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Safety and Operational Performance of Signalized Roundabouts: A Case Study in Doha

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Abstract

Traffic safety is one of the important challenges that urban transportation systems are facing. The common practice of assessing the safety of transportation systems starts with the collection of readily available crash data and crash reports from different resources, and processing these collecting data. This approach, however, requires having an operational transportation system and historical crash data that are extended for long periods that can, which are usually years before proper assessment and proposed countermeasures can be implemented. Therefore, a new trend in analyzing and assessing the traffic safety of different transportation systems has been developed and used lately. This trend relies on analyzing traffic conflicts that are generated through traffic simulation environment. Those simulated traffic conflicts are then associated with different traffic safety assessment measures. The simulated traffic conflicts can be obtained by analyzing observed vehicle trajectories, or simulated ones. Surrogate Safety Assessment Model (SSAM) is an analysis tool that processes simulated traffic trajectories. In this paper, the safety and operational performance of a signalized roundabout in the City of Doha ate assessed through the simulation approach and applying the surrogate safety assessment model. The results indicated that the signal timings and phasing schemes are associated with the level of safety at the signalized roundabout by reducing or increasing the potential traffic conflicts. Moreover, it was found that high traffic demand at signalized roundabouts is not necessarily related to the high traffic conflicts or high conflict severity.

Keywords: Signalized roundabouts, safety performance, microsimulation, surrogate safety assessment model;

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1. Introduction

Although roundabouts have a significant and potentially positive impact at junctions' operational and safety performance, there are several challenges facing roundabouts in Qatar, such as high traffic demand. Accordingly, traffic authorities in Qatar have installed traffic signal control systems at relatively significant roundabouts in the City of Doha in order to improve their operational and safety performance. Most of the urban roundabouts share the following characteristics:

1. All approaching traffic is controlled by a yield sign, giving priority to the circulating traffic
2. Traffic is circulated in a counter-clockwise direction
3. Pedestrians can only cross the roundabout approaches
4. No parking is allowed within the roundabout
5. No public transportation stops are located within the roundabout area

To the best of our knowledge, very few studies have focused on studying signalized roundabouts. For instance, Highway Capacity Manual (HCM 2010) does not include describe recommendations or procedures to analyze signalized roundabouts [1-3]. None of the well-known traffic signal optimization packages (such as HCS, Synchro, and Vistro) have straight forward procedures to estimate delays and level of service or perform capacity analysis on this type of junctions [4, 5]. Therefore, several mathematical and simulation-based methods were developed to optimize signal timings at signalized roundabouts [6-11]. In this study, traffic optimization packages such as Synchro and Vistro will be used to provide optimum signal timing plans for the studied signalized roundabout, by modeling the roundabout as a series of connecting signalized T-intersections.

2. Methodology

In this paper, a case study from Doha, Qatar will be used to evaluate the operational and safety performance of signalized roundabouts. The efficiency of timing plans given by the signal optimization software will be assessed using VISSIM microscopic simulation environment [12]. On the other hand, SSAM will use the simulated traffic trajectories under different signal timing plans to identify potential conflict points [13-15].

2.1. Study Area

For this study, a well-known roundabout "The TV Roundabout" located in the City of Doha has been selected. The satellite image as well as the approach labeling, and the existing traffic signal timings are illustrated in Fig. 1. This roundabout has four approaches, with two directions per approach and three-lane per direction. It connects two major urban arterial streets in the City, the Al-Jamiaa Street, and Khalifa Street. This roundabout has been selected for the following reasons:

- Serve intersecting arterial roads with big demands during peak hours from all legs
- The roundabout is controlled by traffic signals
- The approaches are not influenced by minor links (i.e., no sinks or sources)
- There are no restricted movements
- Pedestrians' movement is very light, and it does not affect the operational performance of the roundabout
- There is no sight distance issue

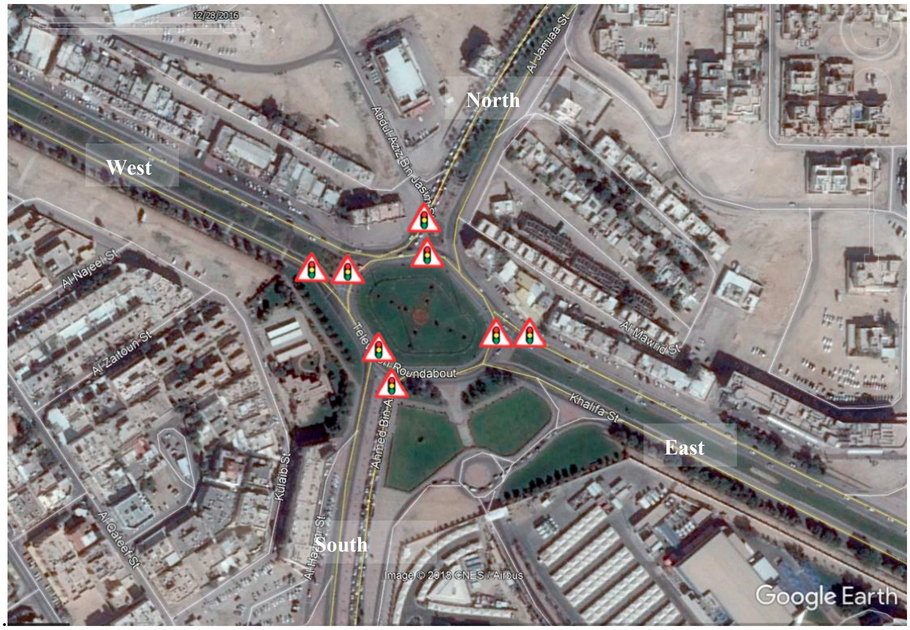
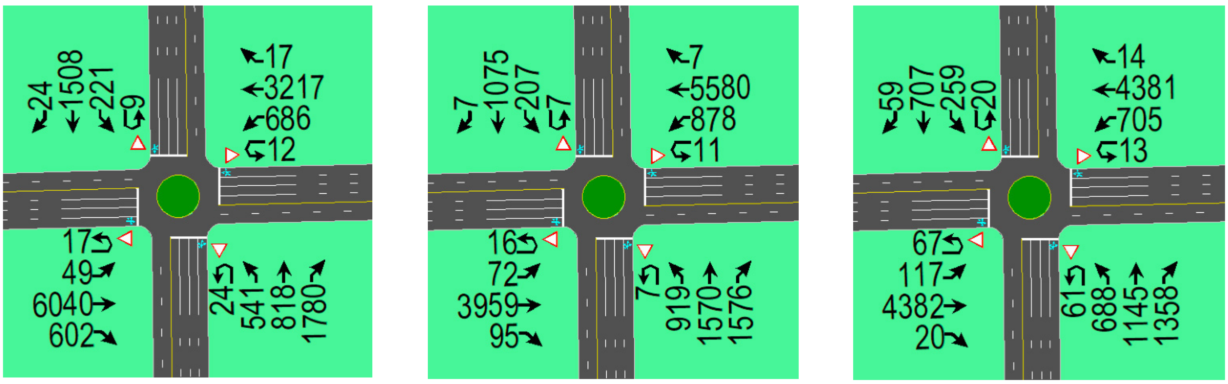


Fig. 1. Areal Imaging showing the studied signalized roundabout and legs directions

2.2. Traffic Demand:

Traffic volumes and turning movements were obtained from the Qatar Strategic Transport Model 2016 (QSTM). This model is used to extract the traffic flows during the morning (AM), mid-day (MD), and evening (PM) peak-hour periods. Traffic flows during each of the studied peak hours are shown in Fig. 2.



AM Peak-Hour Volume MD Peak-Hour Volume PM Peak-Hour Volume

Fig. 2. Traffic Volumes for AM, MD, and PM Peak Hour

2.3. Traffic Control, Signal Timings and Phasing:

Phasing schemes and signal timings were manually collected during each of the three peak-hour periods. Four video capturing devices positioned at each approach were time-synchronized and captured videos at a rate of 30 frames per second. Video capturing and processing technology to extract accurate roundabout's and intersection's signal timings and phases data from the site were used. By employing frame by frame analysis, a reliable accuracy of 0.03 seconds was achieved for determining the signal timings.

The videos were also used to determine the phasing schemes relative to the signal's cycles. Fig. 3 summarizes an example of the signal timing plans for the studied roundabout during the AM peak-period hours. Similar timing plans were developed for MD and PM peak-hour periods.

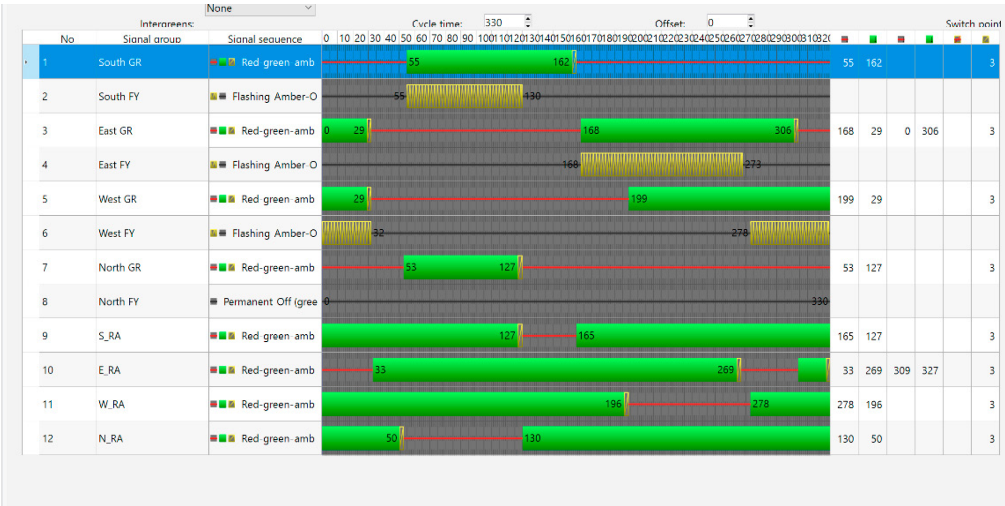


Fig. 3. Signal Timing Plans for AM Peak Hour

2.4. Microscopic Network Modeling

The most important step in this study is to model the signalized roundabout at the microscopic level so that operational performance data and vehicular trajectories can be collected and processed. VISSIM multimodal microscopic simulation tool is one of the state-of-the-art traffic simulation software that is widely used worldwide. Moreover, VISSIM is the only microscopic traffic simulation software that is authorized by the Ministry of Transport and Communications, and Ministry of Municipality and Environment in Qatar. The "Guidelines and Procedures for Transport Studies" [16] has been followed as the main reference to calibrate the microsimulation model in order to reflect the driving behavior in the State of Qatar.

2.5. Surrogate Safety Assessment Model

Surrogate Safety Assessment Model (SSAM) that was developed by Federal Highway Administration (FHWA) is a traffic safety assessment tool that analyses vehicular trajectories based on several criteria, in order to identify and categorize potential traffic conflicts. Some of these criteria, including Time-to-Collision (TTC) and Post-Encroachment Time (PET), are used to determine the conflict severity. On the other hand, conflict angles are used to identify the type of conflict.

In this study, the following characteristics are used to classify traffic conflicts according to their severity:

- Extreme Collision Risk: when TTC is less than 0.1 second
- High Collision Risk: when TTC is between 0.1 and 0.5 second
- Moderate Collision Risk: when TTC is between 0.5 and 1.0 second
- Low Collision Risk: when TTC is between 1.0 – 1.5 second

3. RESULTS AND DISCUSSION

Traffic demands and signal timings for the three peak-hour periods were simulated, and different measures of effectiveness were extracted. As indicated earlier, the most important measures of effectiveness (MOEs) that are used in this study are Average Delay and Stop Delay, and Traffic Conflicts. These MOEs will be discussed in detail in the following sections.

3.1. Average Delay and Stop Delay

Average delay is computed as the difference between the actual and the anticipated time to enter and exit the roundabout averaged across all the vehicles, while stop delay is the time spent while the vehicle is not moving. Traffic delay at intersections is the key traffic parameter that is used to assess the operational performance of intersections. According to the Highway Capacity Manual, a level of service is determined based on the average delay experienced at the intersection. Fig. 4 and Fig. 5. show the average and stop delays experienced for each of the peak hours.

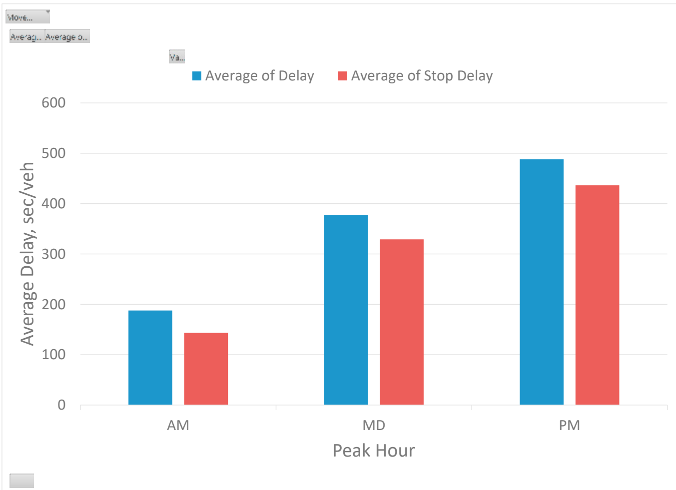


Fig. 4. Average Delay and Stop Delay for each Peak Hour Period, in sec/veh

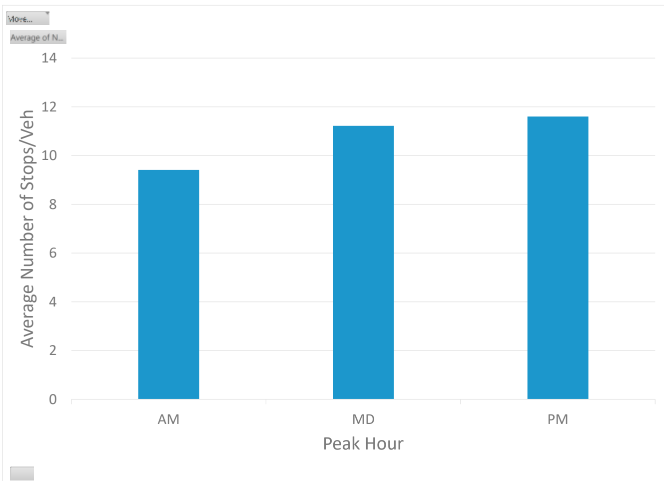


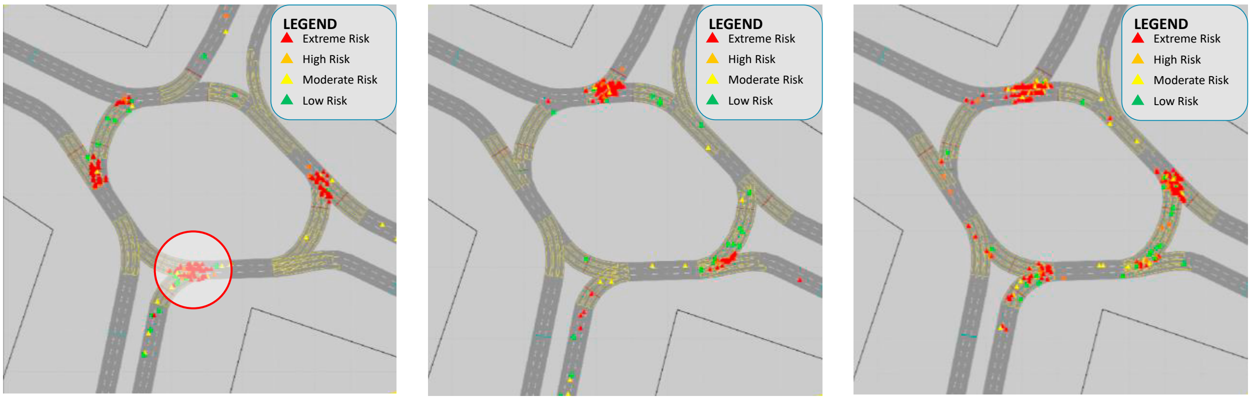
Fig. 5. Average Number of Stops per vehicle for each Peak Hour Period

It can be seen from Fig. 4 and Fig. 5. that the PM peak-hour has experienced the highest delay compared to the other two peak periods. This observation indicates that it is likely to experience more traffic conflicts during the PM peak-hour period. Nonetheless, the number of stops per vehicle tends to have less variation among the peak periods.

3.2. Traffic Conflict Analysis

As indicated earlier, SSAM is used to analyze and classify the potential traffic conflicts based on vehicular trajectory data. Two conflict indicators are used (TTC and PET) to determine the severity of the conflict, while the trajectory direction is used to determine the type of conflict.

Fig. 6 shows that there are differences in the location of traffic conflicts based on the peak period. While this observation is expected as traffic demand varies for those peak hours, observing traffic conflicts is not necessarily correlated with high traffic demand. This observation can be seen for the southbound traffic during the PM peak period. The southbound does experience high traffic demand compared to the other directions, nonetheless, the downstream of this bound has significant traffic friction. This traffic friction does not appear for the AM peak, despite the fact that the southbound during the AM peak has higher traffic when compared to the PM peak. Therefore, it can be explained by the fact that the signal timing plans are not properly implemented.



Traffic Conflicts for AM Peak Period | Traffic Conflicts for MD Peak Period | Traffic Conflicts for PM Peak Period

Fig. 6. Potential Location of Traffic Conflicts for AM, MD, and PM Peak-hour Periods

4. CONCLUSIONS

The performance of signalized roundabouts compared to signalized intersections has become an important engineering solution in the past few years to solve several traffic issues, operational performance and safety as well. To further investigate in such a comparison, a case study has been selected of a signalized roundabout in the city of Doha, Qatar. This study assesses the operational and safety performance of the studied signalized roundabout using microscopic traffic simulation environment. Traffic demand data were derived from Qatar Strategic Transport Model (QSTM) and signal timing parameters were manually collected and processed using video imaging. The studied roundabout was then modeled in VISSIM microscopic simulation environment. Traffic delays were obtained directly from the simulation environment, while traffic conflicts were found using Surrogate Safety Assessment Model (SSAM) by analyzing the simulated vehicles' trajectories. The results indicated that the signal timings and phasing schemes are associated with the safety level of the signalized roundabout by reducing or increasing the potential traffic conflicts. It was also found that high traffic demand in signalized roundabouts is not necessarily related to the high traffic conflicts or high conflict severity.

The findings of this study can be further expanded to compare the performance of signalized roundabouts with signalized intersections. While it is expected that there are significant improvements from the traffic operation standpoint, the differences in terms of traffic conflicts and conflict severity can be further investigated.

Acknowledgments

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