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## Improving the Performance of Traffic Signal Control at Mid-block Pedestrian Crossings

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#### Abstract

Traffic signals controls at pedestrian crossings have a significant effect on the operational performance of road traffic. They interrupt the operations of the traffic stream. Therefore, the objective of this research is to improve the performance of traffic signal control at mid-block pedestrian crossings. This objective can be achieved by optimization of the signal timing plans. Two mid-block pedestrian crossings located in Cairo-Suez desert road in Suez City, Egypt were selected in this study. They are controlled by traffic signals. The selected pedestrian crossings were modeled and analyzed using the micro-simulation software VISSIM. The collected data were used to calibrate and validate the developed model. Signal timing models were developed for the selected pedestrian crossings. They used for optimization of vehicle delay and pedestrian delay times. Various values of performance index function (PI) are generated for different values of cycle length (C); then, the minimum value of PI is selected as the optimum design. The results showed that the changing of signal timing was successful in improving the operational performance of the traffic signals under study.

Keywords: Pedestrian Crossing, Traffic Signal Control, VISSIM, Optimization.

## 1. Introduction

In urban roads, the traffic volume of the road interacts with the pedestrian crossing the road. The pedestrian crossings allowed pedestrians to cross the road safely as well as, have a priority to cross over the traffic volume. The basic types of pedestrian crossings are at-grade crossings and gradeseparated crossings. At grade crossings, pedestrians and vehicles both cross the carriageway at the same level. They may be controlled and uncontrolled. According to locational aspects they can be classified as pedestrian crossings at intersections and mid-block crossings [1].

Mid-block pedestrian crossings are common on arterials where pedestrians from one side cross to other side for business activities or to enter schools etc. Also, they are common near bus stops and areas with high density residential and commercial areas [2]. Understanding how a transportation facility works is essential for performing planning, design, and optimization on similar segments. The developing of micro-simulation models describing the traffic operations at pedestrian crossings is one method to meet this requirement.

The modeling of pedestrian crossings involves some complexities compared to other roadway facilities because of the vehicle-pedestrian interactions. The microscopic simulation models are widely used to analyze the traffic operations and evaluate the management alternatives of any transportation system. They can capture the individual movement of pedestrians and vehicles in the road segments [3].

Road traffic flow has become significantly impacted by pedestrian crossings, particularly in urban areas. Pedestrian crossings affect the operations of the traffic stream and may cause delay, thus affect the capacity and speed of any road [4]. Due to the increase in traffic growth in rapid urbanization countries like Egypt, there is increase of pedestrian road crossings. Therefore, the objective of this research is to improve the performance of traffic signal control at mid-block pedestrian crossings. This objective can be achieved by optimization of the signal timing plans. The optimization process can reduce both the vehicle delay and pedestrian delay times instantaneously.

### 2. Previous Studies

Some studies have focused on the impact of pedestrian crossings on the traffic operations. In a study conducted by Shuming and Yulong [5], the authors investigated the effect of vehicles and pedestrians characteristics on pedestrian crossing under different crossing conditions. Dana and Shi [6] used multiple linear regression models to estimate the pedestrian delay time. They examined a particular relation between right-turning vehicles and pedestrian crossing delay values. Ghanim and Abu-Eisheh [7] analyzed the effect of mid-block crossing on the traffic operations of urban arterials. They investigated three scenarios of pedestrian crossing including no pedestrian crossing, pedestrian crossing area and pedestrian random crossing using a microscopic simulation. The results showed that the operational performance of road traffic was lower in the situation when pedestrians were cross randomly the study corridor.

Yang et al. [8] evaluated the operational performance of road traffic at pedestrian crossings in the major street. The evaluation was conducted based on capacity and vehicle delay. The proposed models were relied on motorist yielding behavior and arrival time of pedestrians. The study concluded that traffic capacity decreased as the rate of pedestrian access increased. Mao et al. [9] analyzed and predicted the violations of pedestrian crossing under different conditions including roadway, traffic, and environmental conditions in addition to the characteristics of pedestrians. They suggested a technique that combines a Markov Chain model and a logistic regression model. The results indicated that the proposed technique was effective in the prediction of pedestrian violations.

Even though most of the previous studies are already available in the literature, it is noteworthy that these studies have demonstrated only on vehicular traffic. Nonetheless, pedestrian crossings are a significant factor in road performance. In this research, the vehicle delay and pedestrian delay times are reduced by optimization of the signal timing plans using microscopic models calibrated and validated using field data.

## 3. Methods

The adopted methodology is presented in three main steps. The first step is data collection, where the selected section located on Cairo-Suez desert road in Suez City, Egypt, was used as a case study section. Collected data include geometric layout, traffic data and signal timing and phasing. In the second step, collected data was used to develop, calibrate, and validate micro-simulation model of the case study section. Finally, the third step includes the analysis of results.

#### 4. Data Collection and Preperation

Collected data are classified into three categories; road geometry data, traffic data and signal control data. Road geometry data included the physical characteristics of the selected section (including; number of lanes, lane width...etc). On the other side, collected traffic data includes; traffic speed and traffic counts of both vehicles and pedestrians. Whereas, signal control data include; signal operating mode and timing plan (including; cycle time, green, yellow and red indications).

The case study is a section with pedestrian road crossing on Cairo-Suez desert road in Suez City, Egypt. The corridor in this section consists of a main and two service roadways. This section consists of 4 lanes for the main road. Two pedestrian crossings located in this section were selected in this study. They are controlled by traffic signals. Figure 1 shows a general layout of the selected section. Traffic data were collected manually at 15-minute intervals from 8:00 A.M. to 4:00 P.M. Figures 2 and 3 depict the vehicle and pedestrian volume variations for both two locations. From these figures, it can be noticed that, location (1) exhibited higher vehicle and pedestrian volumes than location (2).

The traffic signals at location (1) and location (2) are operating in a fixed-timed mode with a cycle time of 126 s and 100 s respectively. The vehicle signal at location (1) is consisting of 88, 5, and 33 s for the green, yellow and red indications respectively. While it at location (2) is consisting of 65, 5, and 30 s for the green, yellow and red indications respectively. The signal timing sequences for both vehicles and pedestrians at the two locations of pedestrians crossing are shown in Figure (4).



Fig. 1. Layout of the Selected Section for the Study.

### 5. Development of Micro-Simulation Model

The geometric characteristics, traffic flow data, and signal timing plan of the selected section were used as inputs into the micro-simulation software VISSIM V. 9.00 [10] to model and evaluate the operational performance of road traffic at pedestrian crossings.



Fig. 2. Vehicle Volume Variation for both Two Locations.



Fig. 4. Existing Signal Timing Sequences for both Vehicles and Pedestrians at the Two Locations of Pedestrians Crossing.

#### 5.1 Determination of Measures of Effectiveness

The selection of the Measures of Effectiveness (MOE) is regarded as the initial stage in the calibration and validation process. In this research, the calibration method employed average travel speeds, whereas the validation process used average travel times. These variables were chosen because they were simple to gather in the field and generated files for VISSIM.

#### 5.2. Model Calibration

The process of calibrating and validating models is a crucial step in simulation modeling. Calibration is the process of changing a model's parameters to ensure that its output matches field data. Consequently, the calibration parameter in this analysis is traffic volume. If there is a statistical agreement between the predicted and actual traffic volumes, the model is deemed calibrated [11]. In this research there is variety of evaluation criteria used in the calibration process including the following:

## 5.2.1. GEH Statistic

The Geoffrey E. Havers (GEH) statistic is a common measure used in traffic simulation to compare observed with simulated link volumes [12]. The formula for the "GEH" is:

$$GEH = \sqrt{\frac{(R-S)^2}{0.5(R+S)}}$$
(1)

where:

R = Observed real-life traffic volumes; and S = Simulated traffic volumes.

S = Simulated traine volumes.

GEH values indicate the goodness of fit, as follows:

GEH < 5: represents a good fit for traffic volumes;

5 < GEH < 10: further investigation may be required; and 10 < GEH: Traffic volumes cannot be considered to be a good fit.

## 5.2.2. Coefficient of Determination (R<sup>2</sup>)

Coefficient of determination ( $R^2$ ) has been widely used to reflect the goodness of fit of the developed models. While  $R^2$ = 0 denotes that there is no correlation between the model outputs and the observed data,  $R^2 = 1$  denotes that the model is exactly predicting the test data [13].

### 5.3. Model Validation

Validation is the process of comparing simulation model outputs to field measurements to assess the simulation model's accuracy. The real data used in this step need to be distinct from those used in the calibration process [14]. The validation parameter in this analysis is travel time. The following evaluation criteria are employed in this process:

#### 5.3.1. Mean Absolute Percent Error (MAPE)

Calculated as follows:

$$MAPE = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{R-S}{R} \right|$$
(2)

## 5.3.2. Root Mean Square Error (RMSE)

Calculated as:

$$RMSE = \frac{\sqrt{\sum_{i=1}^{N} \frac{(R-S)^2}{N-1}}}{\left(\sum_{i=1}^{N} \frac{N}{N}\right)}$$
(3)

## **5.3.3. Normalized Root Mean Square Error (RMSN)** Which is calculated as follows [15]:

$$RMSE = \frac{\sqrt{N \cdot \sum_{i=1}^{N} (R-S)^2}}{\sum_{i=1}^{N} R}$$
(4)

where:

R = Observed travel times;

S = Simulated travel times; and

N = Number of observations.

According to the Wisconsin Department of Transportation (DOT), the FHWA guide [16] indicated that the acceptable margin of error (MAPE, RMSE, and RMSN) is up to 15%.

## 6. Optimization of Vehicle Delay and Pedestrian Delay Times

The objective of optimization for vehicle delay and pedestrian delay times is to enhance the operational performance of traffic signal control at pedestrian crossings. This objective can be achieved by optimization of the signal cycle time and green time.

## 6.1. Signal Timing Model

To combine and accomplish many objectives, one must first decide how to approach the problem of multi-objective optimization. The performance index (PI) function is used to transform the multi-objective programing problem into a traditional single-objective programing problem. The vehicle delay and pedestrian delay times are defined as indexes. The signal timing model is thus:

$$PI = \alpha \times D_V + \beta \times D_P \tag{5}$$

where:

PI = the performance index function;

 $\alpha$ ,  $\beta$  = the weight of vehicle delay and pedestrian delay, respectively;

 $D_V$ ,  $D_P$  = the average vehicle delay and average pedestrian delay, respectively.

The weights  $\alpha$ ,  $\beta$  reflect the relative significance of the two indexes. They are based on the views of a group of experts [17]. In this research, the values of relative weights are considered:  $\alpha = 0.6$ ,  $\beta = 0.4$ .

## 6.2. Optimization of Signal Cycle Time

The length of the cycle time of signals under fixed time operation is dependent on traffic conditions. Taking into account traffic safety and the psychology of the driver [18], the value of the cycle time (C) should be defined as follows:

$$60 \le C \le 120 \sec \tag{6}$$

The optimized cycle time ( $C_0$ ) can be determined by minimizing the PI function. The optimization process used in this study is shown in Figure 5. After the optimization process, the cycle time which achieves the minimum value of PI can be determined. Next, the pedestrian green time is calculated based on pedestrian crossing time assuming an average pedestrian speed of 3.5 ft/s (1.07 m/s) taking into account the walk allowance. Consequently, the vehicle's green time can be determined.

## 7. Results and Discussion

## 7.1. Model Calibration Results

Eight runs were carried out for the selected corridor with the default parameters of VISSIM. The GEH and R<sup>2</sup> values were computed for each location of the selected corridor based on the average results of eight runs. These values are presented

in Table 1. Moreover, the comparisons between the count from field measurements and micro-simulation analysis for vehicles and pedestrians at the selected locations are shown in Figures 6 and 7, in which  $R^2$  values > 0.9. Consequently, it is worth noting that these statistics indicated a good fit so it was deemed that the VISSIM model is calibrated.



Fig. 5. Flow Chart for Cycle Time Optimization [19].



Fig. 6. Comparison of Observed and Simulated Counts for Vehicles and Pedestrians at Location (1).



Fig. 7. Comparison of Observed and Simulated Counts for Vehicles and Pedestrians at Location (2).

Table 1. Results of GEH and R<sup>2</sup> for Model Calibration.

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Location Flow		GEH	Calibration Criteria (GEH < 5) met?	R <sup>2</sup>	
1	Vehicles	1.05	Yes	0.985	
	Pedestrians	0.44	Yes	0.987	

2	Vehicles	0.96	Yes	0.999	
	Pedestrians	0.38	Yes	0.999	

## 7.2. Model Validation Results

A comparison between the average travel time from field measurement and micro-simulation analysis for each location of the selected corridor was conducted. The percent error measurements between the observed and simulation travel times are presented in Table 2. As shown in the Table, the results of the values of different error measurements (MAPE, RMSE, and RMSN) are below 8%. Therefore, the results indicated that the model is successfully calibrated and validated.

Table 2. Error Measurements for	or Mode	el Validation
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Location	Flow	MAPE	RMSE	RMSN
1	Vehicles	4.2%	4.57	4.28
	Pedestrians	6.2%	6.63	6.20
2	Vehicles	3.9%	4.15	3.88
	Pedestrians	6.5%	7.03	6.62

## 7.3 Optimization Process Results

The calibrated and validated VISSIM model was used to obtain the values of average vehicle delay and average pedestrian delay times. To perform the optimization process of signal cycle time, the calculation procedure for performance index function were repeated several times. Next, the cycle time that achieves the minimum value of PI can be obtained. Figure 8 shows the changes in PI as the cycle time changes.

From Figure 8, it can be noticed that  $C_0 = 114$  sec and 108 sec yield the minimum PI at location (1) and location (2) respectively. These cycle times are within the limits defined earlier, taking into account traffic safety and the psychology of the driver. After that, the pedestrian green time and the vehicle green time were calculated. They were used to determine the optimal timing plans. Figure 9 shows the optimized timing plan of the selected pedestrian crossings.



Fig. 8. Changes of PI with the Cycle Time.



Fig. 9. Optimized Timing Plan of the Selected Pedestrian Crossings.

# 7.4 Comparison of Vehicle Delay and Pedestrian Delay Before and After Optimization

To determine the effectiveness of optimizing the vehicle delay and pedestrian delay, the selected pedestrian crossings were simulated before and after changing the timing plans of signals. Table 3 shows the comparison of the values of average vehicle delay and average pedestrian delay times before and after changing the timing plans of signals at the studied pedestrian crossings using the developed model. From Table 3, it was found that there is an improvement in both the vehicle delay and pedestrian delay after optimization. It can be concluded that the changing of signal timing is effective for improving the operational performance of the traffic signal control at pedestrian crossings under study.

Table 3. Average Vehicle Delay and Average Pedestrian Delay at Pedestrian Crossing Before and After Optimization.

	Location (2)			Location (1)		
	Improvement %	After	Before	Improvement %	After	Before
Average Vehicle Delay (sec/veh)	9.02	7.86	8.64	8.51	8.17	8.93
Average Pedestrian Delay (sec/ped)	12.71	2.54	2.91	12.30	2.21	2.52

## 8. Conclusions

This paper described the optimization process of vehicle delay and pedestrian delay times at mid-block pedestrian crossings. Two mid-block pedestrian crossings were selected at an important location in Suez City, Egypt. VISSIM was used for developing micro-simulation analysis for optimizing the model and compared with the field measurements using several evaluation criteria. The developed model was used to reduce vehicle delay and pedestrian delay times instantaneously. The signal cycle times and green times were optimized using the developed model based on performance index function. There is an optimum cycle time that corresponding to minimum performance index function, when the signal cycle time increases from 60 to 120 sec. Finally, the optimization of signal timing is effective in improving the operational performance of the traffic signals under study.

Optimization of the vehicle delay and pedestrian delay times gives practitioners and researchers the option of improving traffic operations at mid-block pedestrian crossings. This study is limited to the optimization of traffic signals at mid-block pedestrian crossings. The proposed approach can be extended to optimize the vehicle delay and pedestrian delay times for pedestrian crossings of different geometry, traffic, and control conditions that are not considered in the present study.

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#### References

- Baltes M., and Chu X. "Pedestrian level of service for mid-block street crossings". *Transportation Research Record*, 1818 (1), 2002, pp. 125-133.
- Merrill j. "VISSIM model development of a mid-block pedestrian crossing between signalized intersections". *Master of Science Thesis in Civil Engineering, Management and Technology*, College of Engineering, University of Nevada, Las Vegas, USA, 2005, pp. 1-5.
- Hassan S. "Improving pedestrian facilities at signalised crossings". Ph.D. Thesis, *Faculty of engineering and the environment*, University of Southampton, UK, 2013, pp. 41-47.
- 4. Papadimitriou E. "Pedestrian behaviour and safety Models in urban road networks". Ph.D. *Thesis, School of Civil Engineers*, National Technical University of Athens, 2010, pp. 2-4.
- Shuming F. and Yulong P. "The study of pedestrian crossing delays". *Harbin Institute of Technology*, 39(4), 2007, pp. 613-616.
- Dan L. and Shi X. "Estimates of pedestrian crossing delay based on multiple linear regression and application". *Procedia, Social and Behavioral Sciences*, 96, 2013, pp. 1997-2003.
- 7. Ghanim M. and Abu-Eisheh S. "The impact of random mid-block pedestrian crossing on urban arterial operational characteristics in developing countries". *International Journal of Engineering Management and Economics*, 5, 2015, pp. 169-180.
- Yang Z., Zhang Y., Zhu R., Ye X. and Jiang X. "Impacts of pedestrians on capacity and delay of major street through traffic at two-way stop-controlled intersections". *Mathematical Problems in Engineering*, Hindawi Publishing Corporation, 2015, Article ID 383121, pp. 1-11.
- Mao C., Bao L., Yang S., Xu W. and Wang Q. "Analysis and prediction of pedestrians' violation behavior at the intersection based on a Markov Chain". *Sustainability*, 13, 2021, pp. 5690.
- PTV. VISSIM 9.00 user manual. ,*Planning Transport* Verkehr, Karlsruhe, 2016.
- 11. Ragab M., Hashim I. and Asar G. "Impact of road traffic on air emissions: case study Kafr El-Sheikh City, Egypt". *International*

*Journal for Traffic and Transport Engineering (IJTTE)*, 7(3), 2017, pp. 391-405.

- Oketch T. and Carrick M. "Calibration and validation of a microsimulation model in network analysis". *Proceedings of the Transportation Research Board 84th Annual Meeting*, Washington, D.C., 2005, Paper No. 05-1938, pp. 1-17.
- 13. Xiong C., Zhu Z., He X., Chen X., Zhu S., Mahapatra S., Chang G. and Lei L. "Developing a 24-hour large-scale microscopic traffic simulation model for the before and-after study of a new tolled freeway in the Washington Dc-Baltimore Region". *Journal of Transportation Engineering, ASCE*, 141(6), 2015, pp. 05015001.
- Kim S., Kim W. and Rilett L. "Calibration of micro-Simulation models using nonparametric statistical techniques". Transportation Research Record, *Journal of the Transportation Research Board*, National Research Council, Washington D.C., No. 1935, 2005, pp. 111-119.
- Balakrishna R., Antoniou C., Ben-Akiva M., Koutsopoulos H. and Wen Y. "Calibration of microscopic traffic simulation models: methods and application". *Journal of the Transportation Research Board*, No. 1999, TRB, National Research Council, Washington, D.C., 2007, pp. 198-207.
- FHWA, Traffic Analysis Toolbox, Volume III. Guidelines for Applying Traffic Micro-Simulation Modeling Software. *Publication FHWA-HRT-04-040. FHWA*, U.S. Department of Transportation, 2004, pp.74.
- 17. Li X., Li G., Pang S., Yang X. and Tian J. "Signal timing of intersections using integrated optimization of traffic quality, emissions and fuel consumption: a note". *Transportation Research Part D*, 9(5), 2004, pp. 401-407.
- Lin C., Gong B. and Qu X. "Low Emissions and Delay Optimization for an Isolated Signalized Intersection Based on Vehicular Trajectories". *PLOS ONE Journal*, 10(12), 2015, pp. 1-17.
- Hashim I., Ragab M. and Asar, G. "Optimization of vehicle delay and exhaust emissions at signalized intersections". *Advances in Transportation Studies: an International Journal*, XLVI issue, Section A 46, 2018, pp. 5-18.