics of Impacts*, 1983, pp. 311–318.

[3] D. M. Beckwith and K. M. Hunter-Zaworski, "Passive pedestrian detection at unsignalized crossings," *Transportation Research Record*, vol. 1636, no. 1, pp. 96-103, 1998.

[4] D. C. Richards, "Relationship between speed and risk of fatal injury: Pedestrians and car occupants," *Department for Transport: London*, 2010.

[5] B. Antic, D. Pesic, M. Vujanic, and K. Lipovac, "The influence of speed bumps heights to the decrease of the vehicle speed," *Safety Science*, vol. 57, pp. 303-312, August 2013.

[6] O. M. J. Carsten, D. J. Sherborne, and J. A. Rothengatter, "Intelligent traffic signals for pedestrians: Evaluation of trials in three countries," *Transportation Research Part C: Emerging Technologies*, vol. 6, no. 4, pp. 213-229, 1998.

[7] M. Pau and S. Angius, "Do speed bumps really decrease traffic speed? An Italian experience," *Accident Analysis & Prevention*, vol. 33, no. 5, pp. 585–597, 2001.

[8] A. S. Hakkert, V. Gitelman, and E. Ben-Shabat, "An evaluation of crosswalk warning systems: Effects on pedestrian and vehicle behavior," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 5, no. 4, pp. 275–292, December 2002.

[9] M. King, "Pedestrian safety through a raised median and redesigned intersection," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1828, pp. 56-66, 2003.

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