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MEASURES TO IMPROVE TRAFFIC OPERATIONS AT SIGNALIZED INTERSECTIONS IN URBAN AREAS

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Abstract: Intersections are usually considered the most complex locations in the road network. They have a very considerable effect on operational performance of road traffic. Traffic signals at intersections have a significant effect on traffic operations. Therefore, the objective of this research is to set measures for improving the traffic operations at signalized intersections in urban areas. Two 3-legged intersections located in Mansoura City, Egypt were selected in this study. Vehicle speed and acceleration profiles obtained using GPS device were used to estimate delay times. The micro-simulation software VISSIM was used to model and analyze the selected intersections. The field collected data were used in the calibration and validation processes. The study investigated three scenarios using the developed models; Scenario 0 (original scenario), Scenario 1 (optimization of signal cycle time) and Scenario 2 (increasing of lane width). The evaluation was conducted based on average delay values and LOS. The simulation results indicated that Scenario 1 and Scenario 2 can reduce the delay values resulting the better LOS values from D to C for both selected intersections. Moreover, Scenario 1 exhibited lower delay values than other scenarios for both intersections.

Keywords: delay time, traffic signals, speed profiles, VISSIM.

1. Introduction and Background

Road intersections are not only nodes of urban traffic network, but also spots of traffic congestion. They involve the highest traffic density within the network that significantly affect the performance of the whole network. Traffic congestion at intersections is a major issue in traffic engineering as it causes excessive fuel consumption resulting in many safety problems. Traffic engineers aim to mitigate intersection congestion usually need to analyze and evaluate traffic operations at signalized intersections in order to measure vehicle delay and level of service (Garber and Hoel, 2009).

Traffic signals are installed when traffic at an intersection becomes too heavy for motorists to efficiently or safely assign their own right of way. They impose significant impact on traffic operations. Moreover they interrupt traffic flow and create additional deceleration, idle and acceleration driving modes to the otherwise cruise driving mode.

The Highway Capacity Manual (HCM) has adopted delay as the principal measure for designing traffic control systems and evaluating traffic improvement plans (TRB, 2010). It is considered the most important measure of effectiveness (MOE) at signalized intersections because it is used to determine

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level of service (LOS). Regular evaluation of the level of service gives traffic engineers the option of improving of traffic operations in the designing of the signalized intersections or timing a signal system. Therefore, the objective of this research is to evaluate and improve the operational performance of road traffic via setting measures for improving the traffic operations at signalized intersections in urban areas.

Some studies have focused on the delay estimation at signalized intersections. In a study conducted by Kumar and Dhinakaran (2012), the authors studied the control delay at signalized intersections for mixed traffic conditions in a developing country (India). They estimated the control delay from theoretical delay model and compared it with control delay measured in the field following HCM 2000 guidelines. The results indicated that there is no good correlation between observed delay in the field and predicted delay from theoretical model. Therefore, field measured control delay was taken into account to define LOS.

Afshar and Yaman (2014) determined the control delay and LOS at signalized intersections according to HCM at four 3-legged signalized intersections in Ankara. The results showed that the intersections on the south corridor have lower LOS levels ranging from C to F whereas the north corridor currently carries less traffic, which resulted in LOS ranging from C to E on peak hour.

Ahmed et al. (2019) used Cell Transmission Model (CTM) to determine optimal signal plans based on control delay at two different locations in Karachi. The study concluded that optimum signal timings can reduce delays and improve the operational performance of traffic network.

Although studies are currently available in the literature, it is noteworthy that these studies estimated control delay and LOS based on HCM guidelines or theoretical models. In this research, the control delay and LOS are determined using microscopic models based on field measurements of delay times.

2. Methodology

2.1. Definition of Control Delay Components

Control delay at a signalized intersection is generally defined as the delay attributed to the traffic signal operation. As illustrated in Figure 1 the sum of deceleration delay, stopped delay and acceleration delay represents the control delay. Based on the following equations for which the definitions of symbols can be found in Figure 1, the delay components can be easily calculated.

$$\text{Deceleration delay } = (t_2 - t_1) - \frac{d_2 - d_1}{v_{ff}} \quad (1)$$

$$\text{Stopped delay } = t_3 - t_2 \quad (2)$$

$$\text{Acceleration delay } = (t_4 - t_3) - \frac{d_3 - d_2}{v_{ff}} \ \dots \quad (3)$$

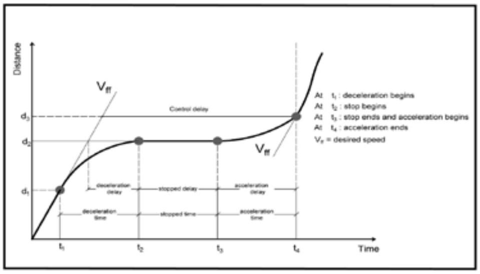
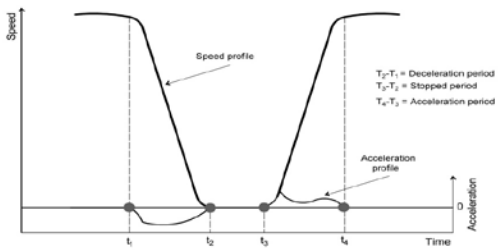


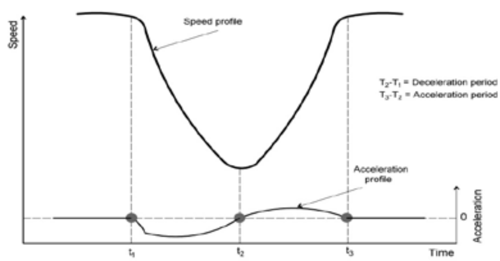
Fig. 1.
Diagram of Intersection Delay Components
Source: (Ko et al., 2008)

2.2. Measuring of Field Control Delay

Field control delay can be estimated based on speed profiles of individual vehicles using different methods. These methods are video image method; path tracing method; and test car using GPS method. In this research, test car using GPS method is used to determine field control delay. Speed and acceleration profiles of individual vehicles passing an intersection can be obtained using GPS device. Based on speed and acceleration profiles, the critical points that have zero acceleration can be identified as shown in Figures 2 (a) and (b) (Quiroga and Bullock, 1999).



(a) Speed profile with stopped delay



(b) Speed profile without stopped delay

Fig. 2.
Vehicle Speed and Acceleration Profiles Near an Intersection
Source: (Quiroga and Bullock, 1999)

2.3. Development of Micro-simulation Model

In this study the micro-simulation software VISSIM was used to model and evaluate the traffic operations at the studied intersections. VISSIM is a stochastic time step microscopic simulation software package developed by PTV AG, Germany. It provides the flexibility to model any type of geometric configuration or unique driver behavior encountered within the transportation system (PTV AG, 2014). Calibration and validation process is a key component of the models building. Calibration process is defined as the adjustment of the model parameters to reflect the real world observation. Whereas, validation process is defined as the process of comparing the output of the calibrated simulation model with a different set of real world observations that were not used in the calibration process in order to determine the accuracy of the simulation model (Manjunatha *et al.,* 2013).

In this research, trial-and-error method is used for performing this process. The field delay data of the two selected intersections was divided into two parts. The first intersection data was used in the calibration stage while, the second intersection data was used for validation purpose. There are a number of parameters can be used for calibration and validation process of VISSIM models. These parameters include: lane changing parameters; car-following parameters; and desired speed distribution parameter (Park *et al.,* 2003). In this research, the desired speed distribution parameter was considered for the calibration and validation process.

2.4. Proposed Improvement Measures

There are different improvement measures can be implemented to improve traffic operations at signalized intersections. The following subsections describe the investigated measures in this study.

2.4.1. Optimization of Signal Cycle Time

The cycle time for an isolated intersection should be considered to minimize vehicle queues on the streets. Preferably, it ranges between 35 and 60 seconds. Although, when approach volumes are very high, it is necessary to use longer cycle time. However, cycle times should not be exceeded 120 seconds, since very long cycle times will result in excessive delay (Lin *et al.,* 2015). Therefore, in this research, the upper limit of cycle time of 120 seconds is assumed. The optimized cycle time (C_0) can be obtained by minimizing of delay values at the intersections. The new scenario (Scenario 1) was created for the selected intersections with the optimized cycle time (C_0).

2.4.2. Increasing of Lane Width

Travel lanes provide the space that moving vehicles occupy during normal operations. The standard width of a travel lane is 12 ft (3.65 m), although narrower lanes are permitted when necessary. The minimum recommended lane width is 9 ft (2.75 m) (MUTCD, 2012). Lane width has a significant effect on saturation flow rates: there is a reduction in saturation flow rates when lane widths are less than 12 ft and there is an increase in saturation flow rates when lane widths are greater than 12ft (Luttinen and Nevala, 2002). To study the effect of increasing of lane width on traffic operation at intersections, a new scenario was created using micro-simulation VISSIM software V. 7.00. The new scenario (Scenario 2) was created for the selected intersections with standard lane width (3.65 m).

3. Data Collection and Preliminary Analysis

To achieve the objective of this research, basic data were collected in addition to the field delay time. These data are: geometric characteristics, traffic volume, traffic composition and signal phasing and timing.

3.1. Site Selection

Three-leg (T) intersection is the most common intersection design in Egypt (Hashim *et al.,* 2018). Therefore, the objective of this research is focused on improving of operational performance at signalized intersections in urban areas in Egypt. To achieve this objective, two 3-legged signalized intersections were selected at important locations in Mansoura City. The selected intersections are presented in Figure 3.

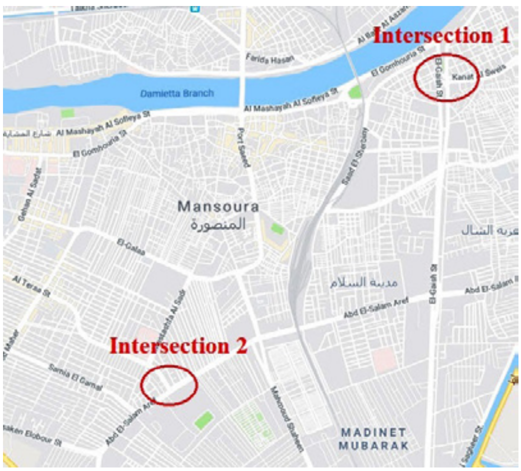


Fig. 3.
The Selected Intersections for the Study (From Google Maps)

3.2. Geometry Data

Table 1 presents the details of geometric characteristics of the selected intersections including number of lanes, lane width, median width and sidewalk width.

Table 1
Geometric Characteristics of the Selected Intersections

Intersection	Approach	Movement	No. of Lanes	Average Lane Width (m)	Average Median Width (m)	Average Sidewalk Width (m)
1	Eastbound	Right-turn	1	3.50	2.00	1.20
		Left-turn	1			
	Northbound	Through	1	3.50	2.50	1.30
		Left-turn	1			
	Southbound	Right-turn	1	3.50	2.50	1.30
		Through	1			
2	Eastbound	Right-turn	1	3.25	2.00	1.10
		Through	1			
	Westbound	Through	1	3.25	1.50	1.00
		Left-turn	1			
	Northbound	Right-turn	1	3.25	1.50	1.00
		Left-turn	1			

3.3 Traffic Counts and Composition

Volume data and traffic compositions were collected manually at 15-minute intervals from 8.00 A.M. to 4.00 P.M. The weather was clear and the pavement was dry during the data collection periods. Traffic was classified into two vehicle classes: passenger cars and light good vehicles. From count survey, it can be noticed that, the most traffic is composed of cars.

3.4. Signal Phasing and Timing

In Mansoura City, traffic signals are used to control the traffic operations. They are operating in a fixed-timed mode with a total cycle time of 110 sec for the selected intersections. The number of phases equals 2. The signal phasing is consisting of 60, 5, and 45 sec for the green, yellow and red indications respectively.

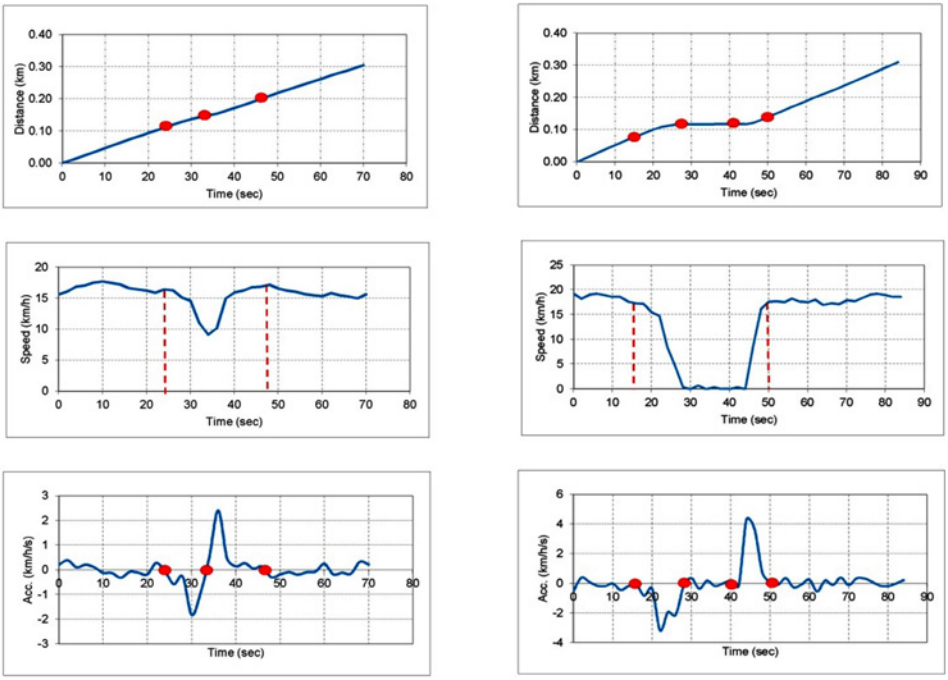
3.5. Vehicle Delays

Figure 4 depicts examples of speed profile, time-space diagram and acceleration profile with and without stopped delay and with stopped delay for right-turn movement of southbound direction at the first selected intersection. Examples of the results of delay components are presented in Table 2.

Table 2
Examples of Delay Computation Results for Sampled Runs of Southbound Approach at the First Selected Intersection

Sample No.	Deceleration Delay (sec)	Stopped Delay (sec)	Acceleration Delay (sec)	Control Delay* (sec)
Right-turn Movement				
1	5.2	0.0	3.2	8.4
2	4.2	0.0	8.8	13.0
3	1.6	0.0	3.6	5.2
4	3.4	0.0	2.4	5.8
5	2.6	0.0	5.4	8.0
6	4.4	0.0	2.6	7.0
7	3.4	0.0	6.4	9.8
8	4.6	0.0	4.6	9.2
9	5.4	0.0	3.6	9.0

**Control Delay = deceleration delay + stopped delay + acceleration delay*



(a) with stopped delay (b) without stopped delay

Fig. 4.
Examples of Speed Profile, Time–Space Diagram and Acceleration Profile with and without Stopped Delay

4. Results

The micro-simulation software VISSIM V. 700 (PTV AG, 2014) was used to simulate and evaluate the traffic operations at the selected intersections with the geometric characteristics, signal timing plan and traffic flow data collected from survey as inputs into software. The results of the 3600 sec (60 minutes) simulation period were used for the analysis.

4.1. Models Calibration and Validation

The simulated values of delays were extracted from the VISSIM model runs with default parameters for the selected intersections. These values were compared with the real world observations of delay. The values of percent error for the VISSIM model runs are presented in Table 3. It was found that, the values of percent error for some movements of the first intersection were above 10%. Consequently, running the VISSIM models with default parameters would not be appropriate.

To perform the calibration process, the desired speed distribution was manually edited to closely match the real world observation of delay (Ragab *et al.,* 2017). The VISSIM models were re-run again and the resulted values of delay from simulation were determined. Again, the values of percent error were computed for the calibrated models; the results are presented in Table 3. From this table, it can be noticed that, the values of percent error were below 10% indicating a reasonable matching between the simulated and the observed delay values. The models calibration was considered to be successfully completed. Validation of the simulation models is the next process in order to determine the accuracy of the simulation models using the data of the second intersection.

To validate the models, the resulted delay values from simulation of the calibrated models for the second intersection were compared to the real world observations of delay. Percent error measurements were computed and presented in Table 4. As shown in this table, the percent error measurements were below 10% indicating a reasonable matching between the simulated and the observed delay values. Therefore, it can be concluded that, the models are successfully calibrated and validated.

Table 3

Results of Percent Error Measurements of Average Delay per Vehicle for Model Calibration

Approach	Movements	Average Delay (sec/veh)					
		Before Calibration			After Calibration		
		Observed	Simulated	Error (%)	Observed	Simulated	Error (%)
Eastbound	Right-turn	35.51	39.22	10.45	35.51	36.92	3.97
	Left-turn	46.29	51.86	12.03	46.29	47.11	1.77
Northbound	Through	48.84	48.21	1.29	48.84	50.01	2.40
	Left-turn	30.38	34.49	13.53	30.38	32.13	5.76
Southbound	Right-turn	43.16	38.81	10.08	43.16	42.72	1.02
	Through	29.25	27.87	4.72	29.25	27.67	5.40

Table 4

Results of Percent Error Measurements of Average Delay per Vehicle for Model Validation

Approach	Movements	Average Delay (sec)		
		Observed	Simulated	Error (%)
Eastbound	Right-turn	41.68	38.91	6.65
	Through	45.72	47.51	3.92
Westbound	Through	44.22	42.55	3.78
	Left-turn	40.46	42.76	5.68
Northbound	Right-turn	41.34	40.76	1.40
	Left-turn	40.42	41.66	3.07

4.2. Simulation Analysis

After conducting the calibration and validation processes, average delay values were collected as outputs from models simulation, in order to evaluate the effectiveness of each investigated improvement scenario. The results of average delay values for different scenarios are shown as follows:

- The optimum cycle time (C_0) that meets the minimum values of average delay for the selected intersections were obtained. It was determined to be 88 sec and 82 for the first intersection and the second intersection respectively. These cycle times are less than the original 110 sec for both selected intersections and within the limits defined earlier. In addition, average delay values for Scenario 1 (optimization of signal cycle time) were determined to be 31.4 sec and 33.2 sec for intersection 1 and intersection 2 respectively;

- The selected intersections were simulated with standard lane width (3.65 m) using the developed models. Average delay values for Scenario 2 (increasing of lane width) were determined to be 34.1 sec and 34.3 sec for intersection 1 and intersection 2 respectively.

Table 5 summaries the results of the original scenario and the proposed improvement scenarios for the selected intersections. From this table, it can be noticed that Scenario 1 and Scenario 2 can reduce the delay values resulting the better LOS values from D to C for both selected intersections according to LOS criteria for signalized intersections as shown in Table 6 [2]. Moreover, the comparisons of different scenarios showed that, the optimization of signal cycle time (Scenario 1) exhibited lower delay values than other scenarios for both intersections. Figure 5 depicts the improvement percentages of delay values with different scenarios for the selected intersections. Noteworthy is that, intersection 2 exhibited higher improvement percentages of delay values than intersection 1.

Table 5

Average Delay and LOS on the Selected Intersections for Different Scenarios

Intersection	Scenario	Average Delay (sec/veh)	LOS
1	Original Scenario (Scenario 0)	38.9	D
	Scenario 1	31.4	C
	Scenario 2	34.1	C
2	Original Scenario (Scenario 0)	42.3	D
	Scenario 1	33.2	C
	Scenario 2	34.3	C

Table 6

LOS Criteria for Signalized Intersections

LOS	Control Delay per Vehicle (s/veh)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

Source: (TRB, 2010)

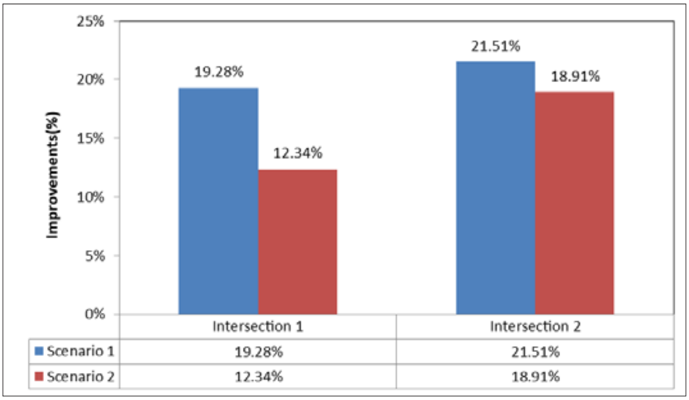


Fig. 5.
Improvements (%) of Delay Values with Different Scenarios for the Selected Intersections

5. Conclusions and Recommendations

This paper evaluates the impact of different improvement measures on traffic operations at signalized intersections in urban areas based on field data and micro-simulation models. Two 3-legged signalized intersections were selected at important locations in Mansoura City, Egypt. Field delay times were measured at the selected intersections based on speed and acceleration profiles. The micro-simulation models were developed for the selected intersections using VISSIM software. Then, they were calibrated and validated using the collected data. The developed models were used to evaluate two different improvement measures; optimization of signal cycle time and increasing of lane width. Analysis showed that:

- Optimization of signal cycle time and increasing of lane width can reduce the delay values. These have resulted in achieving improved of LOS at the selected intersections;
- Optimization of signal cycle time scenario exhibited lower delay values than original scenario and increasing of lane width scenario for the selected intersections.

Improving of traffic operations at signalized intersections gives traffic engineers the option of minimizing vehicle delays in the designing traffic control systems and setting traffic improvement plans. A future extension of this work should be performed on different types of intersections with a wide range of traffic and geometric conditions.

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