Evaluation of Al-Zahara Roundabout in Al-Najaf City Using Simulation Model and Selecting the Optimum Alternative

تقييم ساحة الزهراء في مدينة النجف الاشرف باستخدام نموذج المحاكاة واختيار البديل الافضل

Asst. Prof. Dr Hamid Athab Al-Jameel
University of Kufa-Civil Engineering Dep.
Email: hamid.aljameel@uokufa.edu.iq

Abstract

Nowadays, most of urban areas suffer from traffic congestion. This congestion attributed to the existing of conflicting movements at intersections, merging, roundabouts, etc. In this study, a traffic congestion problem results from roundabouts have been investigated. Although roundabouts are safer from intersections because of less conflict points, roundabouts may have less capacity than corresponding intersections. Several roundabouts were built in Iraq in the last decade as a new design to improve traffic operations. However, most of these roundabouts suffer from high congestions. Therefore this study has focused on the evaluation of AL-Zahara roundabout as a sample from other roundabouts in the city. A simulation model called S-Paramics has been used to evaluate the performance of these roundabouts. Then, field data have been collected for more than 10hours. A video camera has been installed over a multi-story building in order to capture field data from Al-Zahraa Roundabout. This field data has been used to calibrate the simulation model (S-Paramics). After calibrating and validating the simulation model, the developed simulation model has been adopted to find the suitable solution to mitigate traffic congestion using different scenarios.

Keywords: Roundabout, simulation model, S-Paramics, calibration and validation.

الخلاصة

في الوقت الحالي الكثير من المناطق الحضريه تعاني من الازدحام المروري. هذا الازدحام يعزى الى وجود الحركات المتقاطعه في التقاطعات، الحركات المتقاربة والساحات ..الخ. في هذه الدراسة مشكلة الازدحام المروري الناتجة من الساحات تم استطلاعها. بالرغم من الساحات هي اكثر امان من التقاطعات كونها اقل نقاط تقاطع ، الساحات ربما سعتها اقل من التقاطعات المناظرة. العديد من الساحات انشاءت في العراق في العقد الاخير كتصميم جديد لتحسين التشغيلات المروريه. على الرغم من ذلك اغلب الساحات تعاني من ازدحامات شديده. لذلك هذه الدراسة ركزت على تقييم ساحة الزهراء كنموذج لبقية الساحات في المدينة. نوذج المحاكاة يدعى S-Paramics قد استخدم في تقييم الاداء لهذه الساحة. بعد ذلك بيانات موقعيه جمعت لاكثر من 10 ساعات. كاميرا فيديويه نصبت على بناية متعددة الطوابق للحصول على تلك البيانات من ساحة الزهراء. البيانات الموقعيه استخدمت لمعايرة نموذج المحاكاة. بعد المعايرة والتحقق للبرنامج ، النموذج المطور تم اعتماده لايجاد افضل الحلول لتخفيف الازدحام باستخدام خطط مختلفة او سناريوهات مختلفة.

الكلمات الدالة: الساحات الدائريه، نموذج المحاكاة، S-Paramics ، المعايرة والتحقق.

1. Background

Strong evidences regarding those roundabouts are safer than intersections are available widely in literature. Moreover, they they are widely used not only in urban areas but also on high speed roads throughout the U.S. However, there is no enough knowledge about the performance of rural roundabout on state roads in both the U.S. and India [1]. This could be attributed to the database used for developing the HCM 2010. 90% of the data from urban and suburban areas has been used to develop the HCM 2010[2]. For Indiana roundabouts just only a few past studies have been adopted from urban/suburban areas used for developing the roundabouts there [3]. Moreover, the dual-lane roundabouts did not consider in the previous studies for Indiana roundabouts.

Generally, there is a wide usage of roundabouts in different countries as reported by [4] and shown in Table1. It is important here to generally describe the basic features of roundabout. These features could be summarized in Figure1.

As discussed above, the main reason behind the wide spread of roundabouts is that because they were introduced to solve the problems of traffic circles as reported by [5]. The author also found that roundabouts have proven to be more efficient than traffic circles and in some cases signalized and stops controlled intersections. Differences between roundabouts and traffic circles are summarized in Table 2.

Table 1 The number of modern roundabouts in different countries (adapted by [4]).

The country	The number of modern roundabout
France	From 500 to 25,000 in twenty year
Denmark	more than 1400 roundabouts up to 2011
Switzerland	approximately 2,000 roundabouts up to 2004
U.S.	from less than 100 in 1997 to about 1,000 in 2007

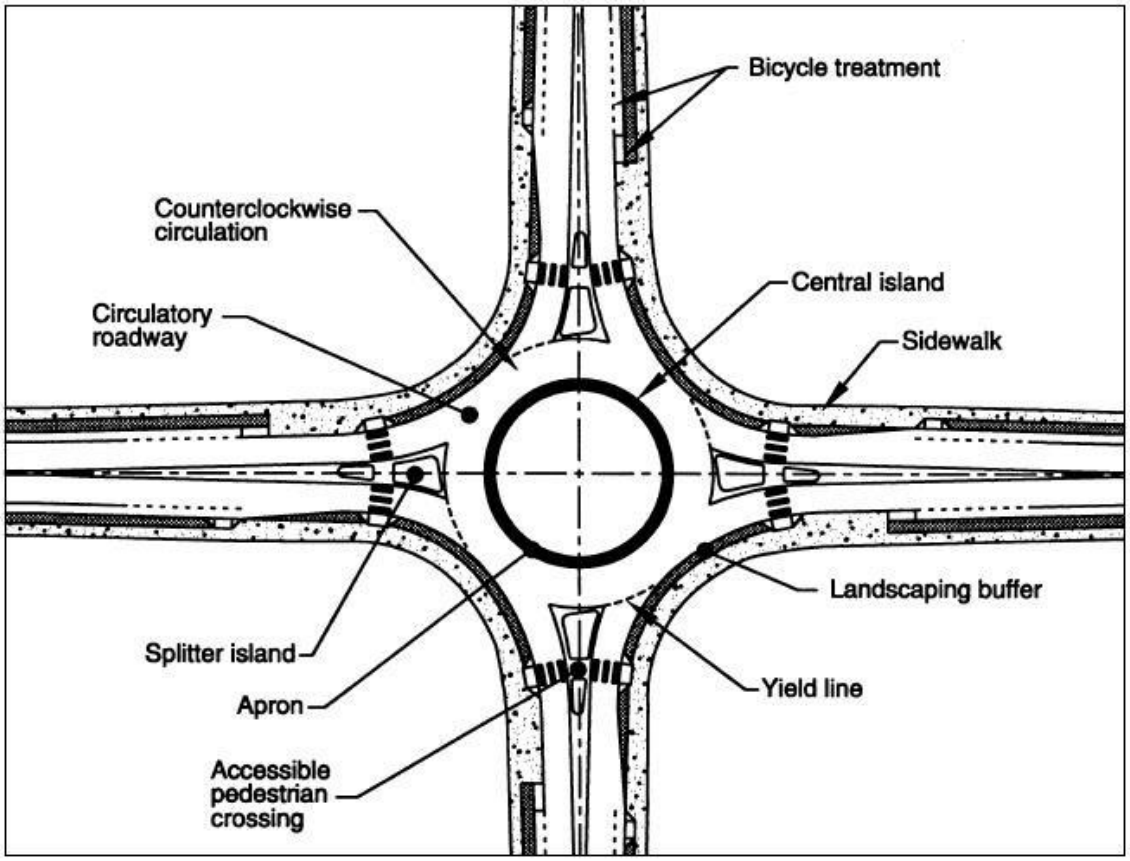

Figure 1 Drawing of key roundabout features [6].

In a roundabout, the drivers are not required to stop; hence, the facility is more efficient under a broad range of traffic volume as drivers need only to find an acceptable gap in the circulating traffic to merge [5]. Rahmi[7] pointed out that when roundabouts operate at capacity, they offer lower vehicle delays than at other intersection forms. It is unnecessary for traffic at a roundabout to come to a complete stop when there are no conflicts. Figure 2 indicates the comparison between conflict points at intersections and roundabouts.

Table 2 Differences between roundabouts and traffic circles [6].

	Roundabouts	Traffic circles
Traffic control	Yield control is used on all entries. The circulatory roadway has no control.	Some traffic circles use stop control, or no control, on one or more entries.
Priority to circulating vehicles	Circulating vehicles have the right-of way.	Some traffic circles require circulating traffic to yield to entering traffic.
Pedestrian access	Pedestrian access is allowed only across the legs of the roundabout, behind the yield line.	Some traffic circles allow pedestrian access to the central island.
Parking	No parking is allowed within the circulatory roadway or at the entries.	Some traffic circles allow parking within the circulatory roadway.
Direction of circulation	All vehicles circulate counter-clockwise and pass to the right of the central island.	Some neighborhood traffic circles allow left-turning vehicles to pass to the left of the central island.

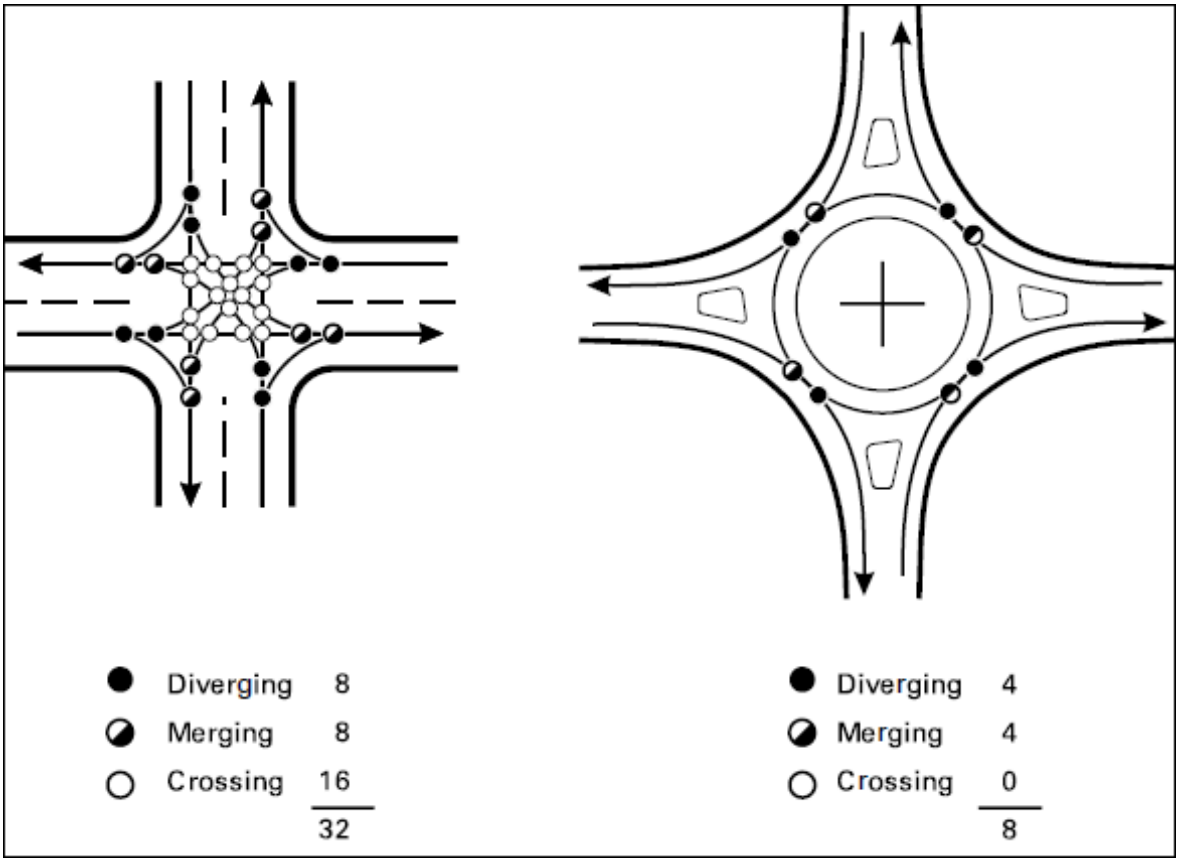

Figure 2 Comparison of vehicle-vehicle conflict points for intersections with four single-lane approaches [6].

2. Merits of using roundabouts

Recently, a lot of intersections have been converted to roundabouts in Europe and U.S. however, in the Europe the development has come earlier than U.S {[8], [9], [10] and [11]}. This widely used could be attributed for two reasons: safety and mobility.

Safety in roundabouts could be represented by producing slowed and smooth traffic flows with few stops and no left turns in front of left coming traffic in countries where traffic drives on the right [9]. Without a doubt, as mentioned by researchers, the conversion from intersections to roundabout plays a vital role in reducing the number of accidents [12]. The conversion of 230

roundabouts reduces the total crashes by 41% in Australia whereas 83 conversions to roundabouts in France reduce by 78% of injury crashes and 82% of fatal crashes. A 45% reduction for all crashes severities and 81% for all injury crashes were observed in the U.S. [2]. Regardless of the good safety record, roundabout performance can be ruined if precautions are not considered either during the design or operation phase [13]. This could be seen in countries where roundabout design is a relatively new concept, issues frequently arise that negatively impact the roundabout safety record.

Another reason behind using roundabouts is the mobility. The mobility of roundabout because they have a larger capacity than give way intersections and signalised intersections due to the fact that left turns are omitted [14].

3. Methods of roundabout evaluation

To analyze the capacity of roundabout, several models have been developed such as empirical, gap-acceptance and microscopic simulation [5]. Then, each model will be dissected in depth.

Firstly, the empirical model bases on statistical and utilizes regression to find out the relationship between capacity and the geometric characteristics of roundabouts (e.g., the UK Transport Research Laboratory (TRL) model). Therefore, the UK empirical model is focused on finding a mathematical relationship between the entry capacity and the circulating flow rate depending on significant factors that may affect the relationship which is either linear or exponential [15]. RODEL and ARCADY are both software packages for the UK model. These models are not applicable for U.S. roundabouts because the UK model is fully empirical and no theoretical basis relating capacity with the geometry characteristics [1].

Secondly, gap-acceptance model is developed based on the mechanism of accepting and rejecting gaps in the major stream (circulating traffic) by drivers on the minor stream depending on critical headway and follow-up time such as the Australian SIDRA intersection model and the HCM 2010. Though both SIDRA and the HCM 2010 are related to the same approach, their arrival headway distribution for circulating traffic is different. The SIDRA is developed based on a bunched exponential assumption whereas the HCM model is developed based on a simple exponential assumption ([16] and [2]). Therefore, the SIRDA gives overestimation of the capacity for U.S. roundabouts because Australian drivers accept considerably smaller gaps than those of the U.S. The HCM 2000 was developed for just single lane roundabout whereas the HCM 2010 in Chapter 21 was developed for both single and two entry lanes approaching one circulatory lane. The main difference between these two types of roundabout depends mainly on two parameters (single and two entry lanes approaching one circulatory lane) (see the HCM 2010). Therefore, the accuracy of the HCM 2010 model depends on how well these parameters are estimated.

Thirdly, it has been found that the simulation model is the best alternative to empirical and analytical methods. Simulation model could mimic the reality in simulating gap accepting behavior of drivers at intersections[2]. Simulation software such as S-Paramics will be adopted in this study to analyze roundabouts.

Not all simulation software allows the user to model roundabouts exactly. There are two categories of simulation software used for roundabouts: deterministic and stochastic simulation models. Deterministic models such as SIDRA, Rodel, Arcady and Kreisel, analyze roundabout performance with a series of equations, correlating features such as delay, queues and capacity with a set of variables [17]. Stochastic models such as VISSIM, Paramics and Integration use an interval-based simulation to depict traffic operations. A summary of the main roundabout software packages is shown in Table 3.

Table 3. Principal roundabout software packages [18].

Country	Name	Model
U.K.	RODEL	Deterministic
U.K.	ARCADY	Deterministic
U.K.	PARAMICS	Stochastic
Australia	SIDRA	Deterministic
Germany	KREISEL	Deterministic
Germany	VISSIM	Stochastic
U.S.A	INTEGRATION	Stochastic
U.S.A	HCS/SYNCHRO	Deterministic
France	GIRABASE	Deterministic

4. Data Collection and analysis

Field data have been collected from Al-Zahara roundabout in the Al-Najaf City as shown in Figure 3. A Sony video camera with 80 GB storage memory and 12 hour charging period has been used for this purpose. This video camera enables from getting continuous recording for more than 10 hours of field data. This could help in capturing the traffic characteristics and their variations. The first stage of data collection is the selection of a suitable site. Al-Zahara roundabout is one of the congested sites in Al-Najaf City.

After getting permission from the security centre in the city, a multi-story building besides Al-Zahara roundabout was selected as a vantage point on Wednesday. A special steel framework was made for the camera in order to capture all movements in the site. The period of 12 hours was collected by the camera.

Figure 3 Field Observations of Al-Zaharaa Square.

Two sets of field data have been collected: one for the calibration and the second for validation processes.This is to make sure that this simulation package represents the reality for these sites. Then,this package has been used to test different scenarios of solutions as discussed later in this study.

Field data have been extracted from video for 8 hours starting from 7:30 A.M to 3:30 P.M. The stage of analysis data consumes time because you have to track each vehicle from the time of entering to the time of exiting. Table 4 figures out the results of analysis. According to these data, it is obvious that the peak hour volume is from 7:30 to 8:30 A.M. The flow rate in this hour is around 7000 veh/hr during which the roundabout is lock because of high congestion.

The local authority in the city tries to solve the congestion problem by regulating traffic using police traffic officers. However, they failed to mitigate traffic congestion. Therefore, the roundabout has partially closed which creates a huge problem at neighboring U-turns. The length of queuing vehicles is up to 600m for both south and west directions.

Table 4 Field data from Al-Zahara roundabout.

	Time	Left turn (veh/hr)	Right turn (veh/hr)	Through (veh/hr)
South Bound	7:30-7:45	708	148	2284
	7:45-8:00	552	188	2756
	8:00-8:15	452	168	2372
	8:15-8:30	384	120	2564
	8:30-8:45	324	148	2104
	8:45-9:00	332	92	2372
	9:00-9:15	428	128	1736
	9:15-9:30	372	144	1364
West Bound	7:30-7:45	200	404	408
	7:45-8:00	200	388	312
	8:00-8:15	160	440	368
	8:15-8:30	180	460	340
	8:30-8:45	220	408	380
	8:45-9:00	240	428	368
	9:00-9:15	160	464	328
	9:15-9:30	160	448	380
North Bound	7:30-7:45	580	600	540
	7:45-8:00	640	288	496
	8:00-8:15	352	304	436
	8:15-8:30	300	292	520
	8:30-8:45	664	380	516
	8:45-9:00	352	424	584
	9:00-9:15	464	272	444
	9:15-9:30	464	364	584
East Bound	7:30-7:45	120	508	344
	7:45-8:00	124	384	380
	8:00-8:15	76	372	308
	8:15-8:30	68	380	268
	8:30-8:45	104	248	236
	8:45-9:00	104	280	364
	9:00-9:15	64	312	240
	9:15-9:30	104	264	288

5. Simulation model

As indicating in the literatures, simulation models have been proved to be the best tools for dealing with the traffic in roundabout facilities. Therefore, S-Paramics model has been adopted in this study. Firstly, building a roundabout in the S-Paramics could be implemented by nodes and links. Then, adding zones for each direction is to provide origin and destination for each movement. After building the roundabout physically as shown in Figure 4, the demand matrix has been supplied with field data.

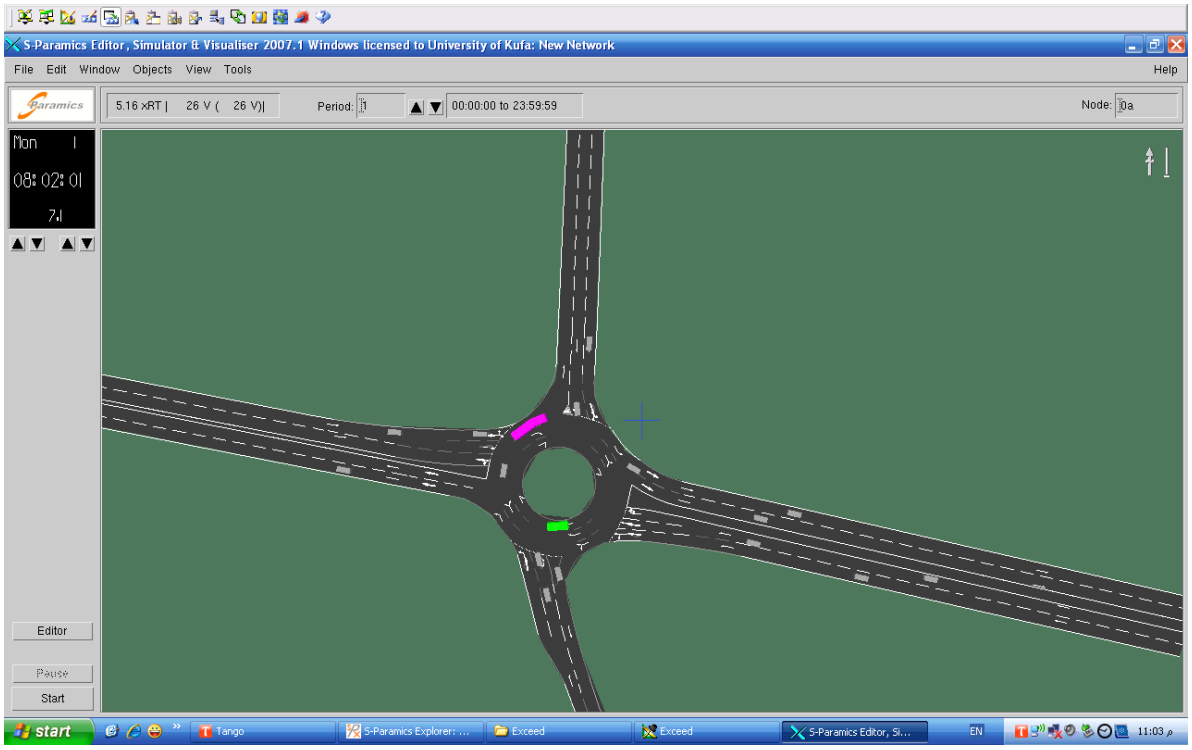

Figure 4 Output screen of S-Paramics simulation model.

Moreover, the S-Paramics mimics the reality not only in determining the traffic stream characteristics such as flow, speed, headway, occupancy but also in representing the three dimensional vision as shown in Figure 5.

Figure 5 Three-dimensional simulation models.

Then, the simulated model has been calibrated with the observed data extracted from videos. The results show a good consistency between simulated and filed data as indicating in Figure 6.

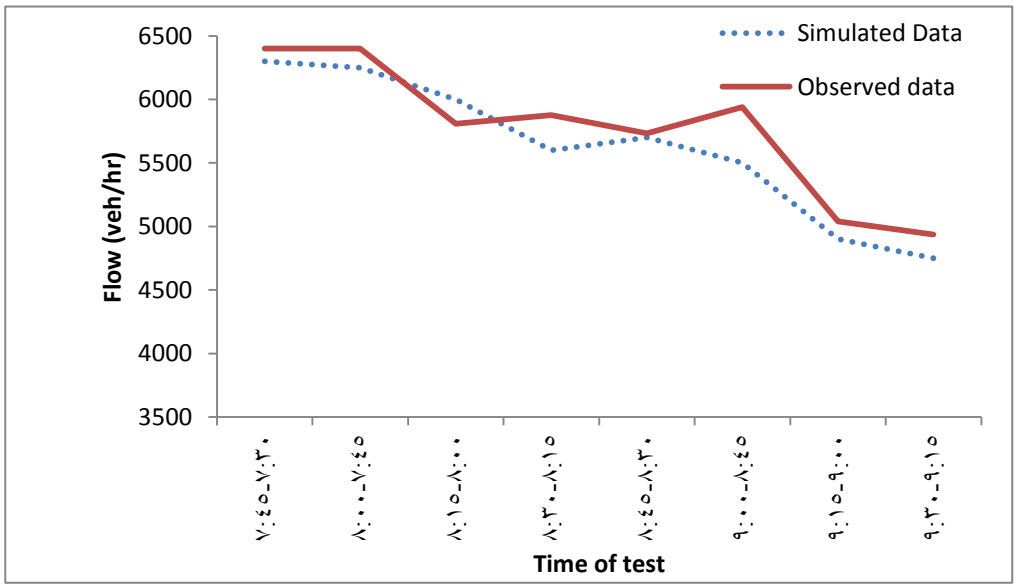

Figure 6 Comparison between field and simulated data.

6. Alternative solutions

After calibration of the developed model, different scenarios have been suggested to improve the capacity of roundabout and Al-Zahara roundabout as a case study. The main important thing provides by simulation model is to show the long queue. These suggested alternatives are:

Firstly, alternatives related to the improvement into geometric design of the roundabout under study. These improvements include change the roundabout from its current case as indicated in Figure 7 to channelized one lane right-turn as demonstrated in Figure 8. The geometric design has been modified using right-turn lane or what is called filter separating by island. This right turn consists of one lane. The increment in the capacity is about 1.25 from the first case due the existence of right-turn lane isolating from other traffic movements as indicated in Figure 8.

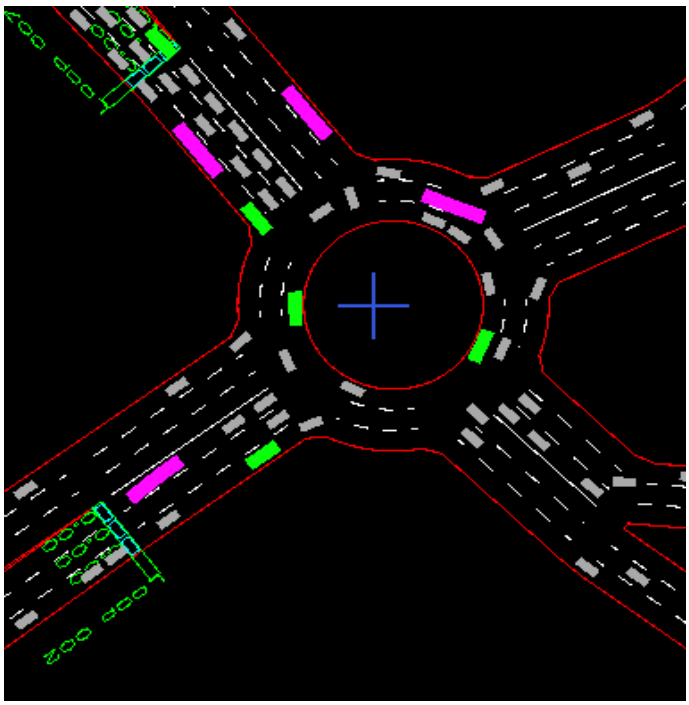

Figure 7 S-Paramics Simulation model for Al-Zahara.

In addition to the above improvement, one could continue with increasing the number of channelized right turn lane even to reach two or more as indicated in Figure 9. However, this improvement depends mainly on the percentage of right turn flow; therefore, in this case no effect when there is an increment of the number of lanes with the same percentage of right turning volume.

Secondly, improvement using interchanged roundabout with specific design related to this roundabout. This specific design has different improvements such as reducing from the effect of right turn movements using channelized right turn, reducing from the effect of left turn using U-turn close to the roundabout as indicating in Figure 9.

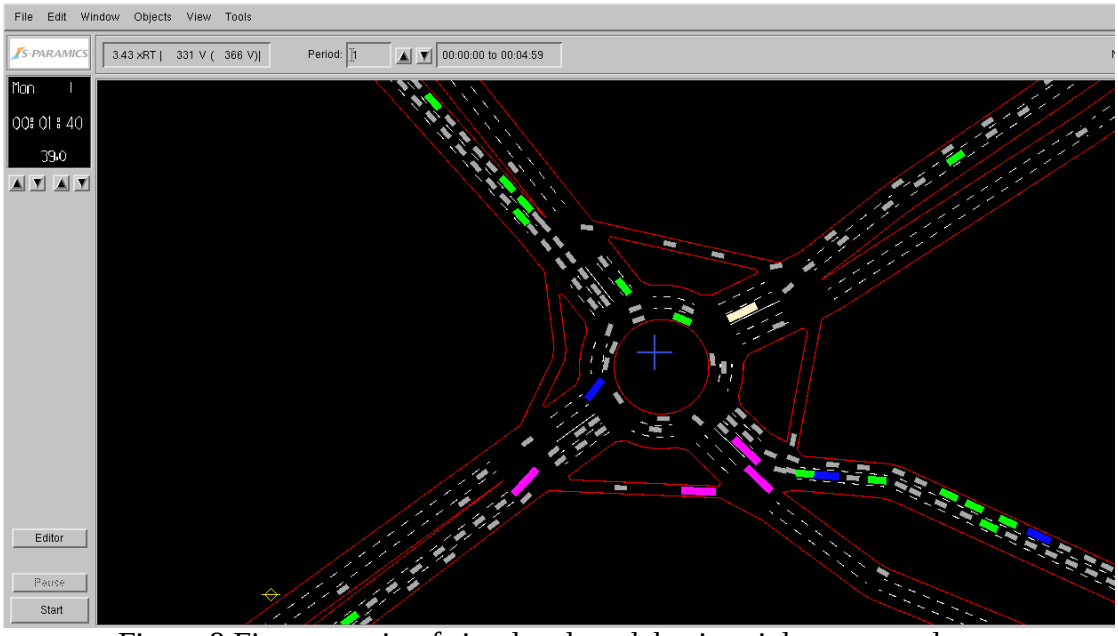

Figure 8 First scenario of simulated model using right turn one-lane.

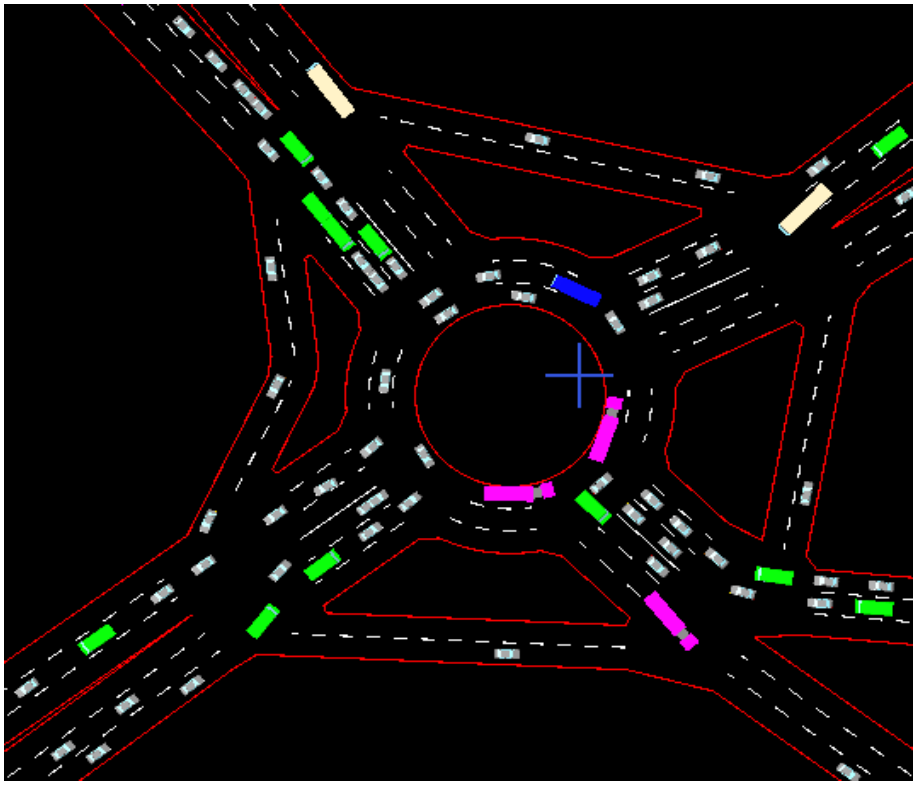

Figure 9 Second scenario of simulated model using right turn two- lane.

Before transferring to the final option (interchanged roundabout), the signalized intersection has been applied using simulation model to the site under study. The results show long queue and congestion. To show clear picture for this congestion, Figure 10 indicates how long will be at each approach of signalized intersection using simulation model (S-Paramics).

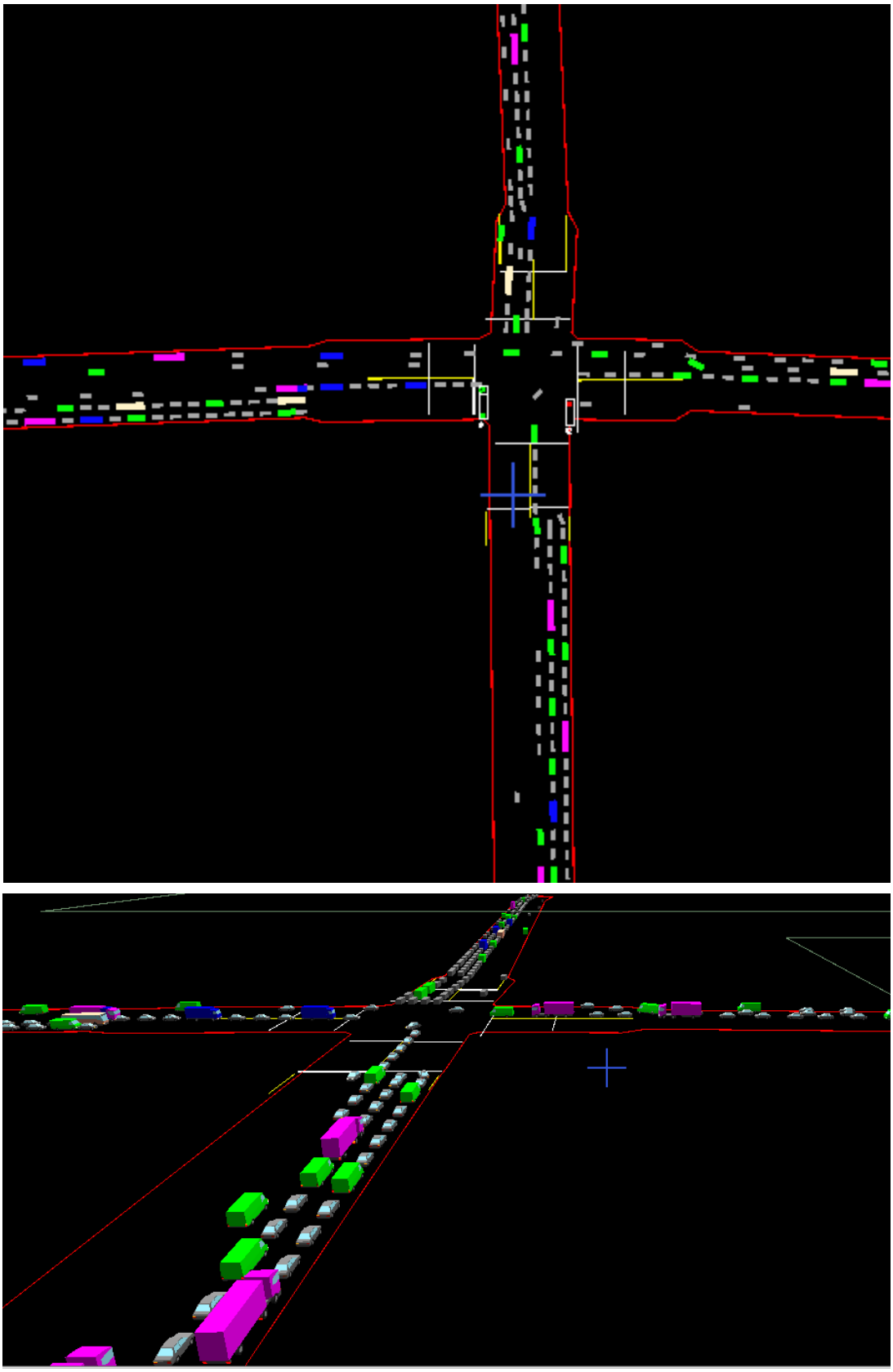

Figure 10 Simulated signalized intersection using S-Paramics (2D and 3D model)

The delay for the each approach exceeds 400 sec/veh which represent LOS F according to the HCM 2000. However, the simulation model shows very long queues as a good measure of effectiveness for judging the performance of the intersection.

The final alternative is indicated in Figure 11. It has been tested using simulation model. There is a high capacity comparing of current case due to overpass for the movement coming from Al-Garage Al-Shamalee. This approach alone could only carry 3000 veh/hr in each direction. This option consists of overpass with two lanes in each direction (from Kufa to Najaf and vice versa). Whereas, Airport road as indicated Figure 11 could also carry double the current flow approximately 3000 veh/hr in each direction. This could increase the capacity to the double. After applying this case, all queuing vehicles have been disappeared from the simulation model due to elevated two-lane section in each direction (North and South) through traffic using the suggested interchange shown in Figure 11.

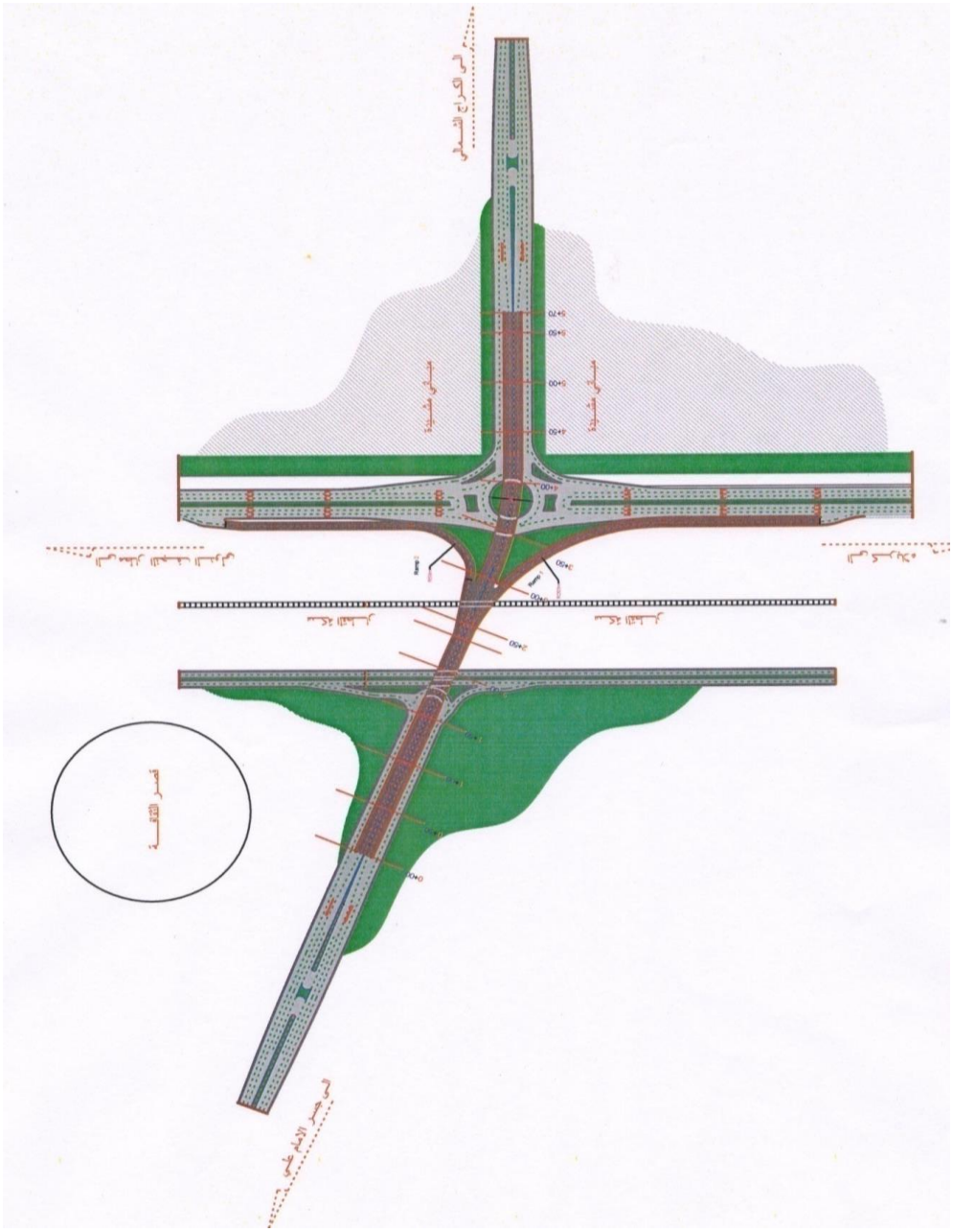

Figure 11 Interchanged roundabout.

Moreover, the final suggestion seems to be the best one for the future because there is a railway line has been suggested by the planners in the city to pass close this roundabout as shown in Figure 11.

7. Conclusions

To sum up, the following conclusions are:

1. Simulation model represents the best solution to model the behavior of roundabout characteristics. This simulated model helps in testing different scenarios close to the reality without any cost of construction in the field.
2. The current roundabout represents the bottleneck along the Airport Road due to high flow rate served by this road and long queues observed along the approaches of this roundabout.
3. Roundabout configuration depends mainly on the total flow and turning movements. It has been noticed the channelized right turn could increase the capacity of roundabout.
4. The optimum solution of Al-Zahara roundabout is to adopt the interchanged roundabout due to high flow rate accommodating by this intersection.

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