Enhancing Sustainable Transportation through Innovative Design: Evaluating the Operational and Safety Impacts of Turbo Roundabout

UNEB GAZDER
Department of Civil Engineering, College of Engineering
University of Bahrain
Sakhir 32028
BAHRAIN

Abstract: - Transportation sector poses a major threat to the sustainable development strategies due to its diverse externalities in the form of emissions and fuel consumption heightened due to congestion, and loss of life and property due to road accidents. Roundabouts are very effective intersections in terms of efficiency and Level of Service (LOS). However, the application of roundabout has a compromise between the safety aspects of single lane roundabouts and capacity of multilane roundabouts. The aim of this research is to evaluate the impact of innovative turbo roundabout design on enhancement of the sustainability of transportation networks. To achieve this objective, three different roundabouts in Bahrain were studied and converted to turbo roundabouts based on volume distributions. Design processes were done using TORUS 5.1 and then imported to PTV VISSIM for the operational comparison with multi-lane roundabouts in terms of delays and LOS. In addition, capacities were calculated of multi-lane roundabouts based on equations in HCM 2010 (Highway Capacity Manual) and the capacities of turbo roundabout based on Gap Acceptance Model (Tanner's Model) and the differences were shown. Advantages of turbo roundabouts were noticed on all three roundabouts in terms of delay and conflict points, making them a more sustainable option.

Key-Words: - intersections; Turbo design; delay; conflict points; Bahrain; level of service

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1 Introduction

In previous years, roundabouts were known as safer and more powerful solutions than other types of priority junctions [1]. It is generally considered that single lane roundabouts are one of the safest alternatives [2]. However, these types of roundabouts are not always applicable for implementation in some areas due to their low capacity. For this reason, multi-lane roundabouts are better solutions in case of high traffic demands rather than using single-lane roundabouts. Unfortunately, these types of roundabouts have higher conflict points than single lane roundabouts. Their geometric layout allows the drivers to increase their speed when cutting going in/out of curvature. In addition, they are very flexible in terms of movements which allow the drivers to adopt incorrect trajectories which lead to weaving conflicts and accidents in the circulatory carriageway [3]. The best solutions that carry both the advantages of high capacities and high safety level are the turbo roundabouts. These kinds of roundabouts were first applied in Netherlands in 1996 [4]. The first thing that makes these roundabouts different than others is the method of separation in the circulatory roadway at the entries and exits because of their spiraling circular carriageways. This is proved in Figure 1. Because of this, drivers are forced to choose their lane before entering the roundabout which directly increases safety and reduces the number of conflict points as well as the risk of side-by-side accidents. Drivers are obliged to reduce their speed at the raised lane dividers which is another indication of higher safety level [5].

Bahrain is a car-dependent country with a smaller land area and an alarming increase in number of vehicles. This corresponds to a high rate of crashes, fuel consumption and traffic violations. The total registered vehicles in 2017 were 686,622, out of which 42,886 were newly registered. 75,998 new driving licenses were issued in addition to 5198 learning driving licenses [6].

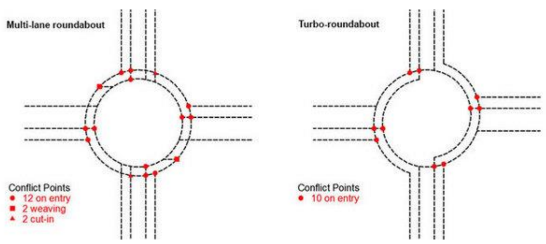


Figure 1: Difference in Conflict points [7]

It is evident from the above discussion that an efficient roundabout design would be highly beneficial to mitigate the negative externalities of traffic systems. Moreover, countries like Bahrain are in dire need of such solutions. In light of these facts, the aim of this research is to evaluate the impacts of innovative design approaches on sustainability of traffic system by implementing turbo roundabouts. This is achieved with the accomplishment of the following objectives:

- Implementing turbo roundabouts on intersection(s) that have a high number of accidents or low capacities
- Comparing the effects of turbo roundabouts in these areas with the current roundabouts.
- Evaluating the results at different locations to check the robustness of the design solution.

The proceeding arrangement of the paper is as follows. The second section of the paper represents the theoretical part of turbo roundabouts like the essential elements of turbo roundabouts, their types, and some theoretical case studies in certain countries around the world. These studies give a complete image about the real benefits and functions of turbo roundabouts. The third section is the design the roundabouts that experience high flows and number of accidents. After the design, traffic simulation on the selected roundabouts is implemented by PTV VISSIM and the results data are analyzed and discussed. Finally, the impacts of turbo roundabouts in Bahrain, over the current roundabouts are summarized in the last section and pertinent recommendations have been made.

2 Literature Review

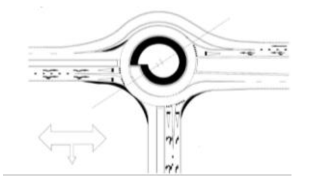
This section talks about types of turbo roundabouts, which depend on the current traffic demands. The advantages of turbo roundabouts and the special features as a new concept to be implemented are described. This chapter also describes case studies that have been done for normal multi-lane roundabouts. The case studies deal with calculations to determine the capacities. After studying the capacities of the current roundabouts, they were converted into turbo roundabouts and benefits of turbo roundabouts in terms of capacities were identified, that would directly affect the delay time, LOS.

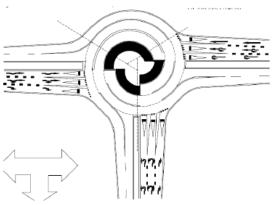
2.1 Types of Turbo Roundabout

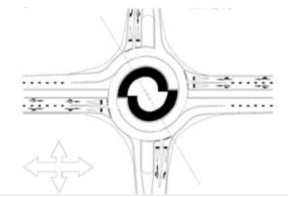
All the available types of turbo roundabouts are shown in figure 2 (a-g). Selecting the correct type of turbo roundabout is based on number of entries as well as the traffic demand [9], as per table 1.

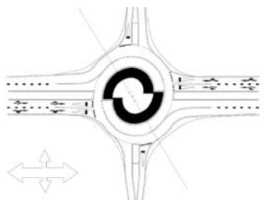
Table 1: Appropriate information for selection [9]

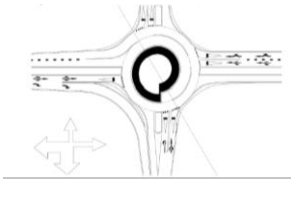
Name of roundabout	Number of legs	Number of legs that experience normal flow	Number of legs that experience high flow	Number of legs that experience low flow
Knee	3	-	2	1
	4	-	2	2
Star	3		3	-
Spiral	4	2	-	2
	4	4	-	-
Basic	4	When the traffic demand is distributed equally throughout all legs		
Rotor	4	-	4	-

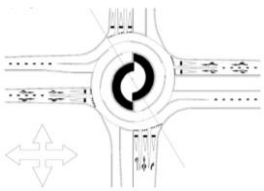

a) Knee roundabout, three entries

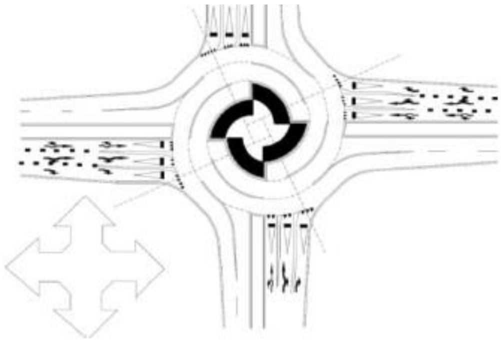

b) Star roundabout, three entries


c) Basic roundabout, four entries


d) Oval roundabout, four entries


e) Knee roundabout, four entries


f) Spiral roundabout, four entries


g) Rotor roundabout, four roundabout
Figure 2: Types of Turbo Roundabouts [9]

2.2 Design Features

Every turbo roundabout contains the following specifications [10]:

1- An additional lane opposite of one or more entry.
2- Spiral smooth alignments are used in the roundabout.
3- Vehicles entering should yield to traffic in no more than two circulatory lanes.
4- Raised lane dividers are used to prevent lane changing, hence increasing the safety level.
5- Each segment of the roundabout contains additional lane to provide choices for the driver (exit or continue rounding).
6- Not less than two legs are two lanes.
7- Diameter remains small.
8- Approach legs are 90 degrees to the roundabout.
9- Roundabout shields cut off view of horizon.
10- Roundabouts are designed with truck aprons to be used by large vehicles

The turbo roundabout is a better alternative because of the following three benefits. A) Safety level is increased as a reason for the reduction of side-by-side collisions as well as the collision speed because drivers are forced to slow their speed since vehicles are deflected at small radius with the presence of raised lane dividers. As a result, drivers speed through the turbo roundabout is close to the speed at single-lane roundabout. B) Number of conflict points are reduced because of the elimination of weaving and cut in conflict points. C) Capacity is increased because of the smooth spiral markings that allow the traffic to be distributed over the different lanes. The inner circulatory lanes are used properly, which is another evidence for a high capacity [11].

2.3 Case Study in the City of Cosenza (South Italy)

Gallellia et al. [12] conducted a study in South Italy aiming to show the advantages of turbo roundabout as an alternative to normal multi-lane roundabout. The main approaching roads, in Northern and Southern directions, present two entry lanes. The secondary ones, in Western and Eastern directions, show single-entry lanes. The inscribed circle diameter is around 37.90 m. Roundabout performance was recorded and captured in the field by 3 cameras on several days to get information and data for peak hours of total 9 hours of investigation. It was found in this study that the existing roundabout is classified by unbalanced flow patterns. To be exact, about 80% of the traffic stream comes from approach A, which is the busiest, and goes through the roundabout towards approach C. This dominant flow, especially during the peak hours, produces high levels of queuing, unequal lane-use and a significant reduction of the entry capacity.

The geometric design of turbo roundabout was defined by the turbo block. Each block is defined by all the necessary radii, which must be rotated in a certain way, to obtain the different traffic lanes. The size of radii of a standard turbo-roundabout and the width of the circulatory lane were selected to guarantee a driving speed through the roundabout smaller than 40 km/h [12]. In this study, calculating the capacity was based on Bovy equation as per equations 1 and 2 [13].

$$C = \frac{1}{\lambda}\left(1500 - \frac{8}{9}Qg\right) \quad (1)$$
$$Qg = Qc * \beta + Qu * \alpha \quad (2)$$

Where
C = Entry capacity (veic/h)
Qc = circulating traffic flow (veic/h)
Qu= existing traffic flow (veic/h)
Qg= disturbance traffic flow (veic/h)
α= factor of the influence of the exit traffic flow
β= factor related to the number of lanes in the circulatory carriageway
λ= factor related to the number of entry lanes

Fortuijn modified the Bovy equation based on turbo roundabout situation by doing some field experiments in Nederlands and the following equations (3 and 4) were obtained [14].

$$C_{E,1}=C_0-b_m.Q_{R,m}-b_M.Q_{R,M}-a_1.Q_U \quad (3)$$
$$C_{E,2}=C_0-b_2.Q_{R,Z}-a_2.Q_{U,N} \quad (4)$$

Where
C_0= 1550
index 1 is for the left traffic at the entry
index 2 is for the right traffic at the entry
Q_R is the traffic flow in the circulatory lanes
index m for the smaller of the two circulatory flows
index M is for the bigger of the two circulatory flows
index N is the flow for the inner lane of the circulatory carriageway
index Z is for the outer lane of the circulatory carriageway
β (factor related to the number of lanes in the circulatory carriageway) is divided into b_1 for the left lane at the entry and b_2 for the right traffic lane at the entry.
α (factor of the influence of the exit traffic flow) which is divided into a_1 and a_2.

It was found that the roundabout's capacity increased after the conversion. It was shown that the biggest difference in capacity is in approach B which is +83.33% and the least difference is about +15% for approach D while the other approaches serve about 40% increase in capacity [8].

2.4 Case Study in Ghana

A study by Kwakwa and Adams [15] was found which focused on a single lane roundabout that has four legs, two of them are dual carriageway roads (East and West legs). These two lanes merged into one lane about 80m before the roundabout. The other two legs are single carriageway roads with low to medium traffic demand. The dual carriageways had very high traffic demand and the traffic queues blocked other intersections located 200-300m downstream of the yield line for both approaches on the dual carriageway [16].

Traffic demand at the intersection was obtained from counts derived from simulation video recordings and it was done for two hours 7:00-9:00 pm. The roundabout was converted into an egg turbo roundabout and conventional two lanes roundabout in order to increase the capacity and hence reduce congestion in the intersection. The roundabout conversion was done using VISSIM software for the purpose of calculating some parameters like queue length, delay and capacity [15].

Based on the VISSIM simulation results, the capacity of the turbo roundabout is 4747 pcu/h while the capacity of the single lane roundabout is about 2990 pcu/h. It is very obvious that the roundabout capacity increased due to this change.

On the other hand, converting the roundabout into multi-lane roundabout resulted in an increase of the capacity to 3889 pcu/h. As this study concluded, turbo roundabout capacity is about 19% higher than conventional multi-lane roundabout. In addition, a huge decrement in delay and queue length of the westbound approach was noticed after the turbo roundabout analysis. The geometry of the turbo roundabout and the conventional multi-lane roundabout showed that the area (spatial requirements) of turbo roundabout is really similar to the conventional multi-lane roundabout. As a result, it can be concluded that the turbo roundabout can be a perfect solution as it results in significant improvement of capacity and the general performance of the studied intersection [15].

3 Methodology

Collection of data is required in order to consider the situations for the roundabouts and select the best types of turbo roundabouts based on volume distribution. As mentioned in the previous section, there are different types of turbo roundabouts and every one of them has its own volume demand. Riffa roundabout, Country roundabout and Alba roundabout (before conversion) were studied. They were converted to turbo roundabouts after the collection of volume data from Ministry of Works. TORUS 5.1 software was used for the design. It takes into account several parameters, such as the design vehicle swept path and line of sight and comes up with a suitable turbo roundabout layout. In addition, analysis is done using PTV VISSIM software. By using this software, we can spot the differences between the current roundabouts and the turbo roundabouts conversions in terms of delays, LOS and capacities.

3.1 PTV VISSIM Software

Following steps were followed to do the analysis of roundabout in PTV VISSIM.

1- Defining vehicle compositions for the intersection (heavy vehicles, passenger cars etc.)
2- Adding Background image and scaling it to the software.
3- Drawing links of the intersection including circular links which represent the roundabout.
4- Drawing connectors that connect the links with the circular link.
5- Adding vehicle inputs to each entry link with collected volume data.
6- Adding routing decisions with their relative flows.
7- Adding priority by adjusting the conflict areas.
8- Adding reduced speed areas.
9- Adding node and getting the evaluation results after doing the simulation.

3.2 TORUS 5.1 Software

Following steps were followed to design a Turbo roundabout in TORUS:

1- Adding a background image and scaling it to the software.
2- Adding legs of the intersection.
3- Using roundabout wizard and specifying roundabout legs.
4- Selecting the suitable type of turbo roundabout based on volume distribution (as discussed in previous section).
5- Designing suitable lane widths, number of entry and exit lanes, inner radius of central island, etc…
6- Checking the swept path of our design vehicle.
7- Checking the sight lines of vehicles entering.

3.3 Capacity of Multi-Lane Roundabout Entries

Capacity calculations of multi-lane roundabouts are based on the equations (5) – (6) [16].

$$C_{e,R,pce} = 1{,}130\, e^{(-0.7*10^{-3})*V_{c,pce}} \quad (5)$$

$$C_{e,L,pce} = 1{,}130\, e^{(-0.75*10^{-3})*V_{c,pce}} \quad (6)$$

Where

$C_{e,R,pce}$= Capacity of the right lane entry adjusted for heavy vehicles (pcu/h).

$C_{e,L,pce}$= Capacity of the left lane entry adjusted for heavy vehicles (pcu/h).

$v_{c,pce}$= Conflicting flow rate (for all entries).

3.4 Capacity of Turbo Roundabout Entries

Capacity Calculations of converted turbo roundabouts are based on Tanner's model, which is also called "Gap Acceptance Model" [17].

$$C_E = Q_R * \frac{(1-q_R*t_M)*e^{-q_R(t_C-t_M)}}{1-e^{-q_R*t_F}} \quad (7)$$

Where

C_E= entry capacity (pcu/h).

Q_R, q_R = circulating traffic volume or conflicting flow rate (pcu/h , pcu/s respectively).

t_C = critical gap (s/pcu).

t_M = minimum headway (s/pcu).

t_F = Follow-on-time (s/pcu).

Headway: The time interval between the arrivals of two successive.

Follow-on-time: Median value of headway data.

Critical gap: The minimum value of the gap in a line of traffic that a driver will accept as large enough to enter [17].

3.5 Data Collection

Volume data was taken from Ministry of Works. This data is required for capacity calculations as can be noticed in the above equations. Headway data was taken from the field in order to calculate the capacity of turbo roundabout. This was done by taking 10 samples at each roundabout.

Table 2: Headway Data

S. No.	Headway (sec)		
	Riffa Roundabout	Country Roundabout	Alba Roundabout
1	1.6	2.6	1.1
2	3.6	3.5	6.9
3	1.0	4.2	10.5
4	7.5	3.3	12.3
5	1.6	1.6	1.2
6	8.4	3.2	4.2
7	5.3	4.1	5.6
8	4.4	2.9	9.8
9	4.9	6.3	4.4
10	5.1	5.5	7.9

4 Results and Comparisons

This section describes the results concluded from the PTV VISSIM. The main aim is to record the differences in terms of delay and LOS. A comparison can also be made in terms of the number of vehicles entered into the roundabouts during the ten-minute period. Finally, the results of the capacity equations discussed in the previous section are summarized for the turbo and the current roundabouts. Capacity calculations are based on equations 5, 6 and 7 discussed in the previous section. The average critical gap time is approximately two seconds. Minimum and the median headways values are taken from table 2. As defined in the equation, median headway is the follow-on-time.

4.1 Country Roundabout

Country roundabout is a very congested roundabout in Bahrain. This roundabout was studied to show the differences in terms of delay, LOS and capacity which are shown in Table 3. In addition, conflict points as potential accident reductions were also drawn as shown in Figure 4.

Table 3: Country roundabout Results

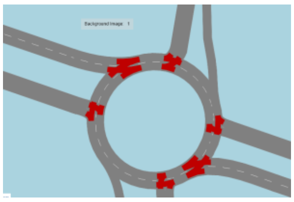
Segment	Normal Roundabout		Turbo Roundabout	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS
east right	98.1	F	49.4	E
east left	10.1	A	43.7	E
west right	45.8	E	13.6	B
west left	4.6	A	12.0	B
south right	130.7	F	5.6	A
South left	21.9	C	47.6	E
north right	188.0	F	16.8	C
north left	21.9	C	42.9	E

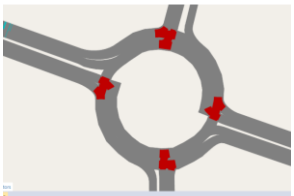
As shown in table 3 for normal roundabout, the delay is too high as it reached maximum in the south approach (188 s/veh) (LOS=F). However, it is minimum in the west approach (4.6s/veh)(LOS=A). As shown in table 3 for turbo roundabout, the maximum delay reached 49.4 s/veh (LOS=E). However, the minimum reached 5.7 s/veh (LOS=A) in the south approach.

From the simulation of PTV VISSIM software, the average delay in the current roundabout case is considered for the whole intersection as E with a delay of 41 s/veh. In the turbo roundabout case, it is considered as D with an average delay of 29.82 s/veh. Also, capacity increment in turbo roundabout is noticeable for every approach, as shown in table 4 below. The maximum difference reached to 35.84% increase in capacity for turbo roundabout in the west approach, while the minimum reached to 9.06% increase in capacity for turbo roundabout in the east approach.

Table 0: Country Roundabout Capacity differences

Approach	Turbo roundabout capacity (pcu/h)	Current roundabout (pcu/h)	Difference (%)
North	1302.831	939.53	27.88%
West	1944.159	1247.43	35.84%
South	1434.159	1137.45	20.69%
East	1929.943	1755.09	9.06%


a) Normal Roundabout


b) Turbo Roundabout

As shown in figure 4, there are 14 conflict points distributed throughout the normal roundabout and there are 10 conflict points distributed throughout the turbo roundabout.

4.2 Riffa Roundabout

Riffa roundabout is a very congested roundabout in Bahrain and has a number of accidents in its history. This roundabout was studied to show the differences in terms of delay, LOS and capacity are shown in Tables 5 and 6. In addition, conflict points as potential accidents reductions are shown in Figure 5.

Table 5: Riffa roundabout Results

Approach	Normal Roundabout		Turbo Roundabout	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS
East (right lane)	57.3	F	5.1	A
East (middle lane)	65.9	F	61.8	F
East (left lane)	9.4	A	56.3	F
West (right lane)	22.4	C	6.8	A
West (middle lane)	49.2	E	20.0	C
West (left lane)	7.8	A	15.2	C
North (right lane)	40.6	E	40.2	E
North (middle lane)	174.4	F	61.8	F
North (left lane)	8.1	A	50.1	F
South (right lane)	10.9	B	0	A
South (middle lane)	52.0	F	56.9	F
South (left lane)	9.2	A	89.3	F

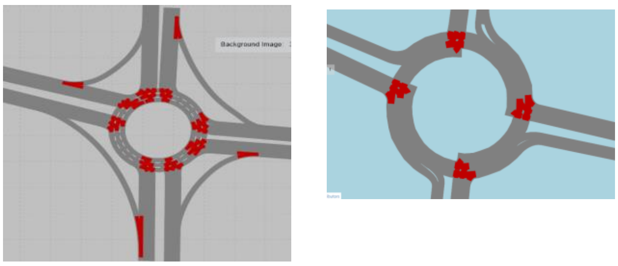
Generally, as shown in table 5, the delay is too high as it reached maximum in the north approach (middle lane) (174.4 s/veh) (LOS=F) for normal roundabout. However, it is minimum in the west approach (left lane) (7.8/veh) (LOS=A). As for turbo roundabout, the delay is high as it reached maximum in the south approach (left lane) (89.4 s/veh) (LOS=F). However, it is minimum in the south approach (right lane) (0 s/veh) (LOS=A).

From the simulation of PTV VISSIM software, the average delay in the current roundabout case is considered for the whole intersection as E with a delay of 48.61 s/veh. In the turbo roundabout case, it is considered as E with an average delay of 43.79 s/veh. Capacity differences are shown in table 6. The maximum difference reached to 7% increase in capacity for turbo roundabout in the west approach, while the minimum reached to 5% increase in capacity for normal roundabout in the east approach. However, the other approaches show the advantage of turbo roundabout in capacity.

Table 6: Riffa Roundabout capacity differences

Approach	Current roundabout capacity (pcu/h)	Turbo roundabout capacity (pcu/h)	Difference (%)
North	939.5286	1014.759	7%
West	1247.428	1304.769	4%
South	1137.445	1209.126	6%
East	1755.093	1667.765	-5%

As shown in the capacity comparison, there is not much difference between the two cases due to the design principles of turbo roundabout that removes the slip lanes and converts it to two-lane turbo roundabout. Moreover, turbo roundabouts have less capacity than the current one in the east approach. However, even with no slip lanes and the conversion to two-lane roundabout, the turbo roundabout has slightly better performance than the current one. There are more than 30 conflict points in the normal Riffa roundabout as shown in figure 5 and 20 conflict points in turbo Riffa roundabout.



a) Normal Roundabout b) Turbo Roundabou

4.3 Alba roundabout

Alba roundabout is a very congested roundabout in Bahrain and has a number of accidents in its history. This roundabout was studied to show the differences in terms of delay, LOS and capacity for which the comparison is shown in Tables 7 and 8. In addition, conflict points with potential accident reduction is shown Figure 6.

Table 7: Normal Alba Roundabout Results

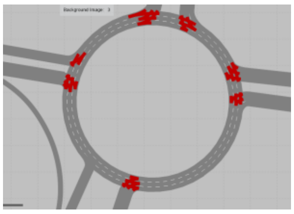
Direction	Normal Roundabout		Turbo Roundabout	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS
East (right)	164.7	F	3.6	A
East (middle)	150.4	F	74.0	F
East (left)	117.3	F	62.8	F
West(right)	111.6	F	5.0	A
West(middle)	93.8	F	95.5	F
West(left)	5.2	A	73.9	F
South(right)	234.1	F	40.8	E
South(middle)	78.8	F	42.4	E
South(left)	14.2	B	40.0	E
North(right)	106.9	F	8.8	A
North(middle)	105.9	F	147.3	F
North(left)	96.6	F	40.0	E

As shown in table 7 for normal roundabout, the delay is too high as it reached maximum in the south approach (right lane) (234.16 s/veh) (LOS=F). However, it is minimum in the west approach (left lane) (5 s/veh) (LOS=A). For turbo roundabout, the delay remained high as it reached maximum in the north approach (middle lane) (147.37 s/veh) (LOS=F). However, it is minimum in the west approach (right lane) (5.1 s/veh) (LOS=A).

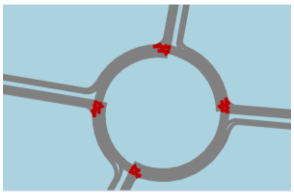
From the simulation of PTV VISSIM software, the average delay in the current roundabout case is considered for the whole intersection as F with a delay of 119.53 s/veh. In the turbo roundabout case, it is considered as F also with an average delay of 64 s/veh. Also, capacity difference is noticeable for every approach as shown in table 8 below. The maximum difference reached 32% increase in capacity for turbo roundabout in the north approach, while the minimum reached to 7.48% increase in capacity for turbo roundabout in the west approach. There are more than 30 conflict points shown in figure 6 of normal Alba roundabout, while 20 conflict points in turbo Alba roundabout.

Table 0: Alba roundabout capacity differences

Approach	Turbo Roundabout (pcu/h)	Turbo roundabout (pcu/h)	Difference (%)
North	934.6482	631.7732	32%
West	443.975	400.448	7.48%
South	585.9823	460.8518	21.4%
East	2026.739	1410.809	30.4%



a) Normal roundabout



b) Turbo roundabout

5 Conclusions and Recommendations

To conclude, the main objective of this research was to investigate the impacts of design of turbo roundabouts on the sustainability aspects of the transportation network, including congestion and safety. The results were compared with the normal roundabouts on the basis of different parameters (e.g. capacity, delay and LOS). The work began by choosing 3 roundabouts in Bahrain which have to be improved and changed to turbo roundabouts which are Country roundabout (in Country road), Riffa roundabout and Alba roundabout. The results in both Country roundabout and Alba roundabout were improved from the actual roundabouts. Capacity increased on Country roundabout by about 9.36% - 35.85 % for different directions and increased by about 7.48 % - 32% for different directions in Alba roundabout. The delay and LOS for the whole intersections have also improved in Country roundabout from 41 sec/vehicle and LOS E to 29.82 sec/vehicle and LOS D. Alba roundabout LOS for both normal roundabout and turbo roundabouts remained F LOS, but the delay decreased from 119.53 sec/vehicle to 64 sec/vehicle. Riffa roundabout capacity in the east approach has better results in the normal roundabout by 5%, but overall, the capacity of Riffa turbo roundabout has improved by (4 % - 7 % in other directions except east approach). However, turbo roundabout is a better solution in this case as it reduces the conflict points in Riffa roundabout with a slight improvement of turbo roundabout.

Based on the results of this study, it can be concluded that converting to turbo roundabouts could solve the problems in most cases before going to high-cost solutions (bridges or traffic lights). Turbo roundabouts can be an effective solution for roundabouts that have a high number of accidents. Local standards need to be updated to incorporate innovative design solutions.

Some of the limitations of this research are as follows. The research is based on the design of three roundabouts in Bahrain. In addition, the comparison is based on the capacity, delays and Level and Service (LOS) not for every parameter like vehicle travel time, queue lengths and saturation flow rates. Finally, due to the usage of the student PTV VISSIM student version, the simulations were only for a ten-minute period not for a full hour. Based on these limitations, the following is recommended. The simulations of the three roundabouts were based on ten-minute simulation. In order to improve the results and have a better image of the advantages of turbo roundabouts over normal roundabouts, simulations should be based on full hour. There are other parameters (e.g. vehicle travel time, queue length and saturation flow rate) that could be used in comparison between normal and turbo roundabout. Turbo roundabout has 5 types and 2 of them were used in this project, the other types could be used and compared with the results in this project.

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