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Evaluation of Traffic Improvement Options Using Traffic Simulation

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Abstract: This research aimed at evaluating traffic improvement options for urban street networks using traffic simulation. Traffic, geometric and control data were collected from a selected study area which consisted of eight major at-grade intersections in Irbid city, Jordan, and the traffic simulation software (CORSIM) was used to evaluate the proposed traffic improvement options. The results of the network level analysis showed that the scenario of two rings of one-way streets provided the highest average travel speed (40% increase) and the lowest average traffic delay (47% reduction) as compared to the existing condition. It was found that a network with moderate intersections traffic volumes performs better with roundabouts than with signals. Replacing the network roundabouts by coordinated and optimized traffic signals provided more improvement in the average travel speed than the average traffic delay.

Key words: Delay, speed, network, congestion, simulation.

1. Introduction

Traffic agencies in Jordan are providing solutions for mitigating traffic congestion, however, most of their improvements are applied at individual intersections resulting, in many cases, in shifting the problems to other locations. It would be more efficient to consider comprehensive solutions on the network level taking in consideration the interactions and effects of different intersections. However, this is not possible to be evaluated in the real world due to cost and safety concerns. Several comprehensive improvement alternatives may be evaluated by the traffic simulation software as the most practical and effective tools for quantifying the limitations and benefits of different improvement options.

Irbid city was taken as an example for main cities in Jordan to evaluate selected practical traffic management scenarios using computer simulation. Irbid city has the second largest metropolitan population in Jordan after the capital city, Amman with a population of around 650,000, and is located about 70 km to the north of Amman. This research aimed at using CORSIM as a tool for evaluating the proposed traffic improvement options in reducing traffic congestion in urban areas.

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2. Literature Review

Different methods are usually followed for mitigating traffic congestion in urban areas. Schrank and Lomax [1] found that traffic signal coordination reduced the arterials delay by about 1.5%. Meyer [2] listed the major congestion reduction strategies along arterials and local streets considering the roadway design (one-way streets, reversible traffic lanes, arterial access management etc.) and operations (traffic signal improvements, turn prohibitions, improved traffic control devices etc.). Arnold [3] concluded that congestion reducing measures by managing the existing supply are usually rated above average in effectiveness and below average in cost and ease of implementation.

Several studies have focused on the advantages of one-way over two-way street systems. Dixit [4] found that networks with increased fraction of one-way streets have reduced driver's perception of likelihood to crash. Enustun [5] found that converting some state trunk lines through cities from two-way to one-way has increased the average travel speed up to 28.2 mph in Lansing. Hocherman and Bar-Ziv [6] reported that converting two-way streets to one-way streets has resulted in a decrease in traffic accidents by 20%-30%. Wright et al. [7] showed that different combinations of one-way streets and turn restrictions can be used to minimize the frequency and severity of traffic conflicts.

On the other hand, Wang et al. [8] found that two-way street systems produce lower emissions than one-way street systems during off-peak periods, but not necessarily during peak periods. Gayah and Daganzo [9] found that the two-way operation with banned left turns has higher trip-serving capacity than the one-way operation. Hawkins et al. [10] evaluated the transportation and safety impacts of converting some existing one-way roadways into two-way operations within downtown CBD of Des Moines due to the belief from retail businesses that two-way operations will attract more customers. Meredith and Prem [11] evaluated the feasibility of eliminating one-way restrictions in the CBD of Kansas city and identified the negative impacts (increase in vehicle hours-of-travel and potential for more accidents) and the positive impacts (decrease in vehicle miles-of-travel).

Dbindsa and Spiller [12] have explained that the recurring localized bottlenecks occur when the approaching traffic rate exceeds the departing traffic rate due to decision points and/or physical constraints. They recommended using the highway capacity manual procedures for analyzing bottlenecks at localized areas, and the simulation procedures for expanded study areas where priority is given to improving the entire system considering different improvement strategies. Yun and Park [13] have shown that the microscopic simulation software like CORSIM outperform the macroscopic analysis software like SYNCHRO in evaluating the coordinated actuated traffic signal networks.

Lin et al. [14] have used traffic simulation and recommended that the traffic congestion at a selected major intersection can be reduced by establishing an alternate route to bypass that intersection reducing the average delay to more than 30%. Chaudhry et al. [15] have utilized traffic simulation among other techniques to develop guidelines for mitigating congestion in traffic signal systems.

CORSIM was used by several researchers to compare alternative control and design strategies for traffic intersections, corridors and networks. It was used by Lin et al. [16] for evaluating the proposed model-based controllers with different criteria to decrease network traffic congestion, by Hale [17] to test the HCM2010 trajectory analysis procedures, by Hummer [18] to study the double-wide design as an inexpensive way to increase capacity of signalized intersections on four-lane highways, by Knapp et al. [19]to study the feasibility of converting the number of lanes on an urban minor arterial from four to three, by Yu and Meyer [20] to develop a downtown traffic circulation plan for the city of Topeka- Kansas, and by Lu et al. [21] to evaluate the safety and operational impacts of different alternative left-turn treatments from driveways and side streets.

3. Methodology

The methodology of this research can be summarized as follows:

(1) Data collection: The collected data included geometric data (the number of lanes, lane widths etc.), traffic data (traffic volumes at links and intersections, traffic mix etc.), and control data (signal timings, phasing etc.).

(2) Simulation model development: The study area traffic network was modeled on CORSIM considering the existing geometric, traffic and control conditions. Part of the collected field data was used for the model calibration and validation. CORSIM is a microscopic and stochastic simulation software which applies time step simulation to model individual vehicle movement theories on a second-by-second basis based on car following theory, gap acceptance, lane changing, and other models for describing the interactions among the driver, vehicle, road and environment [22]. Fig. 1 shows the modeling of the study area on CORSIM with zoomed animation at one intersection.

(3) Analysis of existing traffic condition: CORSIM was used to evaluate the existing network on both individual level (for each major intersection) and network level (considering the whole study area network) using the evaluation criteria based on delay and speed.

(4) Developing traffic improvement alternatives: Based on the results of the analysis and utilizing the input from Irbid municipality, a group of practical alternatives were developed to reduce the traffic congestion in the study area.

(5) Evaluating alternatives and choosing the best alternative: The traffic simulation was used to evaluate different alternatives and the best alternative was selected and recommended.

4. Data Collection and Reduction

The selected study area consists of eight major intersections around Yarmouk University in Irbid city, Jordan as shown in Fig. 1. All geometric, traffic and control data were collected by Alomari [23] with the help of Irbid municipality during the spring of 2010. Tables 1 and 2 show the main intersection geometric elements.

Automatic traffic counts were conducted on the major network links to identify the peak periods. It was found that all intersections had the same a.m. peak period; however, they had different noon and p.m. peak periods. So, it was decided to adopt the a.m. peak period for the rest of the analysis.

Manual traffic counts were conducted to get the volumes of turning movements at all network major intersections, considering the main turning movements

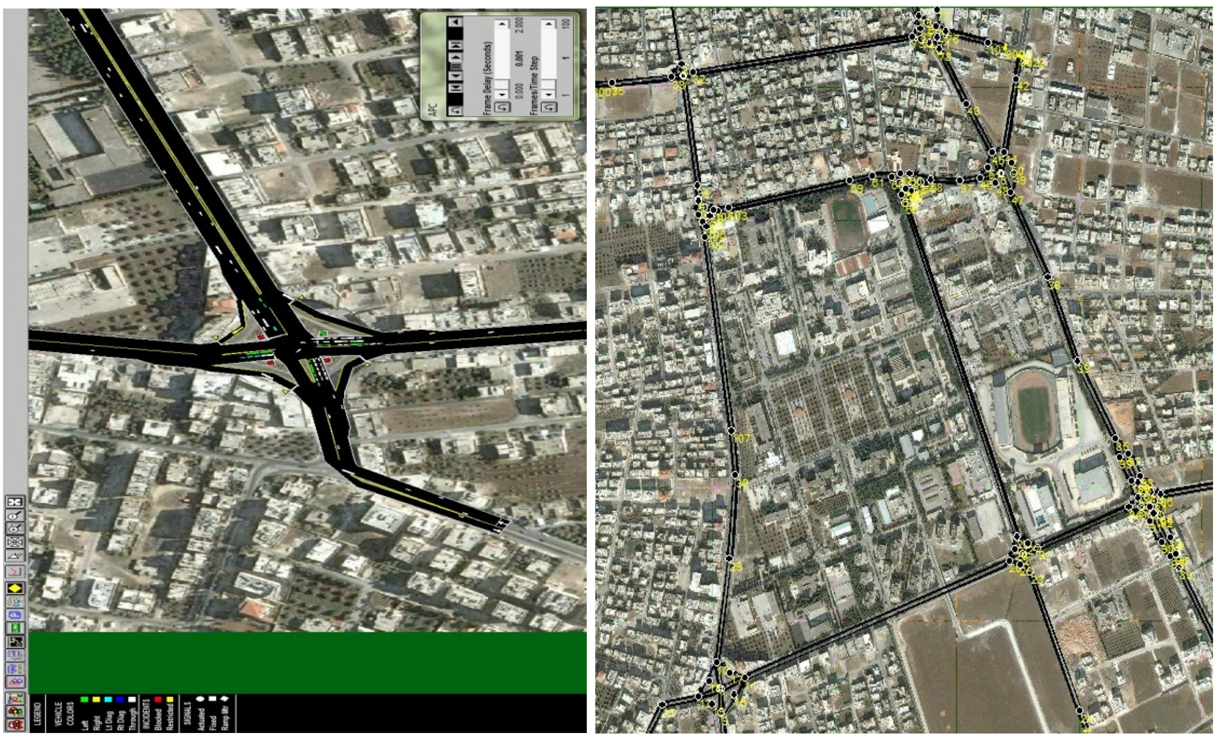


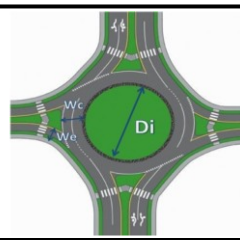
Fig. 1 Modeling the study network on CORSIM (with zoomed animation at one intersection).

Table 1 Intersections characteristics.

Intersection	Control type	Number of lanes				Lane width (m)				Number of approaches
		EB	WB	NB	SB	EB	WB	NB	SB	
T1	Traffic signal	3	4	3	3	3.4	3.3	3.3	3.7	4
T2	Traffic signal	4	4	2	2	3.3	3.2	3.7	3.4	4
T3	Roundabout	2	2	2	2	3.8	3.8	3.8	3.8	4
T4	Roundabout	-	3	3	3	-	3.1	3.1	3.1	3
T5	Roundabout	3	3	3	-	3.8	3.1	3.5	-	3
T6	Traffic signal	4	2	4	4	3.3	3.7	3.3	3.3	4
T7	Traffic signal	2	2	2	3	4	3.6	3.6	3.3	4
T8	Roundabout	2	2	3	2	3.8	3.7	3.5	3.6	4

Table 2 Roundabouts characteristics.

Intersection	[1]Di (m)	[2]We (m)				[3]Wc (m)
		EB	WB	NB	SB	
T3	48	7.6	7.6	7.6	7.6	11.5
T4	16	-	9	9	9	14
T5	20	11.5	9	10.5	-	9
T8	35	7.6	7.4	10.5	7.2	15



[1]Di = Roundabout diameter (m);
[2]We = Width of entry roadway (m);
[3]Wc = Width of circulating roadway (m).

(U-turn, left, through, and right) with vehicle classifications. Digital camera was used to record the data during the a.m. peak period on typical working days (Monday, Tuesday and Wednesday) of April 2010 as Friday and Saturday are the weekend days in Jordan.

5. Analysis and Results

Traffic analysis was conducted in two levels: intersection level and network level.

5.1 Intersection Level Analysis

Although the main purpose of this research was to study alternative traffic options at the network level, an intersection level analysis was conducted first to better understand the existing conditions at each individual intersection, before moving to the network level analysis. The HCS (highway capacity software) was used for the analysis of intersections controlled by traffic signals, and SIDRA software was used for the analysis of intersections controlled by roundabouts. The major scenarios considered in the intersections level analysis included:

(1) Existing condition;

(2) Optimizing the signal timing and phasing;

(3) Optimizing the signal timing and phasing with some geometric improvements (adding free right turns at one approach of intersections T2 and T7, and increasing the roundabout diameter at intersections T4 and T8);

(4) Replacing roundabouts by optimized traffic signals;

(5) Replacing roundabouts by optimized traffic signals with signal coordination;

(6) Using CW (clockwise) one-way traffic ring around Yarmouk University;

(7) Using CCW (counter clockwise) one-way traffic ring around Yarmouk University;

(8) Using two one-way traffic rings in the study network as shown from Fig. 2. King Abdulla II Street was kept running in two ways operation as it is a major entrance to the city and has recently witnessed major traffic improvements.

Fig. 2 Two one-way rings scenarios.

The results of the analysis showed that the last scenario (two one-way rings) was the best alternative based on delay values for intersections (T1, T3, T4, T5 and T7) and the second best alternative for intersections (T2, T6 and T8). The one-way ring scenarios improved the operation at all intersections included in the ring but not necessarily at other intersections in the network. The geometric design improvements scenario was the best for one intersection (T8) and the second best for another intersection (T7). So the one way and/or geometric improvement scenarios were superior to all other scenarios at all intersections.

5.2 Network Level Analysis

The CORSIM was calibrated and validated using the collected field data. It was found that CORSIM may be used for representing the existing conditions with acceptable accuracy (R^2 of 87.6, 89.5, and 96.4 % for traffic speeds, volumes, and maximum queue lengths respectively).

CORSIM produces several MOEs (measures of effectiveness) and on different levels (movement, approach, intersection, link and network). The following are the main MOEs used in this study for comparing different network scenarios:

- Average delay time (seconds per vehicle);
- Average speed (kilometers per hour).

The eight intersection level scenarios were repeated in the network level analysis using CORSIM. Each scenario was compared to the existing condition in terms of percent improvement (increase) in traffic speed as shown in Fig. 3 and improvement (decrease) in traffic delay as shown in Fig. 4.

The best traffic improvements (increase in the average network travel speed and decrease in the average network traffic delay as compared to the existing condition) have been achieved by the two one-way rings, CCW one-way ring, and CW one-way ring scenarios respectively.

It can be seen that the scenario of two rings of one-way streets was the best and provided the highest average network speed (40% increase as compared to the existing condition) and lowest average network traffic delay (47% reduction as compared to the existing condition). This is mainly due to the reduction in the number of signal phases and removal of signals from two T-shaped intersections which ended up having a free traffic operation with only merging and diverging traffic conflicts.

Little benefit was obtained by optimizing the traffic signals (4% speed increase and 7% delay reduction), while adding some geometric improvements provided 20% speed increase and 19% delay reduction. This means that good designed roundabouts with moderate traffic volumes might provide a better network performance than signalized intersections.

Replacing the roundabouts by optimized traffic signals reduced the amount of speed increase to 11% and the amount of delay reduction to only 3%. However, when all signals were coordinated, the speed increase reached 29% and the delay reduction reached 8%. This means that coordinating traffic signals provides more improvement to travel speed than traffic delay.

Using a clockwise one-way ring with optimized and coordinated traffic signals provided 31% speed increase and 19% delay reduction for the network traffic,

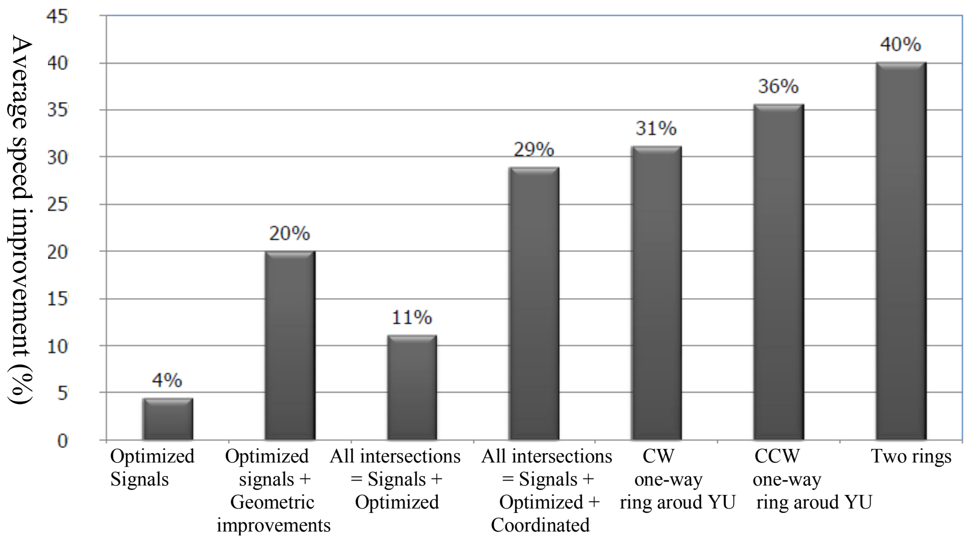


Fig. 3 Percent speed increase for different scenarios as compared to existing condition.

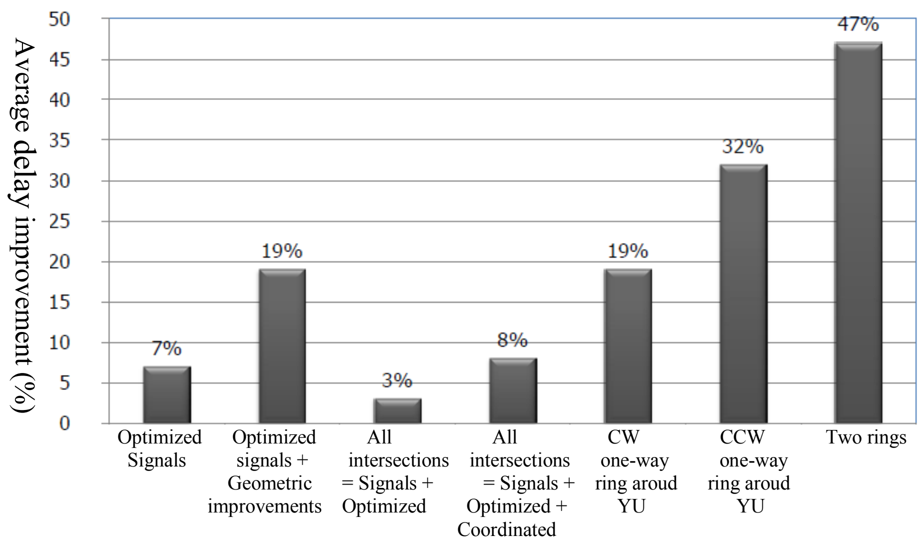


Fig. 4 Percent delay decrease for different scenarios as compared to existing condition.

while using a counter clockwise one-way ring with optimized and coordinated traffic signals provided 36% speed increase and 32% delay reduction, meaning that the counter clockwise is preferred over the clockwise one-way street system. Furthermore, using two rings of one-way streets provided 40% speed increase and 47% delay reduction for the network traffic, meaning that providing more one way-street rings produces higher travel speeds and lower traffic delays over the street network system. The results of this study show that significant operational benefits can be obtained by adopting the one-way traffic system at congested urban street networks.

6. Conclusions

The results of the intersection level analysis based on average intersection traffic control delay showed that the two one-way rings scenario was the best alternative for five intersections and the second best alternative for three intersections. The one-way ring scenarios improved the operation at all intersections included in the rings but not necessarily at other intersections in the study network. The geometric design improvements scenario was the best for one intersection and the second best for another intersection.

The results of the network level analysis based on the percent increase in the average travel speed and the percent decrease in the average traffic delay as compared to the existing condition showed that the scenario of two rings of one-way streets was the best alternative. It was found that little benefit could be obtained by optimizing the traffic signals, while good designed roundabouts with moderate traffic volumes might provide a better network traffic performance than signalized intersections. Replacing the roundabouts by coordinated and optimized traffic signals provided more improvement to the average sub network travel speed than the average sub network traffic delay. The counter clockwise is preferred over the clockwise one-way street direction.

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