Improvements of some roundabout Intersections using capacity model Analysis

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Abstract. Several methods of analysis have been proposed to analyze the ability of vehicles to rotate and manoeuvre during roundabout intersections. Some models have been using formulas and calculations for extracting the results manually, while other models have been used to use the engineering software for the model. Given these differences, it may not be clear how best to use them in a particular situation. When comparing methods of capacity analysis, it will be useful to know how the various techniques are performed across a set of approaches Conflicting volumes. This paper reports on the ability of techniques to rotate multiple pathways based on maximum entry and exit traffic volumes using several methods of analysis. The research study the capacity model for some roundabout intersections in Hilla city, they are, (Al-Mohafada, Al-Saia and, Sahat Abn-Idreas). The capacity equations have been examined using some of the software programs, Highway Capacity HSC 2010, (Signalized Intersection Design and Research Aid) SIDRA, (macroscopic analysis and optimization software application). Synchro 10, to reach the best solutions to describe traffic capacity for each intersection within the study area. Data have been collected according to field survey include traffic volume for different types of vehicles and pedestrians, within antemeridian & post-meridiem (a.m&p.m ) Peak Hour Volume (PHV), Number of lanes, lane width, median width, shoulder width and pedestrians crossing included too, using video technique method. Comparing the capacity for each approach and intersections using the above software programs on the bases of several variables: V/c, delay time, LOS and queue length. It was concluded that all intersections appear with the level of service LOS (E–F) according to (V/c)>1 and increase the delay time. Also, LOS improved from (F to C) when adding one lane for each approach for Al-Mohafada roundabout intersection according to output SIDRA software, as well as it was found that SIDRA software program gives significant results on a capacity model due to take into account the geometric characteristics of the intersections and pedestrian movements and crossing. Likewise, the Syncro program creates simulations of the roundabout with the traffic volumes entering the roundabout intersection, through which it identifies the conflicting points inside the circular intersection and shows the delay in each approach and also shows the queue for each approach.
Keywords: Roundabout, Capacity, HCS, Sidra software, Synchro.

1. Introduction
There are many benefits for roundabouts in comparison with regular intersections with signalized. The major benefits are aesthetics, pedestrian safety, environmental factors, operational performance, and traffic safety. In addition to the other side advantages like decreasing the operational costs and speed control. Around the world, the researchers try to understand, and model roundabout capacity due to capacity measurements present the basis for operational comparison with intersection alternatives [1–4]. Three models classes have appeared that related to parameters involved a model capacity: geometry, a gap acceptance hybrid and gap acceptance. Several controversies happened about the two main methods to develop the models capacity: empirical regression or gap acceptance [5–7], each with benefits and drawbacks, differences and similarities, but the most significant should be related to focus on the best learning method and using of different capacity models. [8,9] Trout beck was stated as regards to that "There is no specific purpose of choosing one of these two methods". [10] investigated traffic flow perfection on un-signalized, signalized, and arterials intersections by utilizing SYNCHRO and SIDRA programs for analysing the performance and assessment of three signalized intersections and four roundabouts by the improvement of three statistical models (polynomial, linear with 50% confidence level and linear with 95% confidence level) to estimate the delay in the roundabout". [11,12] Assessment the traffic performance of the selected roundabouts depending on the delay and level of service (LOS) by analyzing the geometric design features and collected traffic data "and "Developing a mathematical model for critical gap and follow-up headway by utilizing XLSTAT 2016 for all the selected roundabouts".

1.1 Capacity
Capacity analysis is procedures set for assessing the traffic-carrying ability of facilities over a range of defined operational conditions. It provides tools to evaluate facilities and to plan and design improved facilities. The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably could be probable to traverse a point or a uniform section of a roadway or lane during a given period under a prevailing roadway, traffic, and control conditions. Level of service (LOS) is a quality measure showing the operational conditions within a traffic stream, generally in terms of such service measures as travel time and speed, traffic interruptions, freedom to manoeuvre, and convenience and comfort [13].

A) The manual method for highway capacity
The Highway Capacity Manual [14](HCM 2010) adopts simple regression models to assess roundabout entry capacity. The conflicting circulating flow is mentioned in the mathematical formula in all these models, while the geometric characteristics are taken under consideration by classifying roundabouts according to them. The equation for estimating the capacity is given as Equation.
One-lane roundabout entry,
\[ C_e = 1130 \times e^{-1 \times 10^{-3}}v_c \] ... ... ... ... ... ... (1)
For two-lane roundabout entry, Capacity of the left entry lane,
\[ C_{e,L} = 1130 \times e^{-0.75 \times 10^{-3}}v_c \] ... ... ... ... ... ... (2)
The capacity of the right entry lane,
\[ C_{e,R} = 1130 \times e^{-0.70 \times 10^{-3}}v_c \] ... ... ... ... ... ... (3)
\( v_c \) = conflicting flow.
The special capacities of the rotors were calculated using HCM equations and HCS Software program 2010.

B) Sidra Software
Previously (styled SIDRA) was carried the name aaSidra, SIDRA is a software program utilized for network capacity and intersection (junction), performance and service analysis level, and calculations of signalized intersection and network timing by traffic design, operations and planning professionals [9]. The latest Version 8.0 (which was used in this study) involves enhanced network model processing efficiency and enhanced workflow efficiency thru improvements substantial user interface and improvements of model. These involve speeds up the computing of the iterative network analysis technique, optimum time cycle for networks and public control groups, network demand and sensitivity analysis technique, volumes, demonstrations of intersection geometry graphically, signal phasing and Movement IDs in Site input dialogues allowing direct data entry, several new reports and presentations for Sites, Routes and Networks involving Project Summary and the User Report facility depending on user-defined report templates.

C) Synchro software
Synchro is a macroscopic analysis, and optimization software uses. Synchro supports the Highway Capacity Manual’s (HCM) 6th Edition, 2010 and 2000 for both signalized and un-signalized intersections and roundabouts. Also, synchro applied the Intersection Capacity Use technique for identifying intersection capacity. Signal optimization routine of Synchro allows the user to specific weight phases, therefore providing users with more options when developing signal timing plans. Synchro supports multiple scenarios to a single file. Since the software is used easily, traffic engineers are modelling within days, therefore the number of reasons why Synchro remains the leading traffic analysis use [15].

1.2 Performance Analyses
These models were chosen to extract the roundabouts capacities understudy and comparing them to find the best roundabouts solutions, which need to be developed as HCM model deals with roundabout traffic volumes. In assessing the performance of a roundabout design, there are three measures usually utilized; queue length, delay, and a saturation degree [14]. All these measures depend on the roundabout entry capacity in their computations, but each one of them reflects a distinct perspective on the service quality at which the roundabout will carry out under a given set of traffic and geometric conditions. The attention in this paper will be focused on the saturation degree on which both delay and queue length is highly dependent.

A) The saturation Degree
The saturation degree is the ratio of the demand at the roundabout entry to the capacity of the entry.
\[ x = \frac{v}{c} \]  \hspace{1cm} (4)
Where: x, v and c: a saturation degree, demand flow rate and capacity of entry lane, respectively.

B) Delay
Delay is a standard parameter used to measure the performance of an intersection. The Highway Capacity Manual [16] identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersections, with the level of service determined from the delay estimate. Currently, however, the Highway Capacity Manual only includes control delay, the delay attributable to the control device. Control delay is the time that a driver spends queuing and then waiting for an acceptable gap in the circulating flow while at the front of the queue. Two formula is used to calculate delay in Equation (5) HCM2000 and (6) is HCM 2010.
\[
d = \frac{3600}{c_{m,x}} + 900 \left[ \frac{v_{x}}{c_{m,x}} - 1 + \sqrt{\frac{v_{x}}{c_{m,x}} - 1} \right] + 5 \]  \hspace{1cm} (5)
\[
d = \frac{3600}{C_{m,x}} + 900 T \left[ \frac{V_x}{C_{m,x}} - 1 + \sqrt{\left( \frac{V_x}{C_{m,x}} - 1 \right)^2 + \left( \frac{3600}{C_{m,x}} \right) \left( \frac{V_x}{C_{m,x}} \right)} \right] + 5 \times \min(x, 1) \ldots \ldots \left(6\right)
\]

Where: \(d\), \(V_x\), \(C_{m,x}\) and \(T\) = average delay control (sec/veh); movements’ flow rate (veh/h) and capacity (veh/h); and analysis time, h (\(T = 0.25\) for a 15-min).

1.3 Roundabouts and Pedestrians

According to Green Book 2, a crossing of pedestrian located at roundabouts must make a balance between comfort and safety of pedestrian and rotor operations. The more pedestrians cross the rotor, the more likely it is that pedestrians will choose a shorter path that may represent unintended conflicts. Important considerations for the crossing location and the crossing distance are. The crossing distance should be reduced to reduce exposure to conflicts between cars and pedestrians. The location of pedestrian walkways is not frustrated at the production line, as drivers may distract pedestrian movements by observing appropriate gaps in the course of traffic to merge into the deployed road. Crosswalks must be located to take advantage of Taksim Island. The pedestrian sanctuary on the island must be level with street level to avoid using the ramps at the sanctuary. Crossings must be at a distance from the yield line, approximately the length of the vehicle, to reduce the possibility of vehicles lining up the crosswalk [13].

2. Definition of Study Area

The study site was chosen due to multiple roundabouts in Hilla city, the centre of Babylon Governorate, which located in the centre of Iraq. It is located in vital places of the city, as governorate roundabout, which is the most crowded place in the peak time located near the building of Babylon Governorate. Also the Hour Roundabout and the mountain roundabout. Figure (1) shows the location of the city of Hilla concerning the administrative map in Babylon Governorate.

![Figurer 1. AL- Hilla master plan (the Republic of Iraq, Ministry of Construction, 2009).](image)

2.1. Al-Saia Roundabout
Al-Saia Roundabout is a four-leg roundabout, and the west approach is closed due to security reasons (government building). The north process leads to Hilla-Baghdad Street, and the south line reaches to Bab Al-Hussein intersection, which is one of the most significant squares in the city centre. The existing of various essential locations near the intersection (government buildings, Al-Noor hospital for children and some of the secondary schools) caused in a traffic congestion during (a.m) & (p.m) peak hour volume. The intersection layout is shown in Figure (2 a). And Plate (1) shows the intersection AL-Saia (hour roundabout) through the installed surveillance cameras, and it is a model of one of the rotors under study.

Plate 1: AL-Saia roundabout intersection, Hilla, Iraq.

2.2. Al-Muhafadh Roundabout

Al-Muhafadh roundabout intersection an intersection with four-leg; this roundabout is located in the downward of Bab Al-Hussein Bridge. The east approach is Al-Mahkamah Street and leads to Sooq Al-Hilla, which is one of the most congested places in the city centre. The north approach leads to Hilla-Baghdad Street and passing through different important places (government buildings, Al-Noor hospital for children and some of the secondary schools). The geometric illustrated in Figure (2 b). Plate (2) shows the intersection AL- Mohafada (hour roundabout) through the installed surveillance cameras, and it is a model of one of the rotors understudy

Plate 2. AL-Mohaada roundabout intersection, Hilla, Iraq.

2.3. Sahat Abn Idreas Roundabout

Ibn Idris sharie al-Jabal (Aljanayin almuealaqa) roundabout is a four-leg roundabout, and the east approach is closed because it is passed through a street leads to Sooq Al Mosagaaf, which is a
commercial soqq and congested with people. The northern approach (near the Babylon Electricity Maintenance Department) leads to the Babylon Police Command roundabout. The southern approach (near the Aljanayin almuealaqa) leads to the intersection of Bab Al-Mashhad, and the western approach leads to the intersection of Street (40-Al-Jami’a). This roundabout is located in Commercial Square, which is one of the most congested places in the city centre. The geometric illustrated in Figure (2 c). Plate (3) shows the intersection Abn-Idreas Shari Al-Jabal (hour roundabout) through the installed surveillance cameras, and it is a model of one of the rotors under study.

Plate 3. Sahat Abn Idreas roundabout intersection, Hilla, Iraq.
3. Data collection

The procedure of data collection is prepared to gather all the essential data, which is needed to model the traffic flow conditions at the research zone. After a precise concern, the kinds of data that must be gathered were planned to involve:

3.1 Traffic data

The collected traffic data involve peak hours and pedestrian volume. Video technologies were used to collect pedestrian and vehicle sizes in the investigation zone in four-hour intervals throughout the month for each intersection. The most culmination week was chosen to provide a suitable specimen that covering almost of traffic conditions ranges in sunny weather, as well as under standard conditions with no unexpected occasions or breakdowns. There are many reasons make video technology is a credible method such as reviewing the films anytime, less human errors, and cameras usually placed in elevated positions to be unnoticeable by highway users. Hence, the probability of detecting these cameras by highway users is very low, and the produced films will be more credible and accurate. The videos continue within two periods during the specified weekdays: (7:00 to 9:00) am, at afternoon (1:00 to 3:00) Pm. Table 1 lists the volumes of the two hours extracted from the Al-Mohafda Roundabout.

Table 1. Variation of traffic volume for Al-Mohafda Roundabout intersection within (2hr.) peak period

| Time       | EB |         |         | SB |         |         | WB |         |         | NB |         |
|------------|----|---------|---------|----|---------|---------|----|---------|---------|----|---------|
|            | TH | R       | L       | TH | R       | R       | TH | R       | R       |
| 7:30-7:45  | 48 | 164     | 138     | 570| 100     | 250     | 653| 240     |
| 7:45-8:00  | 55 | 170     | 150     | 640| 105     | 313     | 708| 250     |
| 8:00-8:15  | 60 | 180     | 145     | 645| 90      | 350     | 663| 304     |
| 8:15-8:30  | 50 | 163     | 135     | 650| 86      | 300     | 685| 245     |
| 8:30-8:45  | 48 | 174     | 137     | 550| 74      | 338     | 600| 250     |
| 8:45-9:00  | 43 | 162     | 140     | 620| 78      | 300     | 625| 213     |
3.2 Intersection geometric design data
Geometric data included the number of traffic lanes and their mediate width. Geometric data was collected using a combination of several techniques. Initially, satellite imagery was used to get the required data like angle radius, intersection angle etc. Additional data were collected from the relevant local municipalities within the study area, and traditional manual methods characterized by the use of tape measures were used in this study. Figure (2) shows the intersections geometric design. Table (2) shows the engineering design of the intersections under study, while table (3) shows the numbers of pedestrians gathered from the study area.

Table 2. AL-Saia, Sahat Abn-Idreas and AL-Mohafda roundabouts Intersection geometric design layout.

| R* | Approach | Entry width (We) (m) | No. Entry Lanes (Ne) | Exit Width (m) | Entry Radius (Re) (m) | Circulating Width (Wc) (m) | Splitter Island Width (m) | Central Island Diameter (ID) (m) |
|-----|----------|---------------------|----------------------|----------------|---------------------|---------------------------|--------------------------|--------------------------------|
| NE  | Al-Saia  | 10                  | 2                    | 10             | 8.7                 | 12                        | -                        | 27/44                          |
| SW  |          | 10                  | 2                    | 10             | 8.7                 | 12                        | -                        | 27/44                          |
| SE  |          | 10                  | 2                    | 10             | 8.7                 | 12                        | -                        | 27/44                          |
| NW  |          | 10                  | 2                    | 10             | 8.7                 | 12                        | -                        | 27/44                          |
| N   | Sahat    | 9                   | 2                    | 12.5           | 30.3                | 12.5                      | 4                        | 25                             |
| S   | Abn      | 8.4                 | 2                    | 8.7            | 19.1                | 12.5                      | 8                        | 25                             |
| NE  | Idares   | 9.7                 | 2                    | 10.4           | 17                  | 12.5                      | 4.5                      | 25                             |
| SW  |          | -                   | -                    | -              | -                   | -                        | -                        | -                              |
| NE  | AL-Mohafda| 8.5               | 2                    | 8.5            | 38.8                | 13                        | 4.5                      | 18.6/27                        |
| SW  |          | 10                  | 2                    | 10             | 30                  | 13                        | -                        | 18.6/27                        |
| SE  |          | 12                  | 2                    | 13             | 16.8                | 13                        | 6.1                      | 18.6/27                        |
| NW  |          | 8.5                 | 2                    | 8.5            | 35.8                | 13                        | -                        | 18.6/27                        |

Table 3. Pedestrians Traffic volume for Al-Saia, Sahat Abn-Idreas and Al-Mohafda roundabouts intersection.

| R* | Approach       | Time       | Ped. |
|-----|----------------|------------|------|
| Al-Saia | (AL Jzair) | 7:30-8:30 | 32   |
|       | (AL-Bakarly) | 7:30-8:30 | 12   |
|       | (AL Mohafda) | 7:30-8:30 | 72   |
|       | (AL-Aminalwatany) | --- | --- |
| Al-Jabal | (ALItfai) | 7:30-8:30 | 88   |
|       | (AL-Sok alkabeb) | 7:30-8:30 | closed |
|       | (BAB AL Mashhad) | 7:30-8:30 | 892  |
|       | (Street 40) | 7:30-8:30 | 80   |
| Al-Mohafda | (BAB Al-Hussein) | 7:30-8:30 | 508  |
|       | (TO Roundabout AL-Saia) | 7:30-8:30 | 220  |
|       | (AL-Jnsia street) | 7:30-8:30 | 592  |
4. Analysis and Results

After entering the information and all engineering data for each roundabout in the study area, which previously collected from traffic volumes and geometric design data for the rotors in the selected engineering programs. Sidra program, the synchro program, the HCM program 2010 to extract the capacity for each approach and the total capacity of the roundabout intersection, level of serves (LOS) Also, the delay and v / c ratio. To compare models and find a better realistic model were extracted as shown in figure 3 of Sidra program were extracted (a) The engineering data for each roundabout are entered, either Figure (3) for the same programs (b) and Figure 3 (c) where traffic volumes and directions are entered. As for Figure 5 (a, b), the Synchro program shows the traffic volumes, directions and engineering data with all its details. Figure (4) shown the synchro program.

Figure 3. Sidra software program with input data.
**Figure 4.** Synchro software program with input data.
In Figure (5)(a, b) shows the relationship between the capacity and the circulation flow rate of the models used HCM2010 and SIDRA and Synchro for clock and preservative roundabout where it was observed that the capacitance values for both programs (HCM 2010 and Synchro) are less than the resulting capacity in the program (SIDRA). HCM2010) does not enter the engineering data of the rotor or pedestrian. The HCM2010 equations were used and compared with the HCM2010 program. The results for the equations and results for the program were identical. The Sahat Abn Idreas roundabout was chosen here as an example.

The circulatory flow rate for the approximations is calculated as follows:

\[ v_{c,EB,pce} = v_{NBUpce} + v_{WBUpce} + v_{SBTPce} + v_{SBUpce} + v_{SBLpce} \quad \ldots \ldots (7) \]
\[ v_{c,EB,pce} = 1940 \text{ vph} \]

\[ v_{c,NB,pce} = v_{SBUpce} + v_{WBUpce} + v_{SBLpce} + v_{EBTPce} + v_{EBUpce} + v_{EBLpce} \quad \ldots \ldots (8) \]
\[ v_{c,NB,pce} = 360 \text{ vph} \quad v_{c,SB,pce} = 730 \text{ vph} \]

The capacity calculations for each approach are calculated as follows:

\[ c_{pce,SBR} = 1130 \times e^{-0.7 \times 10^{-2} \times 1940} = 291 \text{ vph} \]
\[ c_{pce,SBL} = 1130 \times e^{-0.75 \times 10^{-2} \times 1940} = 264 \text{ vph} \]

Table 4: The outputs of the engineering programs used for the AL-Saia and AL–Mohafada roundabouts intersection.

| MODEL | CAPACITY | V/C | DELAY(sec/veh) | LOS |
|-------|----------|-----|----------------|-----|
|       | S E W N  |     |                |     |
| HCS 2010                     |     |     |                |     |
| Lower bound                  |     |     |                |     |
| S E W N                      |     |     |                |     |
| 659 155 - 139 5.48 24.59 - 27.12 2 | 2033.1 2 10667.9 - 11812. 6 | LOS F |
| 633 134 - 119 5.7 28.45 - 31.68 2132.5 6 12412.1 - 16886. 7 | LOS F |

Figure 5. Capacity and circulation relationship of (a) AL-Saia roundabout and (b) AL-Mohafada roundabout
In the table (3) the values of \((v / c)\) in the Sidra program are less than the values produced in the two programs (HCM2010 and Synchro). As for the delay accounts resulting in the Sidra program, they were less than the values produced in the two programs (HCM2010 and Synchro) as it is closer to reality the results produced in the (Sidra) program of the two programs (HCM2010 and Synchro).

5. Conclusions and Recommendations

1. When comparing the capacity for each approach and intersections using the software programs above on the basses of several variables: \(V/c\), delay time, LOS and queue.

   It was concluded that all intersections appear with a level of service LOS (E–F) according to \((V/c) > 1\) and increase the delay time. Also, LOS improved from (F to C) when adding one lane for each approach for Al-Mohafada roundabout intersection according to output SIDRA software, as well as it was found that SIDRA software program gives significant results on a capacity model due to take into account the geometric characteristics of the intersections and pedestrian movements and crossing. Likewise, the Syncro program creates simulations of the roundabout with the traffic volumes entering.
the roundabout intersection, through which it identifies the conflicting points inside the circular intersection and shows the delay in each approach and also shows the queue for each approach.
2. The study recommends planning the traffic intersection area with signs and furnishing them with the necessary sign to secure the crossing pedestrian safely and in all directions.
3. Through studying the roundabouts in the AL-Mohafada & Ibn Idris sharie AL-Jabal, increasing the capacity of roads to accommodating traffic vehicles and reducing congestion, there is an urgent need for a planning study of Al-Hilla city, and it is necessary to make more researches and studies in this field. This can be accomplished by supplying modern equipment for researchers that require less labour and provide the necessary different data in traffic engineering. As it is possible to redesign the intersection by either expanding the diameter of the roundabout and the number of lines, and it is also possible to use the suspended bridges in the absence of sufficient spaces.
4. It is possible to suggest opening openings in the central carrot with a suitable distance from the rotor to the vehicles through which the cars are rotated to the other side (U-TURN) without entering the rotor as this would reduce the traffic momentum in the washer.

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