Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943


# Turbo-Roundabouts as a Tool for Enhancing Urban Efficiency and Safety: A Case Study

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**ARTICLE INFO**

***Article history:***
Received 23 July 2023
Received in revised form 30 October 2023
Accepted 12 November 2023
Available online 28 November 2023

***Keywords:***
Roundabout; Traffic Congestion; SIDRA; Intersection Safety; Simulation; Level of Service; Urban Road Infrastructures

**ABSTRACT**

Traffic jams occur when a volume of traffic influx produces a demand for space more significant than the road allows. Numerical field data addressing vehicle counts and statistical computer simulations are vital tools in determining a road's serviceability and traffic level. Both have been utilized in this study. The primary objectives of this study are to conduct a comprehensive analysis of the traffic flow, measure the Level of Service (LOS), travel time, degree of saturation, delay time, and articulate a strategy to reduce traffic congestion at roundabouts. The study unequivocally concluded that the LOS at the eastern entrance is F level. The data on the number of vehicles that pass through the roundabout at the eastern entrance of Benghazi were recorded during the peak hours from (12:00 to 1:30) p.m. The mixed traffic stream was then converted to passenger car units (PCU) to be homogenously equivalent. The results of the systematic analysis of the gathered data indicate that the roundabout at Benghazi's eastern entrance requires further development to alleviate the dire traffic conditions. To run an accurate simulation, the existing road layout was surveyed using surveying instrumentation, and the results were used to build a model. Acceleration and deacceleration lanes were proposed to improve the roundabout performance and reduce congestion. Then, the roundabout expansion proposal was introduced into the simulation to study its effectiveness in reducing traffic jams. The data were analysed and tested using SIDRA software. The Level of Service at the roundabout's lanes showed tremendous improvement as the Level of Service varied from A to B levels compared to the current LOS level of F.

## 1. Introduction

Traffic congestion occurs when the amount of traffic necessitates more space than the accessible street limit; this point is sometimes referred to as the saturation level. Traffic jams are brought on by various unique situations, the majority of which lower the speed limit of a street at a certain location or over a predetermined distance. Macro-level and micro-level elements contribute to traffic

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https://doi.org/10.37934/araset.34.1.279288

congestion [1]. As speed is a very sensitive aspect that is connected to the cost of vehicle operation and the safety of the passengers, it is recommended that traffic congestion be measured using speed out of travel time and delay, traffic volume, and level of service (LOS), and speed [2]. Traffic engineers are currently facing challenges due to urban traffic systems' better service levels, traffic congestion, and urban transportation efficiency [3]. Measures used to determine traffic congestion include volume, loss of service (LOS), time and delay, and speed [1,4,5].

Roundabouts could represent an effective and efficient method of traffic control and junction control. Additionally, increased safety is widely acknowledged as the primary beneficial of using the roundabout method. Roundabouts can deliver significant safety and environmental advantages as well as enhance vehicular traffic [6]. Regarding traffic safety, roundabouts greatly slow down approaching automobiles in regard to their speed, hence accidents between vehicles at a roundabout are far less common and less violent than accidents at signalized junctions (where the intersecting roads are straight ahead) [7]. Also, conflict points are greatly decreased when compared to conventional junctions, and roundabouts, in particular, do not contain junction conflict points. Roundabouts may thus be regarded as traffic calming techniques in every way, and as such are especially helpful in urban situations as they are recognized by all types of road users [8].

It ought to be emphasized, however, that the advantages listed previously are mostly obtained at single-lane roundabouts. The installation of roundabouts with more than one lane on the circulatory route is prohibited by most international rules, including the Italian one. Despite this, numerous two-lane (and even three-lane) roundabouts are still employed in infrastructure across the world. The fundamental disadvantage of the aforementioned layouts is that they create dangerous junction conflict points on the circulatory route that do not exist in single-lane configurations [9].

As a result of these factors, several nations are seeking a solution for what to do with their current "conventional" multi-lane roundabouts in order to increase traffic safety and capacity. Many northern European countries have addressed the issues of low traffic safety and capacity of existing "conventional" multi-lane roundabouts in recent years by implementing some alternative types of roundabouts that reduce the number of conflict points. It includes the turbo-roundabout [10].

The turbo-roundabout is a novel approach to the two-lane roundabout. In the late 1990s, it was implemented as a more secure and effective replacement for conventional multi-lane roundabouts. In the turbo-roundabout, traffic flows run independently before entering the roundabout, they occupy different lanes within the circulatory route, and traffic flows depart the roundabout individually as well. Structural separation is achieved using delineators, which are specially shaped components that prevent traffic lanes from changing in the many elements that comprise the roundabout. As a result, the defining feature of turbo-roundabouts is the physical barriers between circular lanes. During the approach leg to the roundabout, motorists must pick an entering lane based on appropriate lane markers. This has a clear benefit for user safety, as the number of conflict points on turbo-roundabouts is fewer than on multi-lane roundabouts. According to Bulla and Castro [11], the usage of turbo roundabouts in Bogota, Columbia, resulting in a 12-20% capacity boost when compared to a two-lane conventional roundabout. Due to the existence of lane dividers, Baranowski and USA [12] reported that the capacity of a turbo roundabout is 25-35% greater than that of a two-lane traditional roundabout. Gallelli *et al.*, [13] reported that converting an existing traditional two-lane roundabout in Cosenza, Italy, into a turbo roundabout enhanced capacity by 15-84% while reducing queue length by more than 90% in some situations.

Measures used to determine traffic congestion include volume, loss of service (LOS), time and delay, speed, and cost [14-16]. Studies about traffic congestion were discussed, along with the best ways to solve the issue [17]. Investigations are done on the width of the network, the intersections, the width of the roads, the availability of space, and most importantly, the vehicle traffic. There are additional multimodal delay studies, the majority of which employ simulation tools that take a time-based approach [18]. In order to minimize the current level of traffic congestion, India's growing urban population necessitates integrated state and national transportation strategies [19].

This research evaluated the efficiency and safety of multi-lane roundabouts with turbo-roundabouts. The traffic flow performance at the eastern entrance of Benghazi measuring the Level of Service (LOS) is assessed, as shown in Figure 1 below. In addition, this study introduces a strategy to improve traffic and reduce travel time. The finding of this study is essential to understand the traffic flow at the important entrance of Benghazi city. The study will explore weaknesses at the roundabout and increase the time trips at a specific period. Finally, the result of this study can be used as a reference for further research and future development.

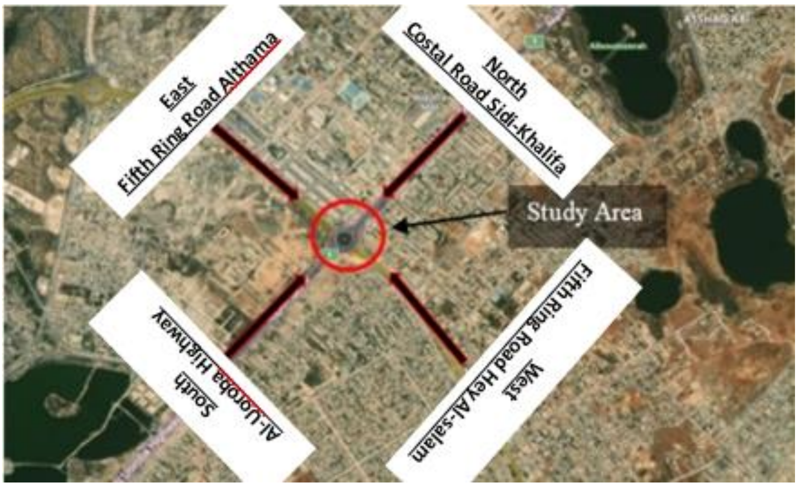


**Fig. 1.** The location of the roundabout

## 2. Methodology

A lane-based micro-analytical software for independent intersection design and evaluation is called the Sidra Intersection package. Several movement classes, such as light and heavy cars, buses, pedestrians, cyclists, trucks, and trams, among others, are modelled using networks of crossings. Several performance metrics are evaluated by the program, including facility capacity, level of service (LOS), queue length, delay, and pauses for cars, bicycles, and pedestrians, as well as limitations like fuel use, pollutant emissions, and operational costs. This study's methodology is divided into four basic phases. Included are data collection, data processing using Sidra Software 5.0, result outcomes, and conclusions. In the proposed areas, a traffic volume study was conducted to gather information for the SIDRA 5.0 program. Research on traffic patterns, traffic counts, movement of junction phases, and wait length provided the variables. The acquired data was evaluated and expanded upon. The Degree of Saturation, queue lengths, and average latency can be calculated using the SIDRA model [20]. The model was created using traffic statistics and geometric design data. The SIDRA model's calibration uses the gap acceptance parameters [21].

The data of the study was collected for one hour and a half, that was from 12:00 p.m. to 1:30 p.m. at the main east entrance of Benghazi city at Tiara-Roundabout. This area was considered a potential PM peak hour. A total of eight observers carried out manual counting at their assigned positions along the North and south fifth ring road, East of the roundabout, and west of the roundabout as shown in Figure 2. Layout Plan at Tiara-Roundabout with Traffic Flow Values in pcu/hr. All traffic movements were recorded and divided into several compositions of cars, heavy vehicles, buses, motorcycles, and bicycles.

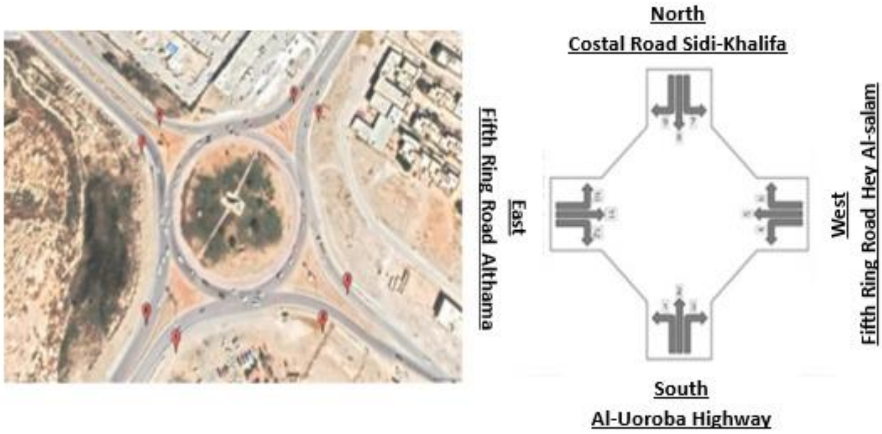


**Fig. 2.** Traffic analysis and labelling for the roundabout directions

## 3. Results and discussion

### *3.1 Traffic Volume*

The collected data was used as input for SIDRA 5.0 software. The results obtained show the LOS, which was used as the measurement for the factors that affect the speed and delay time, traffic interruptions, manoeuvre freedom, safety, driving ease, and convenience. The concept of LOS is utilized in the intersection's capacity analysis. Figure 3 and Figure 4 show the location and the Movement Summary Tiara Roundabout at the east entrance of Benghazi.

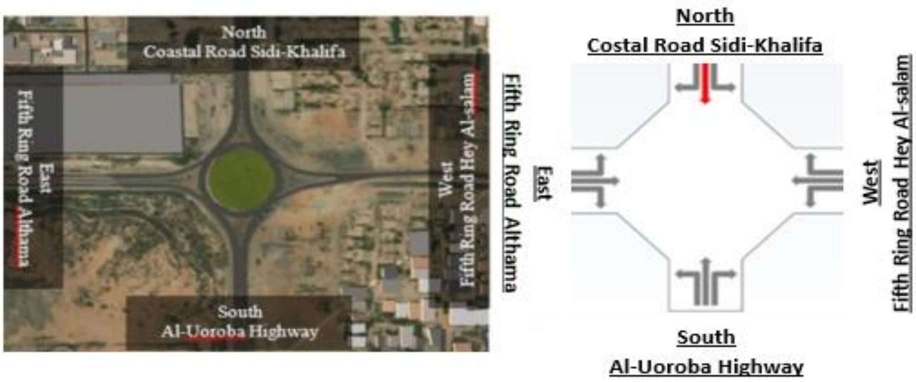


**Fig. 3.** The satellite image represents the roundabout and the four-legs

To accomplish the goal of this study, data collection is crucial. As seen in Figure 4, the roundabout is a four-legged crossroads with two lanes on each approach. The data were collected manually by a team consisting of 8 members for each 15-minute interval for each session, the peak hour in the evening (12:30–1:30) p.m.

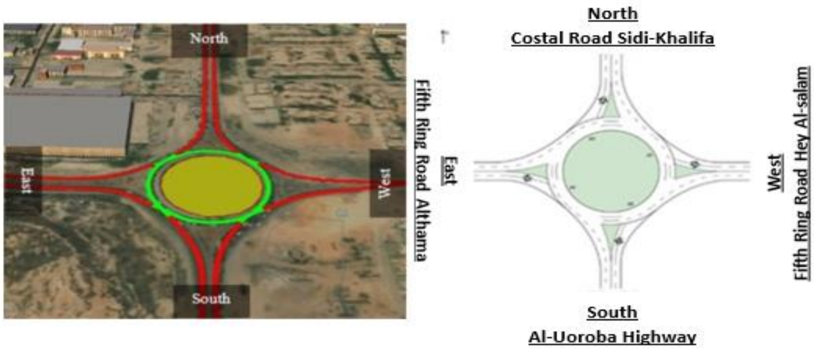


**Fig. 4.** Existing roundabout as shown by SIDRA and four-legs

Table 1 statistics on traffic volume expressed as the number of automobiles traveling in all directions during peak hours.

**Table 1**
Traffic volume at the east entrance of Benghazi –roundabout every 15min

| Time | North Coastal Road-Sidi khalifa | | | West Fifth Ring Road- Hey Al-salam | | | South Al-Uoroba Highway | | | East Fifth Ring Road Althama | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | ST | R | L | ST | R | L | ST | R | L | ST | R |
| 12:00-12:15 | 31 | 380 | 40 | 5 | 28 | 261 | 4 | 33 | 178 | 165 | 16 | 3 |
| 12:15-12:30 | 37 | 595 | 61 | 5 | 34 | 292 | 10 | 50 | 280 | 267 | 34 | 9 |
| 12:30-12:45 | 47 | 610 | 59 | 8 | 52 | 216 | 5 | 55 | 330 | 307 | 37 | 8 |
| 12:45-1:00 | 39 | 700 | 43 | 6 | 54 | 270 | 7 | 63 | 385 | 310 | 65 | 11 |
| 1:00-1:15 | 55 | 665 | 63 | 8 | 23 | 228 | 6 | 53 | 405 | 260 | 20 | 3 |
| 1:15-1:30 | 46 | 680 | 62 | 2 | 29 | 302 | 5 | 60 | 380 | 270 | 45 | 11 |

### *3.2 Data Analysis using SIDRA*
#### *3.2.1 LOS at Tiara Roundabout - before upgrading*

The LOS approach that has been defined according to the US Highway Capacity Manual (HCM) has been applied in the present study to clarify the effectiveness of traffic flow (by calculating the traffic volume per quarter of an hour and using the highest traffic after multiplying it by four to get the traffic flow within an hour). HCM provides six levels of LOS ranging from level A to level F based on the delay (for vehicles) as can be seen in Table 2.

**Table 2**
LOS basis on HCM delay

| LOS | Delay Sec / Vehicle |
|---|---|
| A | 0-10 |
| B | >10-15 |
| C | >15-25 |
| D | >25-35 |
| E | >35-50 |
| F | >50 |

SIDRA simulation software has been applied to investigate the present LOS. Table 3. illustrates the average delay at the roundabout. Results illustrated the LOS of East Costal Road Sidi-Khalifa (North) is (F) while the LOS of Al-Uoroba Highway (South) LOS is (D).

The results obtained from SIDRA show LOS, Average Delay, and Average speed for East Costal Road Sidi Khalifa and Al-Uoroba Highway as shown in Table 3 which is the existing data of Level of Service (LOS) in the study areas.

**Table 3**
Result of analysis of existing Tiara-Roundabout by SIDRA

| Approach | Average Delay | LOS |
|---|---|---|
| South: AL-Uoroba Highway | 31 | D |
| West: Fifth Ring Road Hey Al-salam | 12 | B |
| North: East Costal Road Sidi-khalifa | 78 | F |
| East: Fifth Ring Road Althama | 11 | B |

### *3.2.2 LOS at Tiara Roundabout - after upgrading*

The Tiara-Roundabout was upgraded by increasing the accelerating and deaccelerating lanes in all approaches. This improvement can decrease the delay time and improve the roundabout performance as can be seen in Figure 5. The total number of passenger car units (PCU) in each arm can be seen in Figure 6. Even though the total traffic volume on the Al-Uoroba Highway was 770 PCU, additionally, 884 PCU was the total number of vehicles at the East Costal Road Sidi-Khalifa, the total traffic volume decreased dramatically after the Tiara-Roundabout improvement.

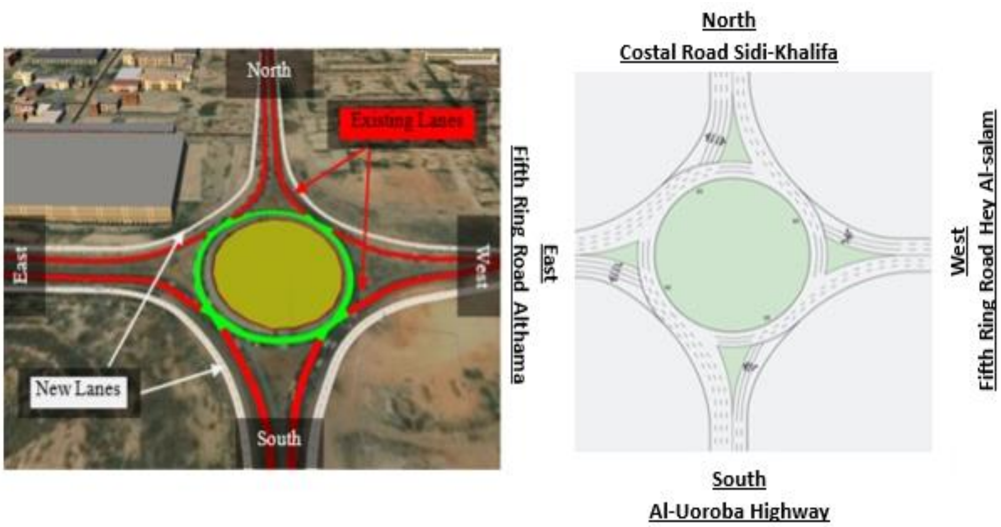


**Fig. 5.** Upgraded Lanes (Acceleration and Deceleration). Roundabout geometry

These two arms are considered the highest volume of traffic when we compare them to other arms as shown in Figure 6. However, Fifth Ring Road Hey Al-salam (West) LOS of the intersection is (B) and Fifth Ring Road Althama (East) is (B), as shown in Figure 6 for peak hour, it could be defined as unstable flow. SIDRA software is used to compute the average delay and is associated with LOS for evening peak house as provided in Figure 6.

**Movement Performance - Vehicles**

| Mov ID | Turn | Demand Flow veh/h | HV % | Deg. Satn v/c | Average Delay sec | Level of Service | 95% Back of Queue Vehicles veh | 95% Back of Queue Distance m | Prop. Queued | Effective Stop Rate per veh | Average Speed km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| South: South: Al-Uoroba Highway | | | | | | | | | | | |
| 1 | L | 385 | 0.0 | 0.266 | 11.0 | LOS B | 1.9 | 13.0 | 0.28 | 0.59 | 47.1 |
| 2 | T | 385 | 0.0 | 0.222 | 2.9 | LOS A | 1.5 | 10.6 | 0.25 | 0.29 | 53.6 |
| 3 | R | 154 | 0.0 | 0.116 | 2.8 | LOS A | 0.7 | 4.9 | 0.25 | 0.28 | 53.7 |
| Approach | | 924 | 0.0 | 0.266 | 6.3 | LOS B | 1.9 | 13.0 | 0.26 | 0.41 | 50.4 |
| East: West: Fifth Ring Road - Hay Al-salam | | | | | | | | | | | |
| 4 | L | 276 | 0.0 | 0.130 | 12.2 | LOS B | 0.7 | 5.1 | 0.52 | 0.75 | 46.2 |
| 5 | T | 36 | 0.0 | 0.130 | 3.9 | LOS A | 0.7 | 5.1 | 0.51 | 0.39 | 49.9 |
| 6 | R | 55 | 0.0 | 0.054 | 4.2 | LOS A | 0.3 | 1.9 | 0.52 | 0.42 | 51.2 |
| Approach | | 367 | 0.0 | 0.130 | 10.2 | LOS B | 0.7 | 5.1 | 0.52 | 0.66 | 47.1 |
| North: North: Costal Road Sidi-Khalifa | | | | | | | | | | | |
| 7 | L | 50 | 0.0 | 0.108 | 12.9 | LOS B | 0.7 | 4.6 | 0.57 | 0.80 | 47.2 |
| 8 | T | 370 | 0.0 | 0.108 | 4.7 | LOS A | 0.7 | 5.0 | 0.56 | 0.46 | 50.6 |
| 9 | R | 50 | 0.0 | 0.108 | 4.8 | LOS A | 0.7 | 4.6 | 0.57 | 0.48 | 50.7 |
| Approach | | 470 | 0.0 | 0.108 | 5.6 | LOS B | 0.7 | 5.0 | 0.56 | 0.50 | 50.2 |
| West: East: Fifth Ring Road - Al-thama | | | | | | | | | | | |
| 10 | L | 30 | 0.0 | 0.029 | 12.1 | LOS B | 0.1 | 1.0 | 0.49 | 0.68 | 46.1 |
| 11 | T | 30 | 0.0 | 0.015 | 4.1 | LOS A | 0.1 | 0.5 | 0.48 | 0.40 | 51.4 |
| 12 | R | 241 | 0.0 | 0.170 | 3.6 | LOS A | 1.0 | 6.7 | 0.50 | 0.36 | 51.3 |
| Approach | | 301 | 0.0 | 0.170 | 4.5 | LOS B | 1.0 | 6.7 | 0.49 | 0.40 | 50.6 |
| All Vehicles | | 2062 | 0.0 | 0.266 | 6.6 | LOS A | 1.9 | 13.0 | 0.41 | 0.48 | 49.7 |

**Fig. 6.** Movement Summary from SIDRA at the roundabout after improvement

### *3.2.3 Average delay*

Forecasting travel time requires careful consideration of the average delay. Results for the delay and LOS are shown in Figure 7 and Figure 8, which demonstrates the reduction in travel time on the North-Costal Road in Sidi-Khalifa, from red (LOS F) to green (LOS A), which indicates the least amount of delay. As the delay is reduced, LOS is inversely correlated with it. While the Fifth Ring Roads Hey-Alsalam and Althama have two hues, green and blue, respectively, these colours stand for LOS A and LOS B.

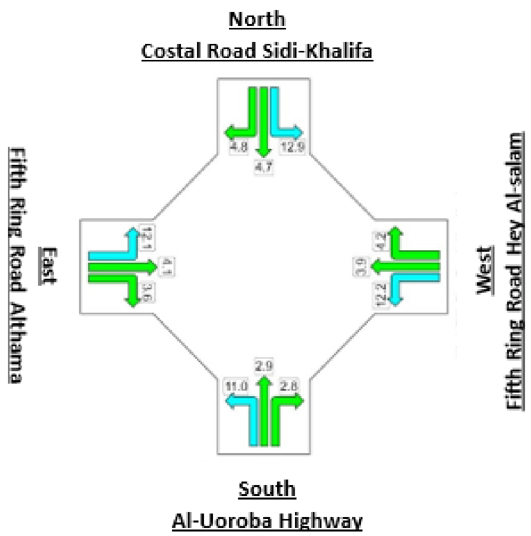


**Fig. 7.** Average Delay of Tiara Roundabout approaches

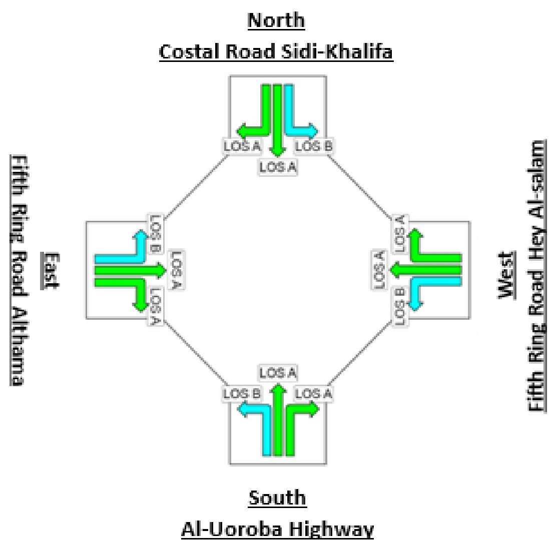


**Fig. 8.** The LOS at the roundabout approaches

### *3.2.4 Degree of saturation*

An estimate of 100% indicates that demand and limit are equal and no more traffic may enter the junction. The degree of saturation (%) is a ratio of demand to limit on each lane to handle the intersection. Numbers above 85% are typically interpreted as suffering from movement congestion, with vehicle queues beginning to form. depending on the saturation level of a colour code. Every degree has a certain colour. Figure 9 provides results regarding the degree of saturation. The Coastal Road Sidi Khalifa has a green hue, meaning that the degree of saturation is 0.11, which indicates high improvement. Green colour relates to less than 0.6 degrees of saturation. Similarly, the Fifth Ring Road-Althama.

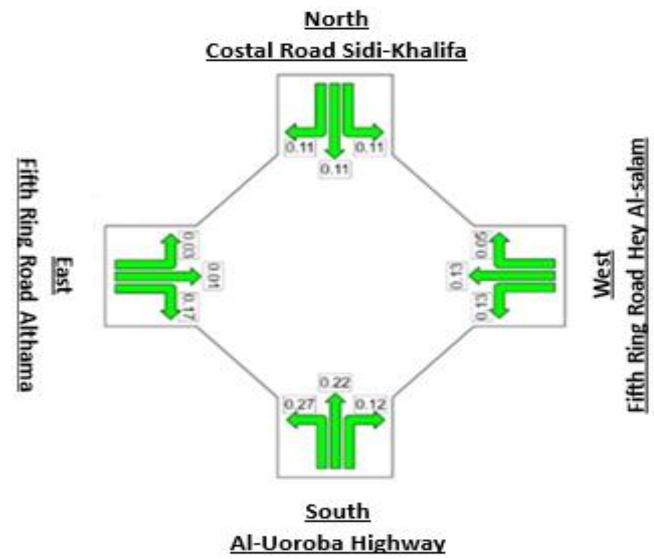


**Fig. 9.** Degree of saturation of roundabout approaches

### *3.2.5 Travel speed*

In Figure 10, the results for travel speed are shown. According to the speed efficiency-based colour code, bright blue and dark blue have speed efficiency ratios between (0.8-0.9) and (0.7-0.8). It was noted that the blue tint on the coastal road at Sidi Khalifa indicates significant progress. Similar to this, the Al-Uoroba Highway, Fifth Ring Road-Hey Alsalam, and Fifth Ring Road-Althama all have blue and light blue tones. Sidi Khalifa Coast Road has a 50.6 km/h speed limit.

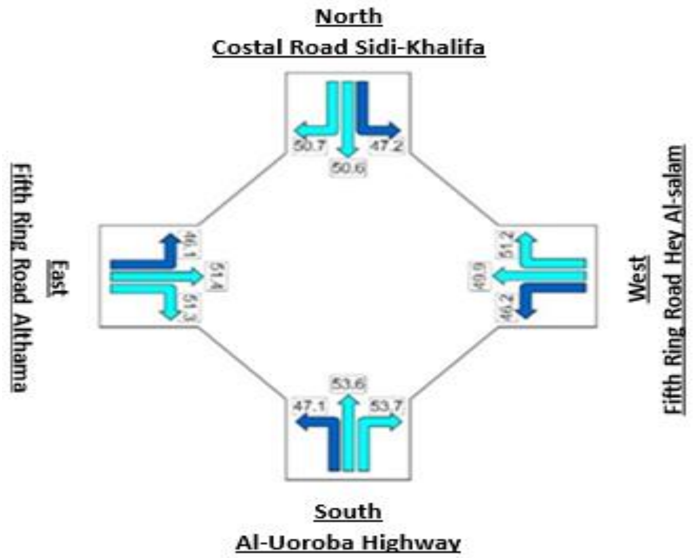


**Fig. 10.** Travel speed for roundabout approach

## 4. Conclusions

Based on the results and analysis carried out in this study, several conclusions and recommendations can be made to improve the performance of the roundabout. The following are the conclusions that can be made from the study:

i. From the manual data collection in the peak hours shows the breakdown flow, where every single vehicle moves in lockstep with the vehicle in front of it. The level of service was (F).
ii. From the data collection, the breakdown flow led eventually to unpredicted travel time.
iii. AutoCAD Civil 3D software was used to propose a new layout of the roundabout by adding new acceleration and deacceleration lanes.
iv. From SIDRA Software analysis shows the performance of the roundabout increase when we use the proposed layout.
v. From Sidra Software analysis shows the roundabout circulation works perfectly without any modification in the circulation number of lanes.
vi. The level of service significantly improved from Level (F) to Levels (A and B).
vii. The average delay decreased dramatically from breakout flow to less than 12 seconds.

### Acknowledgement
This research was not funded by any grant.

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