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*Professional paper*

# THE INFLUENCE OF GEOMETRIC ELEMENTS ON THE SERVICE LEVEL AT ROUNDABOUTS

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**Abstract**

The service level is the quality of traffic conditions in the road network, which includes comfort, safety, freedom of maneuvering and so on. There are different service level depending on the conditions and circumstances of the roundabout construction. The purpose of this paper is to highlight the geometric elements as highly important parameters in the uninterrupted traffic flow in roundabouts, as well as the safety elements for an uninterrupted and efficient traffic flow.

*Keywords:* Service level, geometric elements, roundabouts, safety

## 1. Introduction

Crossroads are one of the most fundamental elements of road networks because they allow drivers to follow the planned trajectory by exercising their own turning choices.
There are different types of intersections, where we can mention intersections with light signaling and intersections without light signaling, level intersections (including roundabouts) and dislevel intersections.
In this paper are analyzed the service level and the geometrical elements of an important roundabout in the city of Tetovo.
Similar studies like this have been done for a roundabout in the city of Alexandria in Egypt, for a roundabout in Vadodara in India and for a roundabout in Italy.
Then are proposed some changes based on the detailed analysis of the roundabouts, which also include calculation of the capacity.
*Aim*
The aim of this study is to evaluate and to improve the performance of the roundabout that is near Pallma Mall (shopping center), which is a focal point since is where we enter and we exit the city.
The proposed changes aim to enhance safety, with a well designed roundabout, and also aim optimizing the traffic flow, that meansbetter functionality of the roundabout.
*Methodology*
Site visits were made to analyze traffic problems in the studied area. For this study, a counting plan was developed and the data was collected on a working day (Thursday), making the observation from the shopping center, to see all the traffic flows entering and leaving the roundabout, so the counting was done manually.

## 2. Roundabouts and geometric elements

Roundabouts represent road communities or road intersections, where vehicle traffic takes place in a circle around the central island. The safest of all types of intersections are roundabouts because their geometric design affects the driver's maneuvering behavior.

The geometrical elements of the circle give directions to the vehicles which approach or which go around the roundabout. Roundabouts are considered safe when their geometry forces vehicles with lower speeds to enter and circulate in it, while roundabouts with poor geometry are considered when the driver, moving through the circle, chooses the lane.
In this way, we understand that the design of a roundabout is the main process to have more traffic safety and a higher service level.

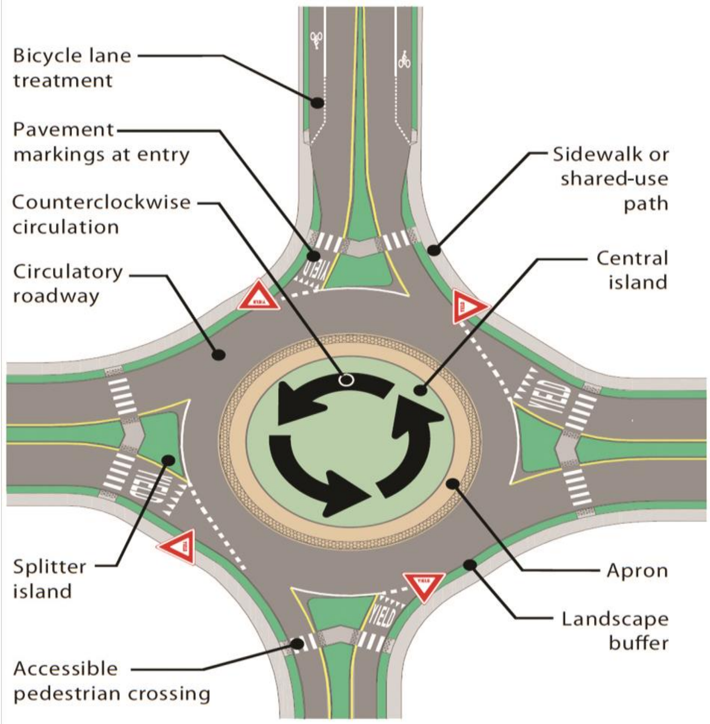



**Figure 1.** Geometrical elements of roundabouts

The geometric elements of the circle are:

- The central island – is the central part of the roundabout, where its height in the center must be at least 10 cm;
- Splitter islands - between entry and exit lane are some constructions which are called splitter islands;
- Circulatory roadway – is the road used by vehicles that move in a circular way and can be two or more lanes;
- Entry and exit lane – these lane are usually perpendicular to the circulatory roadway;
- Apron – helps heavy vehicles to pass the roundabout;
- Horizontal sign at the entrance – are the horizontal lines at the entrance of the roundabout;
- Bicycle lane;
- Pedestrian crossings;
- Sidewalk.

The basic elements of roundabout design are:

- Speed;
- Sight distance;
- Vehicle size.

**Table 1:** Roundabout geometric elements and their limiting and recommended values for the design of roundabouts

| Element | Symbol | Unit of measurement | Dimensions (limits) | Recommended dimensions |
|---|---|---|---|---|
| The outer radius | $R_v$ | m | 6,75 – 86,00 | 7,50 – 50,00 |
| Width of the circulatoryroadway | u | m | 4,50 – 25,00 | 5,40 – 16,20 |
| Width of the lane | v | m | 2,75 – 12,50 | 3,00 – 7,30 |
| Entry width | e | m | 3,60 – 16,50 | 4,00 – 15,00 |
| Stretch length | l’ | m | 12,00 – 100,00 | 30.00 – 50.00 |
| Sharpness of alignment | S | | 0 – 2,90 | 0 – 2,90 |
| Entry radius | $R_{ul}$ | m | 6,00 – 100,00 | 8,00 – 45,00 |
| Entry angle | Φ | ° | 0,0 – 77,00 | 10 – 60 |

Source: [1]

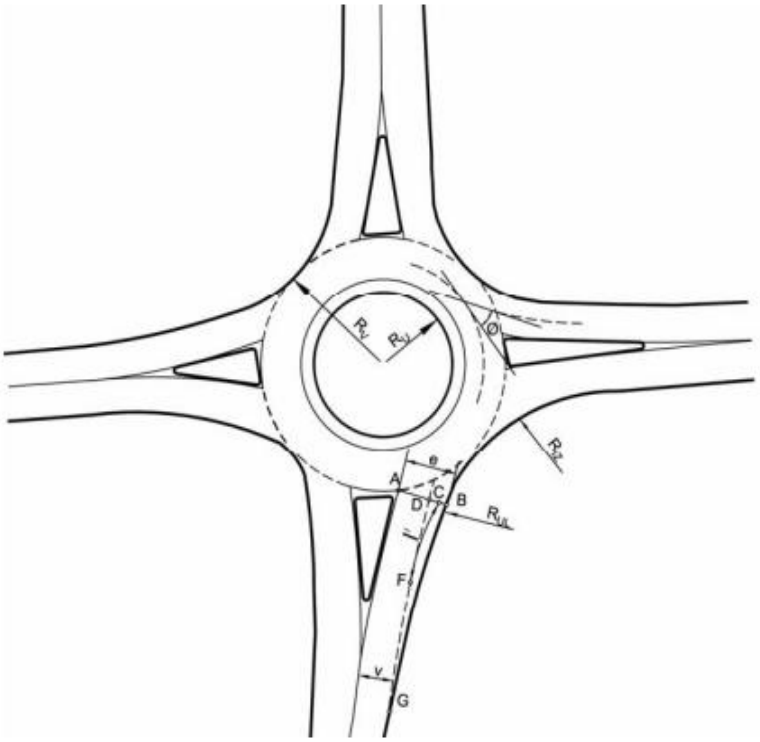



**Figure 2.** Roundabout geometric elements

In many different places such as Europe, the USA etc. big reductions in the number of accidents have been reported after the change of standard intersections into roundabouts.

Some reasons why roundabouts are safer:

- Lower speed of driving - because they have to give priority to passing vehicles that are in the roundabout;
- There is no rush from drivers – at intersections, as usual, there is a rush due to the red light of the traffic lights;
- Fewer serious accidents – because roundabouts have fewer points of conflict compared to intersections

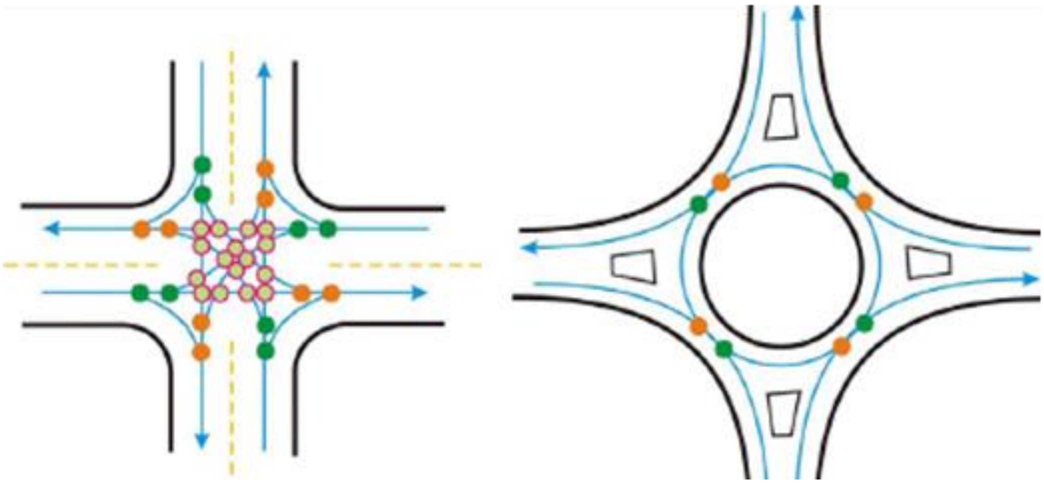


**Figure 3.** Conflicting points at classic intersections (32) and roundabouts (8)

Some of the advantages that roundabout offer compared to classic intersections are:

- Better aesthetics, which mean better appearance;
- Reduction of waiting time;
- Capacity increase (traffic flow);
- Efficiency;
- And most importantly better road safety.

## 3. Advantages and disadvantages of roundabouts

Roundabout have advantages compared to classic intersections, where these advantages are in different aspects, such as:

- in terms of safety - because roundabouts have a smaller number of conflicting points compared to intersections, that means at the same time a smaller number of accidents;
- in terms of the safety of pedestrians and cyclists – because low speeds at roundabouts increase the safety of cyclists, while splitter islands increase the safety of pedestrians;
- in terms of ecology - because the vehicles will consume less fuel, it also means that environmental pollution will be reduced, as well as the noise pollution will be reduced;
- in terms of expenses - because roundabouts, compared to intersections, have lower expenses for both design and maintenance of signals;
- in terms of costs – because roundabouts have better aesthetics, or look better aesthetically compared to classic intersections.

Besides advantages, roundabouts have some disadvantages, such as:

- in terms of safety - because in the beginning there is a possibility of accidents due to the lack of skills of the drivers in the roundabout, because they are used to it being a classic crossroads;
- in terms of the safety of pedestrians and cyclists - because, unlike classic intersections, at roundabouts the paths for pedestrians and cyclists are longer;
- in terms of capacity - because there is a possibility that the roundabout will have more traffic than planned (so there is a possibility that the intersection with a roundabout will have a larger traffic than the designed one), and in this case the ideal solution it would be a signalized crossroad.

The main criteria for placing roundabouts at crossroads are:

- On roads with high speeds;
- When there are a large percentage of left turns at the crossroads;

- When there are a large number of accidents at the crossroads, especially from vehicles coming from secondary roads;
- When there are more than four traffic lanes at the intersection;
- To reduce delays at the entrance of intersections, where these delays are usually caused when the STOP sign is placed at the intersection.

## 4. Service level

By comparing the delays, which are calculated as at intersections without traffic light, the service level of the roundabout branch can be determined.

**Table 2:** Service level for intersections without traffic light according to HCM

| Service level | Average delay for vehicles (s/vehicle) |
|---|---|
| A | ≤ 10 |
| B | 10 -15 |
| C | 15 - 25 |
| D | 25 - 35 |
| E | 35 - 50 |
| F | > 50 |

Source: [4]

## 5. Case study – the roundabout at the entrance to the city

Photo.1**.** The roundabout which has been analyzed

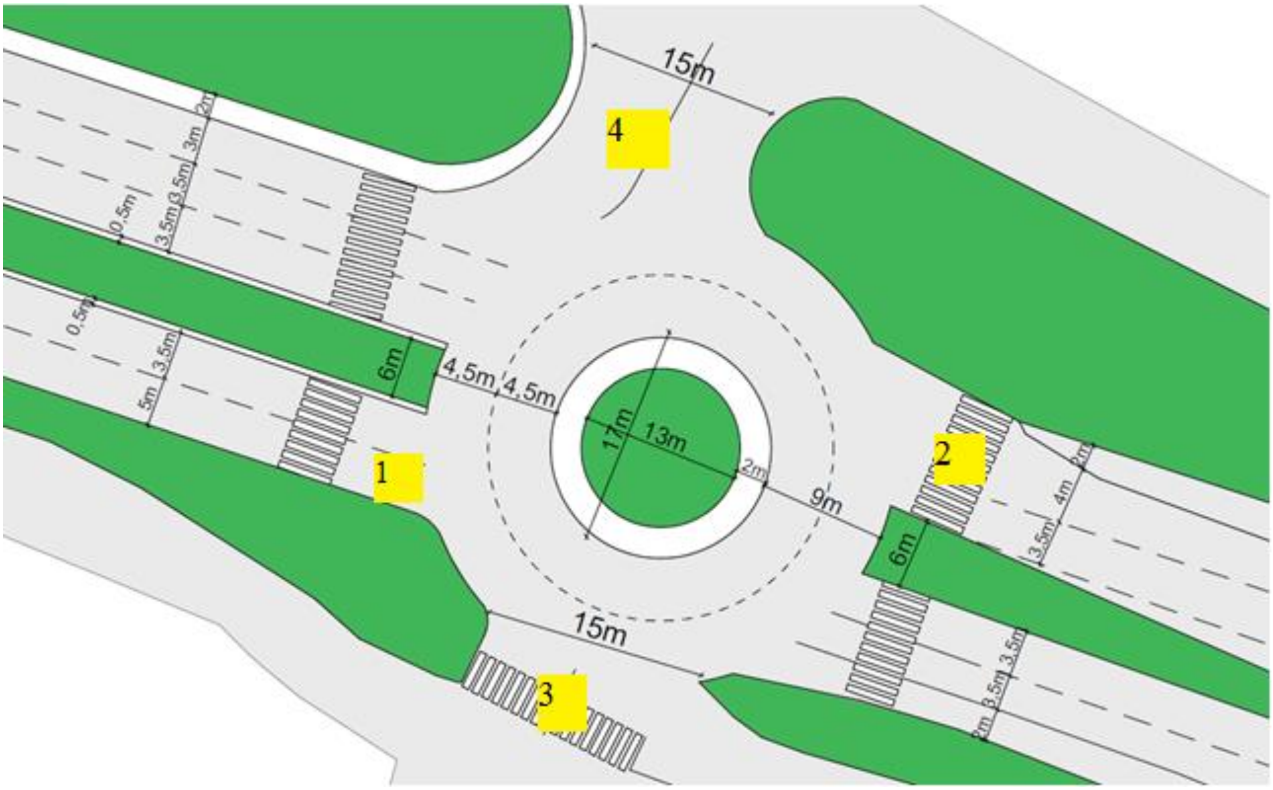
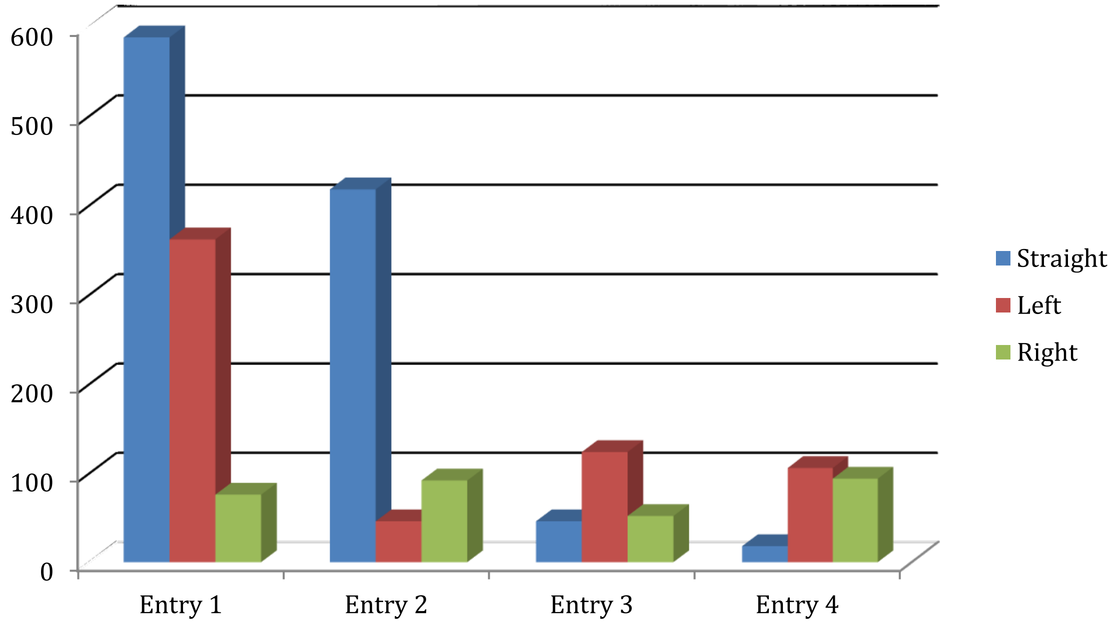



**Figure 4.** Roundabout dimensions – actual situation

The intersection with a roundabout is located near the Pallma Mall shopping center, while the collection of the data on the current state of the roundabout was done on a working day (Thursday).
The data is shown in the following table, where based on the count were obtained some data for traffic in the roundabout, from each direction separately.
The peak hour of this roundabout based on the data was found to be around 14:00 - 15:30.

**Table 3:** Traffic in the roundabout from each direction separately

| | Entry 1 | Entry 2 | Entry 3 | Entry 4 | **Total** |
|---|---|---|---|---|---|
| Straight | $q_1$=588 | $q_4$=418 | $q_7$=46 | $q_{10}$=18 | **2022** |
| Left | $q_2$=362 | $q_5$=46 | $q_8$=124 | $q_{11}$=106 | |
| Right | $q_3$=76 | $q_6$=92 | $q_9$=52 | $q_{12}$=94 | |
| **Total** | **1026** | **556** | **222** | **218** | |

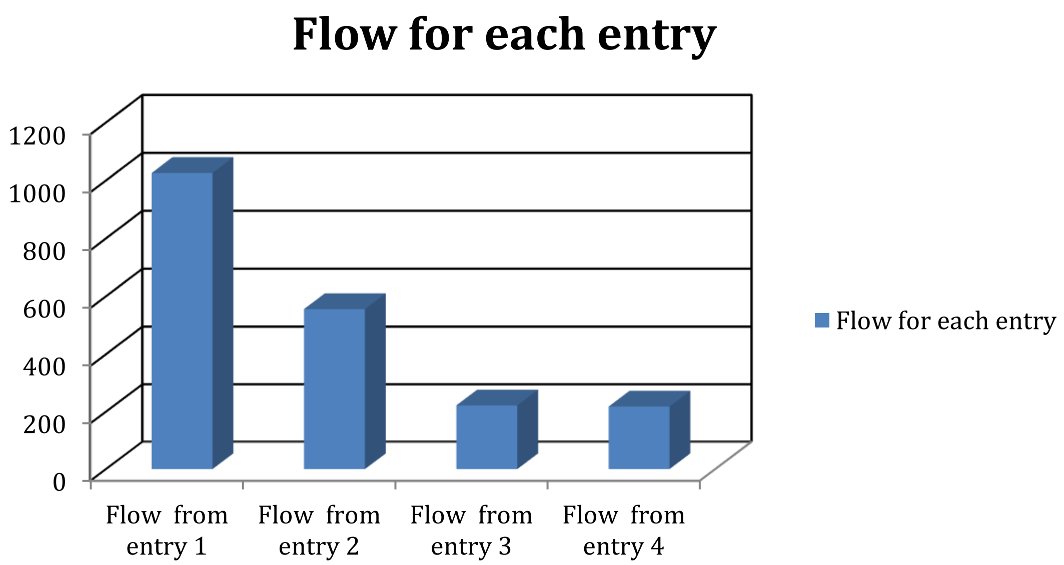



**Graph. 1.** Traffic flow in the roundabout from each direction separately

First is calculated the amount of flows for each entry.

**Table 4:** Sum of flows for each entry calculated for the case study

| Sum of flows for each entry ($q_h$) | $q_h$ |
|---|---|
| $q_{h,}I = q_1 + q_2 + q_3$ | $q_{h,}I = 362 + 588 + 76 = 1026$ |
| $q_{h,}II = q_4 + q_5 + q_6$ | $q_{h,}II = 46 + 418 + 92 = 556$ |
| $q_{h,}III = q_7 + q_8 + q_9$ | $q_{h,}III = 124 + 46 + 52 = 222$ |
| $q_{h,}IV = q_{10} + q_{11} + q_{12}$ | $q_{h,}IV = 106 + 18 + 94 =218$ |




**Graph. 2.** Flow from each entry

Then is calculate the conflicting flows.

**Table 5:** Conflicting flows calculated for the case study

| Conflicting *flows* ($q_c$) | $q_c$ |
|---|---|
| $q_{c,I} = q_4 + q_{10} + q_{11}$ | $q_{c,I} = 46 + 106 + 18 = 170$ |
| $q_{c,II} = q_1 + q_7 + q_8$ | $q_{c,II} = 362 + 124 + 46 = 532$ |
| $q_{c,III} = q_1 + q_2 + q_{10}$ | $q_{c,III} = 362 + 588 + 106 = 1056$ |
| $q_{c,IV} = q_4 + q_5 + q_7$ | $q_{c,IV} = 46 + 418 + 124 =588$ |

Then we calculate the roundabout capacity for each entry, where the following table will help us for this, which shows the values of the critical interval ($t_c$) and the queue scaling time ($t_f$), according to HCM recommendations.

**Table 6:** Critical interval (tc) and follow-up time (tf) according to HCM recommendations

| | Critical interval $t_c$ (s) | the queue scaling time $t_f$ (s) |
|---|---|---|
| Minimum value | 4,2 | 2,6 |
| Maximum value | 5,9 | 4,3 |
| Recommended values | 5,1 | 3,2 |

Source: [4]

Then we calculate the capacity for each entry with the Highway Capacity Manual-HCM-method:

$$c_{h,x} = \frac{q_{c,x} \times e^{-q_{c,x} \times t_c/3600}}{1-e^{-q_{c,x} \times t_f/3600}} \text{[Vehicle / h]}$$

Source: [4]

$$c_{h,I} = \frac{170 \times e^{-170 \times 5,1/3600}}{1 - e^{-170 \times 3,2/3600}} = 952,7 \approx 953 \text{ [Vehicle/h]}$$
$$c_{h,II} = \frac{532 \times e^{-532 \times 5,1/3600}}{1 - e^{-532 \times 3,2/3600}} = 664,4 \approx 664 \text{ [Vehicle/h]}$$
$$c_{h,III} = \frac{1056 \times e^{-1056 \times 5,1/3600}}{1 - e^{-1056 \times 3,2/3600}} = 388,5 \approx 389 \text{ [Vehicle/h]}$$
$$c_{h,IV} = \frac{588 \times e^{-588 \times 5,1/3600}}{1 - e^{-588 \times 3,2/3600}} = 627,9 \approx 628 \text{ [Vehicle/h]}$$

Then we calculate the saturation level:

$$X_{h,x} = \frac{q}{C}$$

Source: [4]

$$X_{h,I} = \frac{q}{C} = \frac{1026}{953} = 1,07$$
$$X_{h,II} = \frac{q}{C} = \frac{556}{9664} = 0,83$$
$$X_{h,III} = \frac{q}{C} = \frac{222}{389} = 0,57$$
$$X_{h,IV} = \frac{q}{C} = \frac{218}{628} = 0,34$$

And finally we calculate the service level according to time losses (sec / vehicle)

$$D_h = \frac{3600}{C} + 900 \times T \times \left[\frac{q}{C} - 1 + \sqrt{\left(\frac{q}{C} - 1\right)^2 + \frac{\left(\frac{3600}{C}\right) \times \frac{q}{C}}{450 \times T}}\right]$$

Source: [4]

$$D_{h,I} = \frac{3600}{953} + 900 \times 0{,}25 \times \left[\frac{1026}{953} - 1 + \sqrt{\left(\frac{1026}{953} - 1\right)^2 + \frac{\left(\frac{3600}{953}\right) \times \frac{1026}{953}}{450 \times 0{,}25}}\right]$$

$$= 67{,}1[s/\text{Vehicle}]$$

$$D_{h,II} = \frac{3600}{664} + 900 \times 0{,}25 \times \left[\frac{556}{664} - 1 + \sqrt{\left(\frac{556}{664} - 1\right)^2 + \frac{\left(\frac{3600}{664}\right) \times \frac{556}{664}}{450 \times 0{,}25}}\right]$$

$$= 26{,}98\ [s/\text{Vehicle}]$$

$$D_{h,III} = \frac{3600}{389} + 900 \times 0{,}25 \times \left[\frac{222}{389} - 1 + \sqrt{\left(\frac{222}{389} - 1\right)^2 + \frac{\left(\frac{3600}{389}\right) \times \frac{222}{389}}{450 \times 0{,}25}}\right]$$

$$= 20{,}85\ [s/\text{Vehicle}]$$

$$D_{h,IV} = \frac{3600}{628} + 900 \times 0{,}25 \times \left[\frac{218}{628} - 1 + \sqrt{\left(\frac{218}{628} - 1\right)^2 + \frac{\left(\frac{3600}{628}\right) \times \frac{218}{628}}{450 \times 0{,}25}}\right]$$

$$= 8{,}75\ [s/\text{Vehicle}]$$

From these time losses we mean that the service levels for entries 1, 2, 3, and 4 are:

- Entry 1 - service level F
- Entry 2 – service level D
- Entry 3 – service level C
- Entry 4 – service level A

From the research done, Figure 5 shows the proposed roundabout, with the improvements. It should be noted that the solution is not a long-term solution, but only as a preventive measure so that this low-cost roundabout can be more functional for a while until a better solution is made with deleveling.

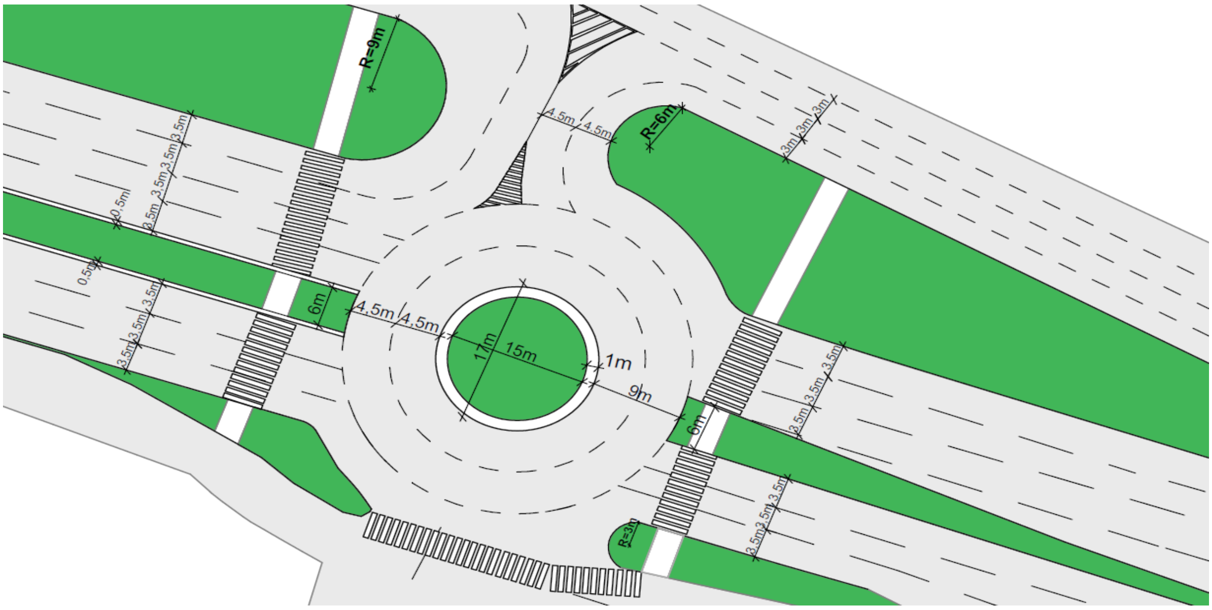



**Figure 5.** Dimensions of the proposed roundabout

## Conclusions

Roundabouts are effective infrastructural adjustments made at intersections to better control traffic. So roundabouts are a good solution for many intersections, including places where there are traffic delays and where there are a large number of accidents.

A well-designed roundabout affects not only the circulation or traffic flow, but also the environment, as pollution is reduced in that way.

The geometry of the roundabout can directly affect:

- the behavior of the driver;
- the safety on the roundabout;
- the loss of time while passing and with it also
- the reduction of environmental pollution.

In our analyzed case, it is necessary to intervene in this roundabout, since practically in some directions we have congestion due to inappropriate geometry and, as a consequence, loss of time (delay). In our analyzed case, it is necessary to intervene in:

- Near the two entry lanes, in addition to the vibration bars which are placed to slow down vehicles before entering the roundabout towards Tetova, there should be an additional lane arrangement, only for turning right towards the shopping center;
- In the direction of Tetova from the shopping center, there should be an adjustment of the lane only for turning right towards the city center;
- In the direction of Skopje, from the exit from the gas station, there should be an adjustment of the lane only for turning right towards the highway, and then it should be connected to the lane to the highway;
- The inner diameter of the roundabout must still be expanded by at least one meter;
- The roundabout apron should be resized to one meter;
- There is a need to change or adjust the dividing islands in their geometry, where there will be an improvement in pedestrian circulation and to better protect pedestrians from collisions with vehicles;
- Establishing even more pronounced and clearer signaling, whether horizontal or vertical signaling, will significantly improve the behavior of drivers and other traffic participants along the circulating trajectories.

From the analysis of the roundabout – on the spot – it can be concluded that the exit traffic flow at point 4 is in critical condition. With these changes, safety will increase in general, the service level will increase, and time loss will be reduced in this roundabout, which is a black point in the urban traffic of Tetova. This choice is not a long-term choice, but only as a preventive measure so that this roundabout can be more functional for a while until a better solution is made, which would be the leveling of this roundabout, which requires a completely more serious approach for undertaking operations around its construction.

## References


[1]. Ivan D., Goran K., Marko Š., Teorija prometnog toka, FPZ. Zagreb, 2014.

[2]. Avdiu, S., Projektimi i komunikacionit, FIM, Prishtinë, 2021.

[3]. Ibrahimi, N., & Bixhaku, M. (2009). Teoria e qarkullimit në komunikacion dhe kapaciteti i rrugëve. Prishtinë, 2009.

[4]. Ibrahimi, N., & Bixhaku, M. (2010). Kapaciteti dhe niveli i shërbimit i infrastrukturës rrugore. Prishtinë, 2010.

[5]. Sinani, F., Bombol, K., Prometni principi revizije sigurnosti cesta, Suvremeni promet, br. 1-2, 2008, 21-24, ISSN 0351-1898. (Rad sa: XV International Scientific Symposium: Transport systems 2008, 17-18 april 2008, Opatia, Croatia).

[6]. Sinani F., Lindov O., Opći principi revizije sigurnosti cesta, Naućno- stručni skup, Sigurnost i zaštita u saobraćaju, transportu i komunikacijama u Bosni i Hercegovini" 07.juni 2014, Zenica, BIH.

[7]. Lindov O., Sinani F., BSM - Black spot menagement as mothodology approach in increasing safety of road traffic, ICAS - International Conference of Applied Sciences, 19-20 May 2017, University of Tetova and Northern Illinois University from USA.

[8]. https://repository.ukim.mk/bitstream/20.500.12188/2421/1/1-s2.0-S1877705817319720-main.pdf

[9]. http://tis.unical.it/tritone_tesi/2016-2017_1.htm

[10]. https://www.academia.edu/35504505/Rrethrrotullimet_Kreisverkehr_Roundabouts_pdf

[11]. https://www.researchpublish.com/upload/book/ANALYZING%20CAPACITY%20AND%20LEVEL-7667.pdf

[12]. https://www.diva-portal.org/smash/get/diva2:1391059/FULLTEXT01.pdf