

# Performance Evaluation of Al Jame' Roundabout Using SIDRA

D. Muley, H. S. Al-Mandhari

**Abstract**—This paper evaluates the performance of a multi-lane four legged modern roundabout operating in Muscat using SIDRA model. The performance measures include Degree of Saturation (DOS), average delay, and queue lengths. The geometric and traffic data were used for model preparation. Gap acceptance parameters, critical gap and follow up headway, were used for calibration of SIDRA model. The results from the analysis showed that currently the roundabout is experiencing delays up to 610 seconds per vehicle with DOS 1.67 during peak hour. Further, sensitivity analysis for general and roundabout parameters was performed, amongst lane width, cruise speed, inscribed diameter, entry radius and entry angle showed that inscribed diameter is most crucial factor affecting delay and DOS. Up gradation of roundabout to fully signalized junction was found as the suitable solution which will serve for future years with LOS C for design year having DOS of 0.9 with average control delay of 51.9 seconds per vehicle.

**Keywords**—Performance analysis, roundabout, sensitivity analysis, SIDRA.

## I. INTRODUCTION

THE streets are a key component and vital artery for the city, and an important timekeeper compass for the movement of population in the city. The fact that the streets have an important role in people's lives, and because the car is the most prevalent means of movement in Oman, must be taken care of and also have efficient designs taking into account the traffic problems. When planning the cities, streets intersect with each other. Intersections can be controlled and uncontrolled. One of the best methods to facilitate the movement of traffic at uncontrolled intersections is roundabouts. Frequently, the presence of the roundabout is inevitable because of its advantages such as, reduced delays, improved traffic flow and safety, less conflicts and economy. But where the rising rate of congestion and accidents are observed, there is a need to study this problem to find a solution. There is no doubt that the traffic problems whether congestion or accidents is one of the crucial problems of most of the countries in the world. However, the phenomenon of traffic congestion in the streets [1], especially in the streets which are not controlled by traffic control devices have exacerbated dramatically in the recent years, especially for Oman. The problem of increasing traffic volume is that the absorptive capacity of the roads is not able to accommodate the traffic flow at peak hours resulting in traffic congestion.

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Roundabouts are widely installed in Oman. Muscat has large number of roundabouts, majority of them operating using yield control. The increasing traffic volumes are posing operational difficulties for peak hour operations which need to be addressed. This study aims to carry out an assessment of the performance of the roundabout during peak hours using Degree of Saturation (DOS), average delays and queue lengths and suggest solution in accordance with the engineering design and site conditions.

In past, previous studies have analysed performance of roundabouts using various mathematical models and software packages. The following section briefs about some important studies conducted for roundabout analysis.

Roundabouts operate differently as compared to intersections; hence specialized methods are applied for estimating driver behavior and performance measures. UK TRL model, HCM 2010 model and Austroads method are most widely used all over the world. A study presented meta-analysis of main features of these models, gap acceptance parameters were used to represent driver behavior except in case of UK TRL model which does not represent directly any aspect of driver behavior [2].

Critical headway and follow-up headway are two important parameters of drivers' gap-acceptance behavior. The results of these two parameters were presented at seven single-lane and three multilane roundabouts in California. Results indicated that the mean critical headway was 4.4s to 4.8s and the follow-up headway was 2.2s to 2.5s. It was also revealed that circulating flow rate and speed are two major factors affecting critical headway and follow-up headway [3].

The influence of entering traffic volume on the traffic operation was analyzed; particularly delay reduction, for modern roundabouts in Korea using traffic simulation (VISSIM). Unsignalized intersections in small and two-lane both-way roadways were selected for the analysis. As a result of this study, the average volume of traffic with less than 110 vphpl or more than 400 vphpl did not show any effects on delay reduction while changing the volume of entering traffic to 160 ~ 180 vphpl showed greater reduction in delay [4].

Roundabouts and four legged intersections with yield, two-way stop, four-way stop, and signal control were compared on the basis of the average delay and capacity with reasonable assumptions using SIDRA package. Roundabouts with two-lane or three-lane approaches provided increased capacities compared to signal controlled intersections while roundabouts with single approach lane were similar to signalized intersections [5].

The performance of roundabout as an effective option to

other conventional intersections, in terms of safety, environmental, space utilization and operational aspects, was studied for a five-leg traffic circle located in Nagano prefecture, Japan. The delay comparison for various options indicated that roundabouts offered a good alternative to other intersections under low traffic conditions [6].

Roundabout models were calibrated and compared using three different methods; manual calibration of gap-acceptance parameters, manual calibration of the parameter environment factor and automatic calibration of the environment factor based on optimization [7].

VISSIM roundabout models have been widely applied in practice to facilitate analyzing the operational performance of roundabouts. Numerical recommendations for calibrating VISSIM roundabout models were developed using field data, and validated using a congested two-lane roundabout in De Pere, Wisconsin [8].

The lane-by-lane modelling ability of SIDRA package was demonstrated by comparing results from SIDRA package with ARCADY software using performance measures such as capacity, degree of saturation and average delay for two three legged roundabouts and one four legged roundabouts [9].

## II. METHODOLOGY

After selection of case study roundabout, first step is to collect accident data, geometric data and traffic data for peak hour. In the second step, the collected data was analysed to determine peak traffic flow and gap acceptance parameters (critical gap and follow up headway), and in third step, a SIDRA model was developed to study the traffic operations at the roundabout. The SIDRA model was calibrated using local field conditions and sensitivity analysis was carried out for general parameters and roundabout parameters. Further, the performance of the roundabout after modification to signalized roundabout and fully signal control junction was also studied.

## III. DATA COLLECTION AND ANALYSIS

### A. Roundabout Selection

AlJame' roundabout in Al-Khoud region is infested with congestion, especially at peak hours because it connects three developing areas in the governorate of Muscat (Al-Hail, Al-Khoud and Al-Mawaleh). The significance of the surrounding area of the roundabout is due to the existence of many government, educational and health institutions as well as sports clubs and commercial areas. Also, there is Mazoon mosque, where Friday prayers are held in the region, and a petrol station at the roundabout. Due to this, this roundabout has become a point of high traffic congestion and this problem has been observed increasing rapidly.

Al Jame' roundabout is a modern roundabout, as priority is given to circulating flow rather than entering flow, operated with yield control on all approaches. It has four legs with two entry, exit and circulating lanes in each direction, entry and exit lanes separated by medians, right angled to each other. As per Oman rules, drivers drive on the right side of the road. The roundabout has central island diameter of 58m, with two

circulating lanes of 4.5m width. The average entry and exit lane width is 4.25m and 3.8m respectively. All approaches, except south, have a dedicated right turn lane.



Fig. 1 Al Jame' Roundabout

### B. Data Collection and Extraction

The accident data, containing details of past years' accidents and their causes, was collected from the Royal Oman Police (ROP). Geometric design data contains measurements of the dimensions of the roundabout. The geometric data for roundabout includes details of circulating lanes, approach and exit lanes. This data was collected from Google Earth. The traffic data, only for peak period, was collected using video recording technique for a typical weekday, followed by manual extraction of turning movements and gap acceptance parameters from this video.

The roundabout typically had two distinct peak periods, on a typical weekday; morning peak (between 6am to 9am) and evening peak (from 6 to 9pm). In order to avoid the difficulties in video recording and data extraction during evening time, morning peak time was selected for recording the roundabout movements. The video recording for the roundabout was taken on Tuesday, 15th April 2014 from 6am to 9am. The video camera was located such that all of the turning movements are visible from one location. Minaret of the Mazoon mosque is the highest point close to the roundabout which was used to record the video.

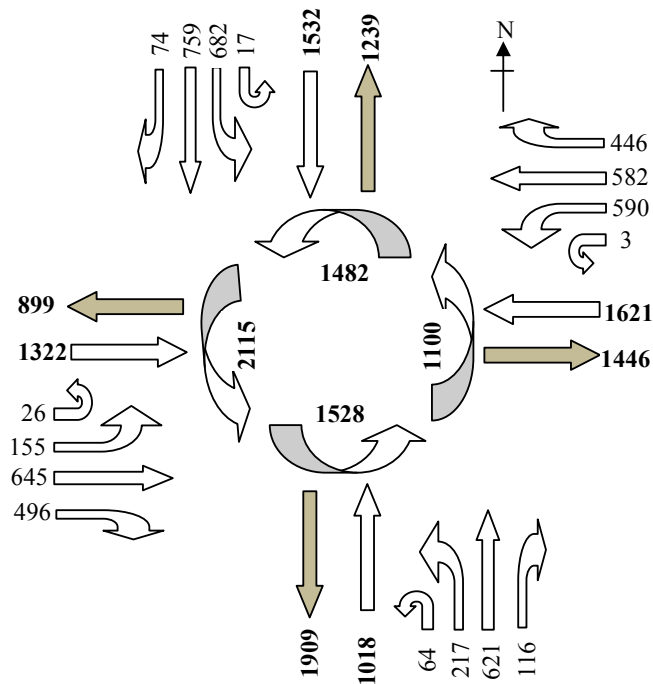
### C. Accident Data

The accident data for past five years was collected from the ROP in Al-Khoud region. Total eight accidents happened during last three years. They were divided in two types; collision and fixed object collision. These accidents resulted in 10 injuries and no deaths. The main reason varied between speed, sudden stop and failure to leave a safe distance.

### D. Traffic Data

The traffic data, presented in fifteen minutes interval, indicated peak hour from 7:30am to 8:30am with volume of 5493 veh/hr with 3.4 percentage of heavy vehicles. Fig. 2 shows the turning movement volumes for peak hour for each approach. The flow at the roundabout arms in descending order are as follows: North, East, West and South with the number of vehicles in each direction 3170, 2981, 2682, and 1947 respectively. The turning movement for all approaches showed that the straight movement is the highest compared to

other movements. Al Jame' roundabout represents a fairly balanced condition of traffic flow demanding equal attention to all approaches.



Note: All volumes are in veh/hr

Fig. 2 Traffic volumes for peak hour (7:30am to 8:30am)

#### E. Critical Gap

All the entering vehicles need to find gap in circulating traffic for entering into the roundabout. The minimum gap which vehicles accept at a particular lane is called as critical gap. No vehicle enters the roundabout if the gap available is less than critical gap. The value of critical gap found from accepted and rejected gaps. The intersection of the cumulative percentage curves gives the value of critical gap.

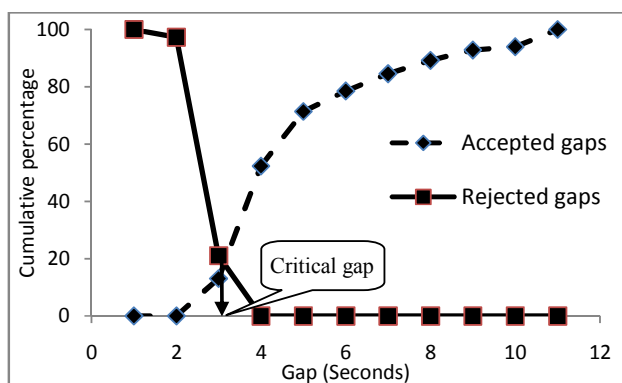


Fig. 3 Critical gap for North Approach

The critical gap was determined for all four approaches separately. The total number of gaps observed for North, East,

West, and South approach were 122, 98, 101, and 102 respectively. The critical gap for North, East, West, and South was determined as 3.12, 3.36, 2.80 and 2.81 seconds respectively. Fig. 3 shows critical gap determination for North approach.

Generally, the values for critical gap for Al Jame' roundabout are lower as compared to other countries, US, and Japan [3]–[6]. This indicates that drivers accept smaller gaps showing more aggressive driving behavior, this also provides increased capacity of roundabout.

#### F. Follow Up Time

If the available gap is more than critical gap then more than one vehicle can enter the roundabout using same gap. The follow-up time is the average time gap between two cars that are queued; enter the same gap one behind the other. Follow-up times were measured directly by observation for various vehicle movements from each approach and average of all observations gives the follow up time. The results of analysis are shown in the Table I below.

The values for follow up time for Al Jame' roundabout were little bit lesser than American conditions while they were almost half of the values observed for roundabouts in Japan [3]–[6]. This also indicates drivers' familiarity for using the roundabout which also results in increased capacity. This small value of follow up time may be the reason of collisions at the roundabout.

TABLE I  
FOLLOW UP TIME FOR AL JAME' ROUNDABOUT

Follow up time (Seconds)	Approach			
	North	East	West	South
No of observations	52	51	50	50
Mean	1.48	1.66	1.53	1.65
Standard Deviation	0.27	0.29	0.25	0.25

#### IV. ROUNDABOUT (SIDRA) MODEL

The SIDRA INTERSECTION 6.0 has been developed by the Australian Road Research Board (ARRB), Transport Research Ltd. It is an auxiliary tool use to design and evaluate the intersections. It is a traffic assessment tool that provides lane-by-lane and vehicle drive cycle models. It can be also used as a tool for assessment and comparison of alternative treatments for each of the networks of intersections and individual intersections. For developing SIDRA model, lane disciplines and all movement data needs to be identified. All lane flow calculations, capacity and performance evaluation, are determined from outputs. The software allows modeling of movement classes, where different vehicle classes, for example light and heavy vehicles, buses, bicycles, large trucks and light rail, are modelled.

SIDRA allows intersection analysis using various models and LOS specifications, HCM2000 (based on Delay), HCM2010 (based on Delay & LOS), RTA NSW (based on Delay), SIDRA method (based on DOS) and ICU method [10]. This study uses SIDRA STANDARD Model for analysis and SIDRA model, based on DOS, for determining quality of traffic flow movement for the roundabout. SIDRA model

recommends roundabout model calibration using Environment Factor for each approach; the same method is used for this study. Later the current performance is analyzed and sensitivity analysis for various parameters was carried out with options testing for performance improvement.

#### V. ENVIRONMENT FACTOR

Environment Factor in SIDRA model allows calibration of capacity model for less restricted (higher capacity) and more restricted (lower capacity) environments. The Environment Factor represents the general roundabout environment in terms of roundabout design type, visibility, significant grades, operating speeds, size of light and heavy vehicles, driver aggressiveness and alertness, pedestrians, heavy vehicle activity, parking maneuvers, etc. which affect the vehicle movements on approach and exit sides as well as at circulating road as relevant [10]. Environment Factor value ranges between 0.5 and 2 representing less restricted to more restricted conditions. The default value for Environment Factor set in SIDRA is 1.0. To study the effect of environment factor and calibrate it for each approach of roundabout, different values are provided to the model.

##### A. Effect on Gap Acceptance Parameters

The relationship between critical gap and follow up time with environment factor is shown in Figs. 4 and 5 respectively. For very low environment factor, the value of critical gap and follow up time is small and remain constant for initial values but it increases proportionally with increase in environment factor for all approaches. The critical gap and follow up time vary from 2 to 5 seconds and 1 to 4 seconds respectively with increase in value of environment factor from 0.5 to 2. As the value of critical gap and follow up headway increased the circulating flow rate decreases up to 35%.

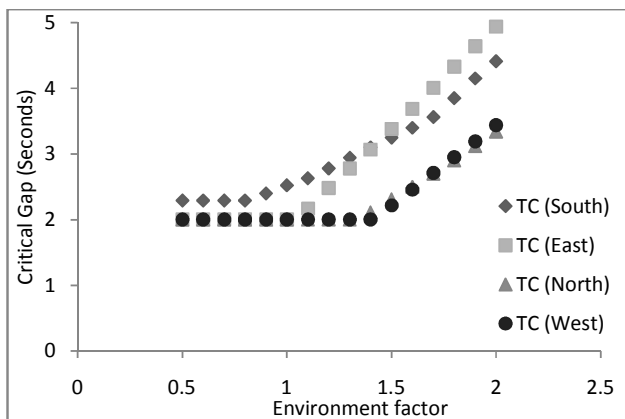


Fig. 4 Effect of Environment Factor on critical gap

##### B. Effect on Roundabout Capacity

The relationships between Environment Factor and circulating flow rates (Fig. 6), and Environment Factor and total capacity (Fig. 7) showed opposite trends to gap acceptance parameters for all approaches. Both capacities are highest at low value of Environment Factor and lowest for the

highest value of Environment Factor.

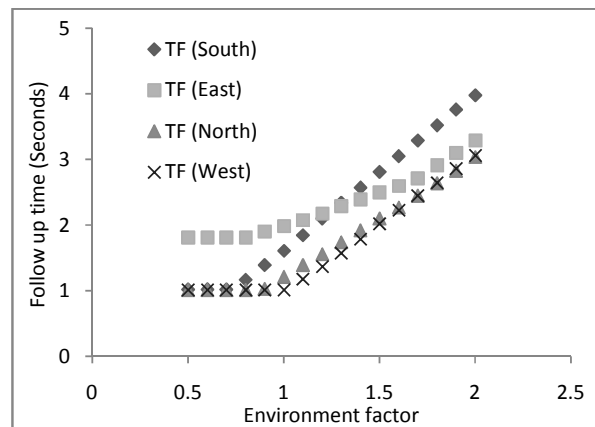


Fig. 5 Effect of Environment Factor on follow up time

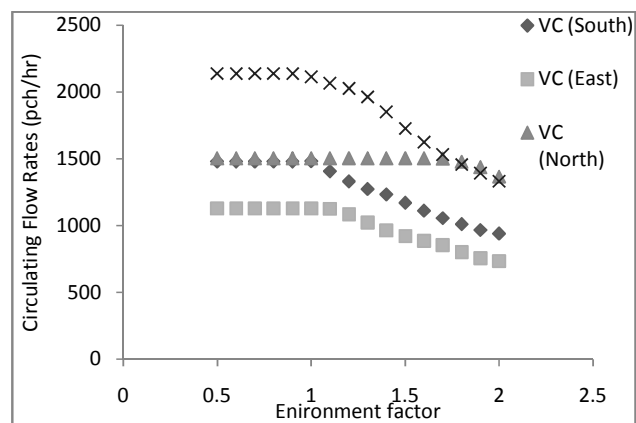


Fig. 6 Effect of Environment factor on circulating flow rate

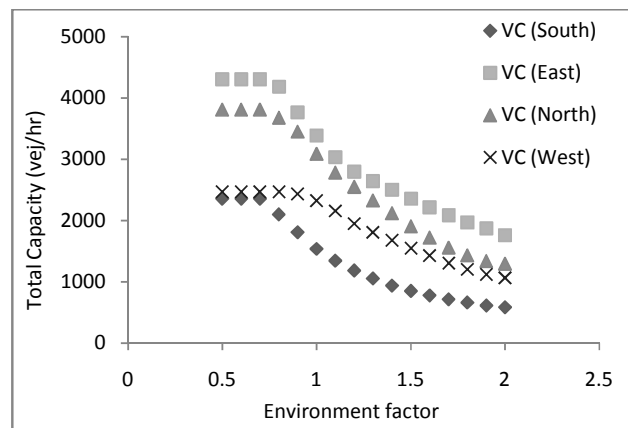


Fig. 7 Effect of Environment Factor on total capacity

##### C. Calibration of Environment Factor

The Environment Factor was calibrated using time headways; critical gap and follow up headway. The outputs from various environment factors were examined to match the observed values of critical gap and follow up time values for each approach. The Environment Factor for North, East, West

and South were found as 1.1, 1, 1.3 and 1.1 respectively. These values were used for further analysis. The value of Environment Factor for Australian conditions is calibrated as 1.0 and for American conditions it is calibrated as 1.2. The Environment Factor for American conditions is higher to give lower capacity values as drivers are comparatively less familiar to using roundabouts resulting in lower capacities compared to UK and Australia [10], [11]. For Norwegian conditions, it was indicated that 1.1 is a good value of environment factor [12]. The value for Environment Factor was observed to be closer to Norwegian conditions.

## VI. RESULTS AND DISCUSSION

### A. Performance Analysis

The flow rates and performance of the Al Jame' roundabout for current situation is shown in Table II using various performance measures. All approaches, except East approach have reached to their capacity. Currently, the roundabout was observed to be operating in congested condition with LOS F for three approaches and LOS B for one approach in morning peak hour. Overall, the roundabout is experiencing an average control delay of 190.9 seconds per vehicle with DOS as 1.67 and average queue length of 977m. The West approach is experiencing major operational difficulties.

TABLE II  
PERFORMANCE RESULTS FOR AL JAME' ROUNDABOUT

Performance Measure	Approach			
	North	East	West	South
Approach flow (veh/h)	1532	1621	1322	1018
Circulation flow (pcu/h)	1504	1128	2075	1284
Capacity (veh/h)	2617	3021	1676	1314
Degree of saturation	1.09	0.62	1.67	0.97
LOS	F	B	F	E
Avg control delay (Sec)	135.4	4.4	609.4	27.7
Avg queue length (m)	285	14	977	69

### B. Sensitivity Analysis

SIDRA allows sensitivity analysis for design life and various roundabout parameters. The sensitivity analysis for design life was not performed as the roundabout was already congested and any increase in traffic volume will result in increased queue lengths and delays. The sensitivity analysis for lane width, cruise speed, inscribed diameter, entry radius and entry angle was performed. Out of these, inscribed diameter was found as the most sensitive parameter affecting performance of Al Jame' roundabout. Results for the same are described here.

The sensitivity analysis for inscribed diameter for east approach shown that as inscribed diameter increased from 20 to 90 percent, the DOS increased by small amount but delay remained constant for 20 to 200 percent of inscribed diameter. The results for South approach showed that the DOS reduced from 20 percent to 160 percent and later increased slightly. Also, the delay fell sharply till 100 percent of inscribed diameter, later the rate of increase was minimal. The delay showed small increase and DOS indicated a uniform increase

in delay for north approach from 20 percent to 90 percent value. Later the values remained fairly constant for remaining analysis. For west approach, both the parameters showed marginal increase for increase in inscribed diameter from 20 percent to 200 percent.

### C. Up-Gradation to Signalized Roundabout

The performance of the roundabout was assessed by converting the operation control of roundabout from yield sign to signals. SIDRA model was prepared for the same keeping all parameters constant. A two phase signal was designed with cycle time of 100 seconds. The results indicate that the upgraded signalized roundabout will ease the congestion only for south approach and all other approaches will observe greater delays and higher DOS suggesting that the modification is not suitable for current traffic conditions. The values of delay, queue length and DOS were exorbitantly high so not presented here.

### D. Modification to Fully Signalised Intersection

To determine the best suitable combination for modification to fully signalized intersection, various options were tested. From the outcomes, it was found that, a fully signal controlled intersection with three approach lanes (including one short lane for traffic turning left and making a U turn), with a dedicated right turn lane for all approaches, and two exit lanes for each approach would exhibit satisfactory performance for current as well as for future traffic demand also. A compound growth model was used for forecasting traffic at rate of 4.2%. The optimum cycle time for base year was 120 seconds and design life of 13 years was found as 140 seconds. The phasing for signal was designed to have split phasing.

The signalized intersection indicated that it will operate at LOS A with DOS as 0.52 for current traffic conditions, solving problems of delays and formation of long queues at all approaches. The average queue length will be reduced from 977m to 132m and the delay per vehicle will be reduced from 191 seconds to 46 seconds. Table III shows the parameters indicating performance of the proposed upgraded signalized intersection. At design life of 13 years, the intersection would operate with a LOS C with average control delay of 51.9 seconds per vehicle, DOS 0.9, and average queue length of 250m. If the traffic still increases further after 20 years the DOS will be 1.187 with an average control delay of 297.5 seconds per vehicle. Hence, the intersection may need further treatment after handling traffic for 13 years.

TABLE III  
PERFORMANCE RESULTS FOR SIGNALIZED AL JAME' INTERSECTION AT DESIGN LIFE

Performance Measure	Approach			
	North	East	West	South
Approach flow (veh/h)	2615	2767	2258	1738
Capacity* (veh/h)	3399	2238	1776	1734
Degree of saturation	0.88	0.90	0.90	0.89
Avg control delay (Sec)	55.1	48.8	43.8	62.5
Avg queue length (m)	250	214	175	171
LOS	C	C	C	C

Note: \*indicates capacity excluding value for dedicated right turn lane

## VII. CONCLUSIONS AND RECOMMENDATIONS

This study determined the performance of a busy roundabout operating in Muscat, Oman. The average critical gap and follow up time were about 3.02 seconds and 1.58 seconds respectively. The SIDRA model, calibrated using gap acceptance parameters, identified different environment factors for each approach with an average value of 1.1, representing resemblance to Norwegian conditions.

The current yield control at roundabout seemed to observe delays and queues daily during peak hour. The calibrated roundabout model showed current LOS F with a queue length of 977m. The sensitivity analysis indicated inscribed diameter as most important factor affecting the roundabout performance. However, it was not considered as an option to improve the performance. The modification of roundabout control to signals did not provide a satisfactory solution either. However, when the roundabout was upgraded to a fully signal controlled intersection, significant improvement for current as well as future years was observed. The signalized intersection is expected to provide more safety to drivers reducing the collisions.

Al Jame' roundabout was assessed as an independent site. This roundabout has small roundabouts on upstream of all approaches. Hence, the effect of the adjoining roundabouts needs to be considered in future analysis. Also, for performing this analysis in future for other roundabouts the gap acceptance parameters, and Environment Factor, need to be calibrated for Oman considering roundabout operations for different sites.

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## REFERENCES

- [1] I. M. Mazharul, and A. Y. S. Al Hadhrami, "Increased Motorization and Road Traffic Accidents in Oman, " *Journal of Emerging Trends in Economics & Management Sciences*, vol. 3, no 6, pp 907-914, 2012.
- [2] R. Akçelik, "Some common and differing aspects of alternative models for roundabout capacity and performance evaluation," *International Roundabout Conference, Transportation Research Board*, Carmel, Indiana, USA, May 2011.
- [3] F. Xu, and Z. Z. Tian, "Driver Behavior and Gap-Acceptance Characteristics at Roundabouts in California," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2071, pp 117-124, 2008.
- [4] I. Chang, S. Y. Ahn, and J. S. Hahn, "Analysis of Delay Reduction Effects on Modern Roundabouts according to the Entry Traffic Volume," *KSCE Journal of Civil Engineering*, vol. 17, no 7, pp 1782-1787, 2013.
- [5] V. Sisiopiku, and H. Oh, "Evaluation of Roundabout Performance Using SIDRA," *Journal of Transportation Engineering*, vol. 127, no. 2, pp143-150, March/April 2001.
- [6] S. Manage, K. Suzuki, H. Nakamura, "Performance Analysis Of Roundabouts As An Alternative For Intersection Control In Japan," *Journal of the Eastern Asia Society for Transportation Studies*, vol.5, pp 871 – 883, 2003.
- [7] A. Ekman, "Calibration of traffic models in SIDRA," Department of Science and Technology, Linköping University, Sweden, 2013.
- [8] Z. Li, M. DeAmico, M. V. Chitturi, A. R. Bill, and D. A. Noyce, "Calibration of VISSIM Roundabout Model: A Critical Gap and Follow-up Headway Approach," *In Proc. TRB 92nd Annual Meeting*, Washington, D.C., January, 2013.
- [9] R. Akçelik, "Lane-by-lane modelling of unequal lane use and flares at roundabouts and signalised intersections: the SIDRA solution," *Traffic Engineering + Control*, vol. 38, no. 7/8, pp. 388-399, 1997.
- [10] SIDRA, "Quick guide to SIDRA intersection 6," Akçelik & Associates Pty Ltd, Australia, 2014.
- [11] TRB, "NCHRP Report 572 Roundabouts in United States," National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2007.
- [12] H. K. Myre, "Praktisk uttesting av SIDRA for å vurdere kapasitets- og avviklingsforhold i rundkjøringer" Norgestechnisk-Naturvitenskapelige Universitet, NTNU, 2010.