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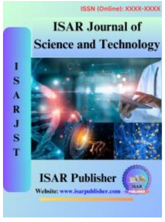

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Roundabout the basic element of modern road infrastructure and traffic

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Abstract: The use of roundabout intersections, regardless of the environment in which they are built (extra-urban, urban or rural), brings substantial benefits to road traffic. These benefits consist in improving the flow of road traffic by increasing the volume of vehicles passing through such an intersection, increasing the level of safety, decreasing the number and severity of undesirable events (road accidents). This scientific paper represents in an elegant and logical manner a research, but also a personal point of view of the authors on roundabout intersections as a basic element of modern road infrastructure and traffic. In this way, those interested can learn from the context of the work about certain interpretations, definitions, concepts, constructive elements, geometry, design concepts, dimensional values of elements, formulas for calculating capacity and the main elements influencing the capacity of vehicle throughput, classifications, characteristics, advantages, access rules, vehicle traffic rules and the stages of designing roundabout intersections. It also presents a case study of some roundabout intersections that have a special design (turboroundabout, tear-type roundabout and magic-type roundabout). Conclusions drawn on the basis of the research data are presented at the end of the paper.

Keywords: *intersection, roundabout, roundabout geometry, design, traffic volume, turboroundabout.*

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1. Introduction

Compared to other types of intersections, roundabouts operate with priority rules for traffic already in the roundabout and traffic leaving the roundabout. They eliminate much of the driver confusion associated with roundabouts but also eliminate driver waiting time for traffic-light intersections. Although they have the same dimensional characteristics and capacities as a classic intersection, roundabouts have a smaller diametric area than circular intersections. They separate road traffic entering and exiting the intersection by specially designed pedestrian areas designed to encourage drivers of road vehicles to reduce their speed. Therefore, roundabout intersections are much safer for pedestrians and drivers compared to ordinary roundabouts, as they require much lower traffic speeds of road vehicles within the roundabout at the entrance to the roundabout. These types of intersections are not specific to freeways or expressways (they are not built on these categories of roads), except at junctions connecting them to the other categories of roads. The main objective of a roundabout intersection is to reduce the waiting time in queues of vehicles at the entrance of the intersection while maintaining safety for all traffic participants. When designing and realizing a roundabout intersection, the way in which road vehicle traffic is distributed on its branches should always be taken into account, as it is known that this type of intersection become efficient when traffic flows can balance between the branches or become high traffic capacities for left-turn connections. We are also aware that intersections are not recommended in conjunction with traffic management systems (adjacent intersection signalization, green wave, etc). For this reason, at this time there is an increased interest in the construction and conversion of classic signalized or undirected intersections to roundabout intersections, considering their benefits.

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2. Literature review. Interpretations, definitions, concepts of roundabout intersections

The first circular forms of convergence for a road intersection appeared in the Middle Ages. The development of this type of intersection then continued during the Renaissance period, constituting the basic pillar of the road infrastructure of that period. The Frenchman Eugéne Hènard proposed roundabouts as an alternative for traffic control and safety at intersections, and in 1907 his concept of the "boulevard-roundabout" was materialized in "La Place de l'Etoile", known by its architectural emblem, the Arc de Triomphe (Figure 1), while in the USA, the first roundabout intersection was not documented until 1905 in New York and was named "Columbus Circle" (Figure 2). The roundabouts that appeared in the USA at the beginning of the 20th century did not have strict systems of rules at the basis of their construction. They did not yet have a defined set of rules for driving around roundabouts.

Fig. 1. *La Place de l'Etoile, Paris (Arch of Triumph), first roundabout, 1907 [1, p. 2].*

In 1909 such roundabouts also appeared in the UK in various forms. The official record of their existence dates back to 1929, when this limit was first mentioned. This trend continued until the middle of the 20th century. For the first time in England, in 1963, it was made the rule that vehicles entering a roundabout must give way to vehicles already in the roundabout [1, p. 3].

A further stage in the evolution of this type of junction in the literature dates back to 1975 in the United Kingdom, when the first revisions were made to the design and construction rules for junctions.

In 1984 new design standards for roundabouts were established, regulating the vital characteristics of modern roundabouts: priority for vehicles in the roundabout, diverting/directing the traffic flow at the entrance to the intersection by constructing level islands, and the reduced speed achieved by the orientation of these islands [1, p. 3].

In the mid 1980s, the French took over the modern roundabouts, building more than 17,000 modern roundabouts between 1983 and 2000 (approx. 1,000 roundabouts/year).

In the US the first modern roundabout intersection appears in 1990 in a suburb of Las Vegas, once such an intersection is built at a highway interchange in Vail, Colorado. In 2009 the US had 2,300 modern roundabouts [1, p. 4].

Fig. 2. Columbus Circle, New York USA , first roundabout, 1905 [1, p. 2]

The first miniroundabout appeared in 1970 in England. The effect of constructing such a one-way is to reduce speeds on the roads concerned and so, as well as making traffic safer, it allows drivers to be more aware of pedestrians and cyclists. As traffic is low and calm, there is no need to build traffic islands. Care must be taken to ensure that the gauges are sufficient [1, p. 4]. Figures 2 and 3 show some models of the miniroundabout.

The definition of roundabout intersections in the literature and online (specialized websites) has over the years acquired different interpretations, definitions and concepts. What has inspired the authors of these definitions are their characteristics, role, shape, vehicle speed, direction of movement, construction elements, vehicle and pedestrian safety, road traffic flow, traffic rules and other elements that define them.

We present these interpretations, definitions and concepts of roundabout intersections as follows:

- A roundabout is one of several types of circular intersections or junctions where traffic is slowed down and enters a one-way detour around a central island [2];
- A roundabout is a type of intersection where one-way traffic flows around a central island [3];
- A roundabout is a type of circular intersection where traffic is slowed and directed in one direction around a central island. These junctions are often referred to as *"modern roundabouts"* to emphasize the differences from the old types of roundabouts, which had distinct rules and characteristics [4];
- The roundabout or circular intersection is an efficient solution that leads to traffic flow, more advantageous than traffic lights. Not all intersections can be designed in this way, as they need a wider space [5];
- The roundabout is an essential part of the road infrastructure and, in order to maintain the safety and smooth flow of traffic, it is crucial to understand the traffic rules associated with it [6];
- The role of a roundabout is to smooth traffic flow at an intersection and prevent traffic jams [7];
- Roundabouts are intersections formed by a one-way circular path around a central island. Vehicles using the ring road have priority over vehicles wishing to enter the intersection. This turns the classic junction into a sequence of T-junctions [8, p. 1];

Fig. 3. Models of miniroudabouts [1, p. 5].

- Roundabouts are signalized intersections, where vehicles driving through the intersection have priority over vehicles entering the intersection [9];
- A roundabout is one of several types of circular intersections or junctions where vehicular traffic is slowed down and enters a one-way detour around a central island [10];
- The turboroundabout is the *"big brother of the roundabout"*. The concept was first introduced in 1996 by Dutchman Lambertus Fortuijn [11];
- Modern roundabouts are circular intersections that have brought considerable improvements in traffic safety, due to the new traffic rules applied and the different construction of their elements [1, pp. 2-3];
- Miniroundabouts are modern, much smaller roundabouts adopted in residential areas, where space permits, as an alternative to unpaved intersections, with the aim of ordering and calming traffic [1, p. 4].

3. Construction elements, geometry and design concepts of a roundabout intersection

The construction elements, geometry and pre-design concepts of a roundabout intersection are (Figure 4a and b):

- ***Central island***, represented by a raised area in the central area of the roundabout intersection. This central island is the traffic island. Smaller central islands are preferred with the maintenance of a larger safety zone, which is uncomfortable for cars, but which allows easy driving at the roundabout for heavy and long vehicles. It has been found that the most complicated and serious accidents occur when vehicles lose control by entering the roundabout and hitting the center island, and to prevent and reduce these accidents the island must be free of constructional obstacles (pillars, or sloping pavement). If the roundabout has a two-lane entrance, the location and diameter of the central island shall be chosen in such a way that it does not present an imminent danger to vehicles on the entrance lane near the median island;
- ***Separation island***, represented by a raised or painted area at the access to the roundabout. It is used to separate the entry lane(s) from the exit lane(s) in order to divert and slow down oncoming traffic, but also as a refuge area for pedestrians crossing the road in two stages;
- ***Circular tape***, represented by the circular road on which road vehicles travel. In Romania and the countries that have regulated right-hand traffic, the direction of entry and traffic is clockwise around the central island. In countries where traffic is clockwise (trigonometric), entry and movement in the direction of traffic is on the left-hand side, around the central island. Large roundabout intersections have several lanes on which traffic can travel;
- ***Inner belt***. If required at roundabout intersections with small diameter roundabouts, a threshold shall be provided and constructed adjacent to the center island over which the wheels of vehicles with large turning radii can access (pass);
- ***Priority yield line***, repeated by a transverse marker placed at the entrance of the roundabout lane of the roundabout intersection. Before entering the roundabout, motor vehicles must stop and give way to all vehicles coming from the left, without overtaking;
- ***Area with safety vegetation***, represented the areas separating vehicular and pedestrian traffic. They encourage vulnerable people in road traffic to cross only at designated crossing places;
- ***Diameter of the inscribed circle***, represented by the principal dimension used to determine the size of the roundabout. It is measured between the outer edges of the intersection;
- ***Circular belt width***, defines the width of the roadway for vehicular traffic around the center island. It is measured as the width between the outer edge of the roadway and the center island, not including the width of the inner belt adjacent to the center island. One-way roundabouts are the safest. In their design and construction, roundabout lanes should be of adequate width to allow turning of agabaritic vehicles, but not to discourage drivers of small vehicles from driving parallel to them. In the case of roundabout intersections with two or more lanes, concordant signalization of the presignal zone at the entrance to the roundabout is required to avoid lane-changing maneuvers when driving through the ring lane;

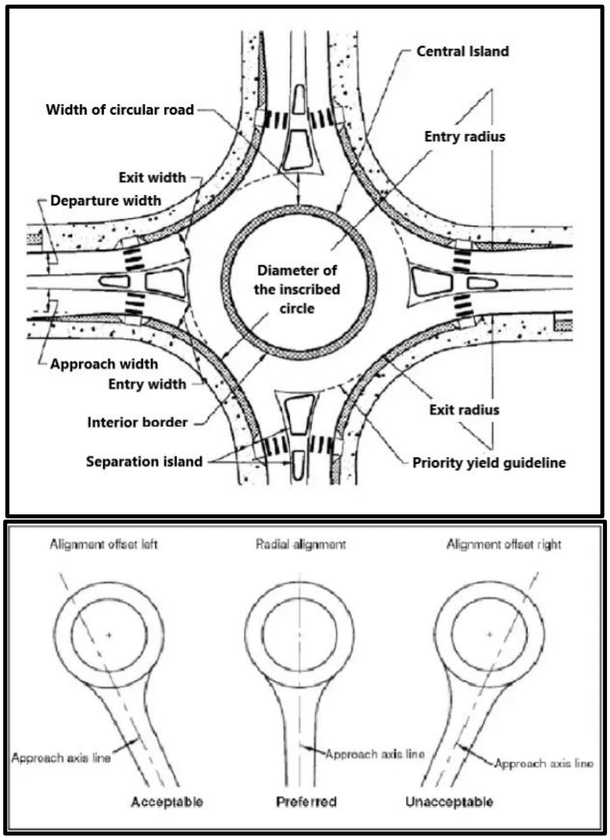

Fig. 4 a). Basic construction elements of a roundabout intersection; b) Aligning the axes of a roundabout intersection [8, p. 3].

- ***Width of the entry lane into the intersection***, is the width of the roadway used by the traffic flow entering the roundabout. It does not normally exceed half the total width of the carriageway;
- ***Exit lane width from the intersection***, is the width of the roadway used by the traffic flow exiting the roundabout. As a rule it is not more than half the total width of the roadway;

➢ ***Entry lane width***, is the width of the area where the entrance lane intersects the circular lane. It is measured on the perpendicular line drawn from the point of intersection of the left edge of the entrance lane with the circle inscribed on the right edge of the lane. Its cut and the number of lanes at the entrance greatly influence the ability to pass through the intersection, and the deviation is the deciding factor in road safety. Where it is not possible to design roundabout intersections with multiple lanes per direction at the entrance, only a 15-25 m length of the roundabout can be created. It has been observed that the number of road events at the entrance is high and is directly influenced by the number of entrance lanes, but the severity is low, providing adequate visibility and appropriate diversion will reduce the number of motor vehicle accidents;

➢ ***Output width***, is the width of the area where the exit lane intersects the circular lane. It is measured on the perpendicular line drawn from the left-hand edge of the exit lane to the point of intersection of the right-hand edge of the lane and the inscribed circle;

➢ ***Entry radius*** (***R_{in}***), The minimum turning radius on the outside of the entry lane. It can influence the capacity of vehicles passing through the intersection. If it is less than 15 m the capacity of the intersection decreases significantly. If it is greater than 25 m it has little positive influence on the capacity of vehicles passing through the intersection. It is recommended that this connection should be correlated with that of the exit lane to ensure a natural and comfortable flow of the turning direction that vehicles make by turning right, but also to avoid the layout of the outside edges in a *"camel hump"* against the curve mode;

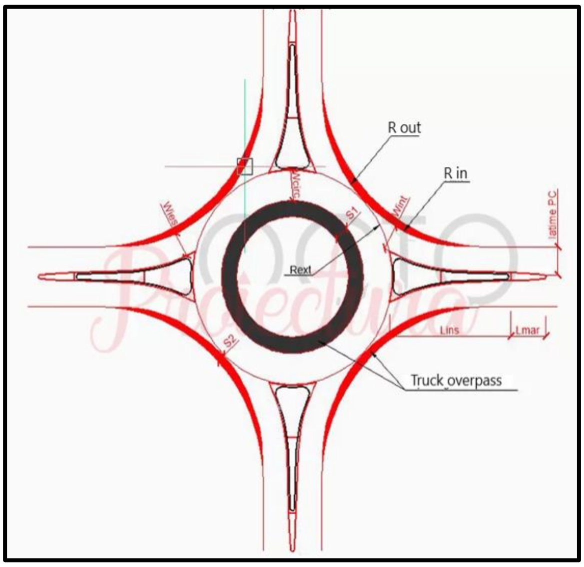

Fig. 5. Other construction elements to be taken into account when designing a roundabout intersection [2].

➢ ***Output radius*** (***R_{out}***), epresented by the minimum turning radius on the outside of the exit lane.

In Figure 4 we have presented the construction elements, geometry and pre-design concepts of a roundabout intersection, and in Figure 5 we present other construction elements, geometry and pre-design concepts that road designers need to take into account when designing a roundabout intersection, as follows:

➢ ***Gyration radius (turning radius), (***R_{ext}***)*** is the minimum radius necessary to provide the intersection with the road vehicle capacity for which it was designed and constructed. If it has a large value, the speed of traffic on the ring road increases but safety decreases. If the surface area of the intersection is small, designers may consider reducing the radius of the central island, but in order not to increase the width of the ring road too much, the safety zone around the ring road should be adequately measured;

➢ ***Deflection radius*** is one of the most important factors influencing road safety through the intersection because it can be used to determine the speed through the roundabout. It can be seen in this case that the branch axes do not pass through the center of the island. They are shifted smoothly to the left in order to obtain the expected deflection. Offsetting the axis is the most convenient method by which to achieve that deflection (deflection) because in this way the size of the roundabout intersection can also be reduced and the exit path from the roundabout can be clarified;

➢ ***The gradients*** on which roundabout intersections are located also influence vehicle safety. For this reason, both in design and construction, it should be taken into account that gradients higher than 5-6% together with the ring road overhang create some stability problems for trucks when traveling through the roundabout because they reduce their stability. Placing them in a vertical concave junction is preferable as it gives a perfect overall view of the junction, but has the disadvantage of high vehicle speeds when entering the junction. The arrangement in a vertical convex junction is feasible and, if properly signalized, does not affect the safety of vehicles passing through the intersection;

➢ ***Right-turn*** separation is achieved through the design and construction of dedicated right-turn vehicle lanes. These lanes can only be realized if the road infrastructure and zoning architecture in large urban metropolitan areas allow it;

➢ ***Ring road dever***, should be downward sloping towards the outside of the roundabout, thus contributing to the improvement of the awareness of the ring road and, correlated with the general gradient on which the roundabout is located, should not exceed 3%. For roundabout intersections in urban areas, the roof layout of the ring road is the most representative, as it provides increased safety for agabaritic road vehicles;

➢ ***The traffic speed*** at roundabout intersections is defined by international practice and is recommended to be in accordance with the data shown in Table 1.

Table 1. Traffic speed at roundabout intersections based on international practice [8, p. 8].

Urban roundabout intersections	Miniroundabouts	25 km/hour
	with 1 band	35 km/hour
	with 2 bands	40 km/hour
Extra-urban roundabouts	with 1 band	40 km/hour
	with 2 bands	50 km/hour

- ***Vertical and horizontal semanlization***, affect the passability and safety of vehicles through the intersection. For good visibility at night, street lighting is particularly required for illumination of the entrance lane, if pedestrian crossings are also provided;
- ***Pedestrian crossings,*** represented by a separate passage allowing access for pedestrians must be provided in this type of intersection for any roundabout. The location of this crossover is behind the yield line, and the dividing island is interrupted to allow access for pedestrians, wheelchairs, wheelchairs, strollers and bicycles;
- ***Cyclists tracks,*** is represented by the specially designed lanes at these intersections for cyclists and offer the possibility for cyclists to pass through them either as vehicles or pedestrians. When designing and constructing a roundabout intersection, if feasible, pedestrian and cyclist crossings may be provided offset from the median island crossing in order to break up the pedestrian and cyclist path, thereby preventing the latter from crossing on a bicycle. They will be placed in the intersection configuration away from the exit tangency point of the ring road so that a minimum of two road vehicles access and fit between the ring road and the pedestrian crossing.

4. Classification of roundabout intersections

Depending on the area in which they are located and built, the number of lanes and their size, roundabout intersections can be classified into:

- small roundabout intersections (miniroundabouts);
- compact urban roundabout intersections;
- urban one-lane roundabouts;
- urban two-lane roundabouts;
- rural one-lane roundabout intersections;
- rural two-lane roundabout intersections. Intersections with more than two lanes can be assimilated to two-lane intersections;
- turboroundabouts;
- rotors.

5. The characteristics of the roundabout and the advantages for road traffic

The main defining characteristics of roundabout intersections are:

- ***Road traffic is one-way.*** This is in contrast to traditional intersections, where vehicles intersect from different directions. This creates a multitude of points of conflict between them and the roundabout imposes a single, specific traffic flow, in principle counter-clockwise (in countries with right-hand traffic). This strongly influences the flow of traffic and significantly reduces the risk of collisions, increasing safety;
- ***Low speed***. Due to their circular design and specification and the absence of electric traffic lights, the speed of entry and travel in the roundabout is implicitly reduced. This increases the safety of all road users, in particular pedestrians, scooters, cyclists, moped and motorcycle drivers;
- ***Clearly defined priority.*** Vehicles that are already in the roundabout have priority over vehicles traveling on the on-ramps into the intersection. This simple rule eliminates confusion, prevents unwanted road events and increases road traffic safety;
- ***Non-stop traffic.*** The roundabout intersection is designed to allow for smooth traffic flow without redundant stops. This reduces vehicle congestion and pollutant emissions;
- ***Versatility.*** Roundabout intersections can be easily adapted to a variety of road infrastructure and traffic configurations (simple intersections with two or three streets to complex intersections with multiple vehicle traffic arteries);
- ***Saving fuel and reducing harmful emissions.*** Roundabouts allow vehicles to move more smoothly and efficiently, helping to save fuel. Reducing the need to stop and start in traffic leads to more efficient use of fuel and, consequently, to reduced greenhouse gas emissions. This is increasingly important in the context of climate change and air pollution concerns;
- ***Reduced serious crashes.*** Studies have shown that roundabouts are associated with fewer serious crashes compared to traffic-light intersections or those using stop signs and traffic signals. This is because the speed in the roundabout is lower and vehicles are traveling in the same direction. Roundabouts also reduce the risk of head-on collisions as vehicles have to line up on the same circular path.

If all of these characteristics are met, then the following advantages can be obtained:

- Calms road traffic;
- Reducing the seriousness of the consequences of road events involving pedestrians, cyclists, drivers of two or three-wheeled vehicles, including the elderly, children and people with disabilities;
- Increased time for drivers to make decisions to reduce speed and enter gaps in traffic giving right of way;
- Allow entry into traffic from the roundabout in increased safety;
- An offer of complementary time for all road vehicle drivers to correct any errors of their own or their traffic partners;
- A reduced frequency of collisions between road vehicles;
- Lighter road accidents;
- Safer intersections for novice drivers.

6. Steps in designing a roundabout

At the basis of the design of this type of intersection there are appreciable needs and quantities of iterations such as: the design of geometric elements, operational analysis and, last but not least, the analysis and evaluation of the degree of safety of the vehicle traffic crossing them. Figure 6 shows the block diagram of the design process of a roundabout intersection based on the flow diagram principle.

Relatively insignificant changes in geometric elements can lead to significant changes in the safety or passability of road vehicles through the intersection. For this reason, the design of such an intersection may frequently be put in the circumstance of having to redesign some geometric elements in order to achieve the optimum crossing capacity, or maximum safety.

The design of such intersections is a rather repetitive process, where small changes in geometric elements can result in large changes in operational or safety characteristics. It is recommended that the initial design should be in the form of sketches, with all details being finalized. In the inception phase, basic elements such as the optimal alignment of the access arteries in the intersection, the optimal position and size of the intersection should be established.

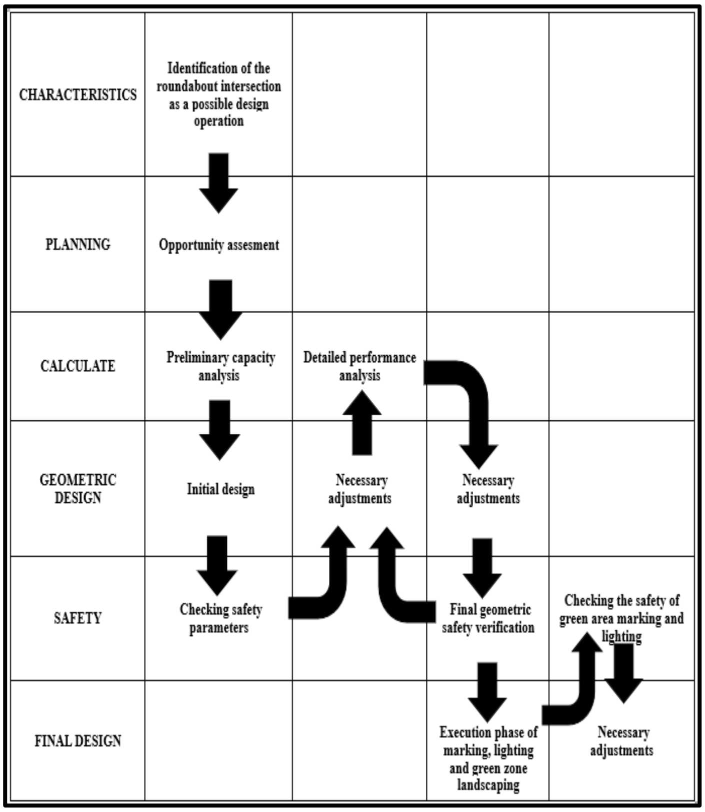

Fig. 6. Block diagram of the phases of a roundabout design.

7. Geometric elements and recommendations for the design of roundabout intersections

According to the classification types, in Table 2 we present some geometric elements and recommendations to be taken into account in the design, as shown in Figure 5, regarding the choice of a roundabout intersection type. By analyzing the presented picture it can be seen that a standard roundabout intersection cannot have more than 4 arms. However, in real life there are also intersections with more than four arms, which are standardized and whose construction is typical of the road network for certain urban or suburban areas. For an intersection with four arms, the angle between two neighboring arms should be as close as possible to 90°.

Table 2. Geometric elements and recommendations on the choice of the type of roundabout intersection [2].

Name	R_{min} [m]	R_{max} [m]	Recommendations/Suggestions
Miniroundabouts	3	6	Their role is to calm and even traffic; They are placed in residential, commercial areas; They are not placed on arteries with heavy traffic exceeding 10%.
Roundabout	6	20	Their role is to distribute traffic between the arms of the intersection; they are not placed on arteries with heavy traffic exceeding 40%.
Rotors	20	-	Intended to increase the capacity of the intersection; May be semaphores;

In Table 3 we present the geometric elements of mini-roundabouts (to which the minimum values can be applied) and roundabouts at the intersection of one-lane roads.

Table 3. Geometrical elements of mini-roundabouts (to which minimum values can be applied) and roundabouts at the intersection of one-lane roads [2].

Element	Value Minimum [m]	Value Recommended [m]
Interior ray, R_{in}	6	9
Outer radius, R_{out}	11.5	16
Entrance connection radius, R_{in}	12	15

Output connection radius, R_{out}	12	15-20
Width of the roadway on the ring road, W_{circ}, (R_{circ})	5.5	7
Width of roadway at entrance, W_{in}	3.5	4
Width of roadway at exit, W_{out}	4	4.5
Inside supercharging S_1	2	2
Inside supercharging S_2	1.5	1.5
Length of bumped separator island, L_{ins}	15	25
Length of the island, L_{min}	2	2
Length of separator island marking, L_{max}	25	25

Note: If possible, it may be recommended to apply the principle of successive beams: $R_{in}<R_{circ}<R_{out}$.

Overlay surfaces shall be made of materials that are different in color and texture from the materials used for the current path. Cubic stone pavers are recommended. The radius at the entrance to the roundabout intersection shall be determined by the inside radius of the roundabout intersection and the vehicular travel speed to be established by regulation. The width of the lanes on the roundabout may be set according to the composition of traffic traveling on the intersecting arterials. Where heavy traffic is occasional, the width of the lanes may be decreased in accordance with the light traffic, while providing for paved overlaps with cubic stone inside the ring road and at the inside of right turns.

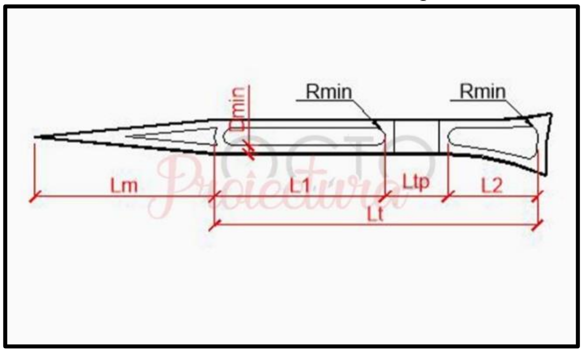

Fig. 7. Creating the separator island [2].

The islands separating traffic from the centerline of the access arms shall be sized according to the minimum values shown in Figure 7 and Table 4. As a recommendation, the separating islands shall be constructed with green colored overlays to be easily distinguishable from the roadway side by traffic participants. It is recommended, in accordance with the standards in force, that these islands should be constructed with a sloping gradient in order to contrast with the roadway side.

According to the data presented above, it is possible to design and realize roundabout intersections solving road traffic problems with reduced fuel consumption, reduced waiting times in queues formed by road vehicles at intersections and, of course, with a significant reduction in accidents and traffic incidents.

Table 4. Geometrical elements of the separating islands [2].

Element	Recommended value
Island width, l_{min} (m)	>2.00
Connection radius, R_{min} (m)	>0.50
Safety distance, D_{min} (m)	>0.50
Effective area, S_{min} (m^2)	>5.00
Length of marking, L_m (m)	>25.00
Island length (diameter), L_1 (m)	>10.00
Island length (diameter), L_2 (m)	>6.00
Pedestrian crossing width, L_{tp} (m)	>2.50
Total length, L_t (m)	>18.50

A comparison of the categories of roundabout intersections in terms of the main design features is presented in Table 5.

Table 5. Comparison of the categories of roundabout intersections in terms of the main design features.

Design element	Small roundabouts (miniroundabouts)	Compact urban roundabout intersections	Urban one-lane roundabout intersections	Urban two-lane roundabout intersections	Rural one-lane roundabout intersections	Rural two-lane roundabout intersections
Maximum recommended design speed (km/h)	25	25	35	40-45	40	50
Number of entry lanes	1	1	1	2	1	2
Typical diameter of the inscribed circle (m)	13-25	25-30	30-40	45-55	35-45	55-60
Type of separation island	If possible raised, cut through the pedestrian crossing	Picked up, cut by pedestrian crossing	Picked up, cut by pedestrian crossing	Picked up, cut by pedestrian crossing	Raised and extended, cut by pedestrian crossing	Raised and extended, cut by pedestrian crossing
Traffic volume for four entrances (veh/hour)	10,000	15,000	20,000	3,.000	20,000	30,000

The recommended values for the diameter of the inscribed circle for roundabout intersections with four roundabouts and a 90° angle between them are given in Table 6.

Table 6. Recommended values for the diameter of the circle inscribed at four-way roundabout intersections with four roundabouts and 90° angle between them [3, p. 54].

Roundabout category	Vehicle taken into account when designing the intersection	Diameter of the inscribed circle [m]
Small roundabout	Truck	13-25
ompact urban roundabout intersection	Truck or simple bus	25-30
Urban one-lane roundabout junction	Semi-trailer truck or articulated bus	30-40
Urban two-lane roundabout junction	Semi-trailer truck or articulated bus	45-55
Rural one-lane roundabout	Truck with trailer	35-40
Rural two-lane roundabout	Truck with trailer	55-60

Note: Circles greater than 60 meters in diameter are not recommended because the speed at which the intersection can be traveled can cause collisions with serious consequences.

However, if the percentage of trucks passing through the roundabout intersection is less than 10% the vehicles to be taken into account in the calculation and design will be one passenger car and one truck. Otherwise one truck and one passenger car will be considered. In Table 7 we show the recommended values for the width of the circular roadway for intersections where trucks are less frequent.

Table 7. Recommended values for the width of the circular carriageway for intersections where lorries are less frequent [3, p. 56].

Diameter of the inscribed circle [m]	Circular road width [m]	Diameter of the central island [m]
45	9.8	25.4
50	9.3	31.4
55	9.1	36.8
60	9.1	41.8
65	8.7	47.6
70	8.7	52.6

8. Calculation of the traffic carrying capacity of road vehicles through roundabout intersections and the specific characteristics influencing it. Other design elements

The low capacity of roundabout intersections is created by the upper limit of the road traffic volume loading on the roundabout (the sum of the conflict volume of road vehicles on the ring road at the access and the input volume on that access) [8, p. 8]. The literature states that miniroundabouts and roundabouts with more than three lanes on the ring road are not recommended. This is also shown in Table 8.

Table 8. Vehicle capacity/standard/hour by number of lanes in roundabout intersections [8, p. 8].

Number of lanes on the ring road	Number of entry/exit lanes	Capacity [vehicle/standard/hour]
1	1	1,500
2	1	1,800
2	2	2,100-2,400

The elements for which the traffic volume calculations for roundabout intersections are performed are shown in Figure 8.

In the following, we present how to calculate the through capacity of road vehicles through roundabout intersections.

The conflicting traffic on the median ring is determined with the mathematical relation:

$$V_c^b = V_{\text{return}}^{b-1} + V_{\text{left}}^{b-2} + V_{\text{forward}}^{b-3} \qquad (1)$$

where,

V_c^b s the volume of conflict for lane *b*, the lane for which the calculations are made (vehicles/hour);

V_{return}^{b-1} - inflow volume for the turning flow of vehicles, corresponding to the right hand lane for which the calculations are made (anticlockwise), (vehicles/hour);

V_{left}^{b-2} – the inflow volume for the left-turning vehicle flow corresponding to the opposite arm to the one for which the calculations are made (vehicles/hour);

$V_{forward}^{b-3}$ - the conflict volume for the forward flow of vehicles on the lane to the left of the one for which the calculations are made (clockwise) (vehicles/hour);

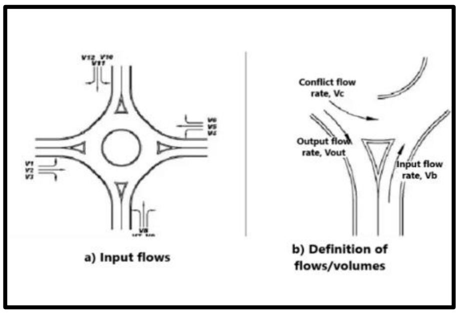

Fig. 8. Traffic elements of roundabouts for which calculations are made [8, p. 9].

The recommended values for the critical access time and for the following time is shown in Table 9.

Table 9. Recommended values for the critical access time and for the following time [8, p. 9].

Interval	Critical access time [seconds]	The following time [seconds]
Upper limit	4.1	2.6
Lower limit	4.6	3.1

- ***The capacity of a one-lane roundabout intersection*** on the ring road is determined by the mathematical relationship:

$$C = \frac{V_c \cdot e^{\frac{-V_c \cdot t_c}{3600}}}{1 - e^{\frac{-V_c \cdot t_f}{3600}}} \tag{2}$$

where,

C is the lane capacity (vehicles/hour);

t_c - critical access time (seconds);

t_f – the following time (seconds).

The literature indicates that the capacity of a one-way roundabout intersection with a ring lane can also be verified by using alternative methods, such as:

$$C = 1.500 - V_c - 0{,}3 \times V_i, \tag{3}$$

where, 1,500 is the maximum amount of road traffic that can become conflictual, i.e.:

$$\sum V_c + V_i); \tag{4}$$

where,

V_c is the conflict volume of the lane (vehicles/hour);

V_i – output volume corresponding to the lane (vehicles/hour).

- ***The capacity of an intersection with a two-lane roundabout*** on the ring road is determined by the mathematical relation:

$$C = 3600 \cdot \frac{n_e}{t_f} \cdot e^{\frac{V_c \cdot}{3600} \cdot \left(t_c - \frac{t_f}{2}\right)} \tag{5}$$

where,

t_c is the critical access time (seconds);

t_f – the following time (seconds);

V_c - conflict volume related to the lane (vehicles/hour);

n_e – parameter for the number of lanes, for two lanes $n_e = 1{,}14$.

- ***The control delays*** are determined with the mathematical relation:

$$d = \frac{3600}{c} + 900 \cdot T \left[\frac{V_b}{C} - 1 + \sqrt{\left(\frac{V_b}{C} - 1\right)^2 + \frac{\frac{3600}{C} \cdot \frac{V_b}{C}}{450T}} \right] + 5 \tag{6}$$

where,

d is the value of control delays (seconds/vehicle);

C – lane capacity (vehicles/hour);

V_b – the input volume of the lane (vehicles/hour);

T - analysis period (hours).

It is recommended that the analysis be carried out over a period of 15 minutes (0.25 hours). The value of 5 seconds/vehicle in relation (6), takes into account the deceleration of vehicles from the speed of queuing vehicles and the acceleration from the stop line to the speed of the moving column of vehicles.

Summing the delays on roundabout intersections can be done with the mathematical relation:

$$d = d_{b1} x V_{b1} + d_{b2} x V_{b2} + d_{b3} x V_{b3} + d_{b4} x V_{b4} \quad (7)$$

The determination of the level of service of a roundabout intersection is done according to the data presented in Table 10.

Table 10. Determining the level of service of a roundabout intersection [8, p. 13].

Level of service	Control delays [sec/veh]
A	<10
B	10-15
C	15-25
D	25-35
E	35-50
F	>50

- ***The speed - curve relationship at a roundabout intersection*** will be calculated with the mathematical relationship:

$$V = \sqrt{127R(e+f)} \quad (8)$$

where,

V is the speed (km/h);
R – radium (m);
e – the over-elevation (m/m)
f – coefficient of adherence.

The over-elevation e has a value of +0.02 for the entry and exit curves and -0.02 for the curves around the center island. The coefficient of adhesion *f* is variable and is directly proportional to the speed as shown in Figure 9.

By using an appropriate coefficient of adhesion for each value of the velocity, a graph of the dependence between velocity and radius can be plotted for both a value of the overhang of + 0,02 and - 0,02, as shown in Figure 10.

- ***Approaching curves in a roundabout.*** As the approach of the curves in a roundabout is determined by the radii of the radii of each arm of the intersection, as shown in Figure 11, the five radii of the vehicle paths will be taken into account when designing and realizing such an intersection, as follows [3, p. 47]:

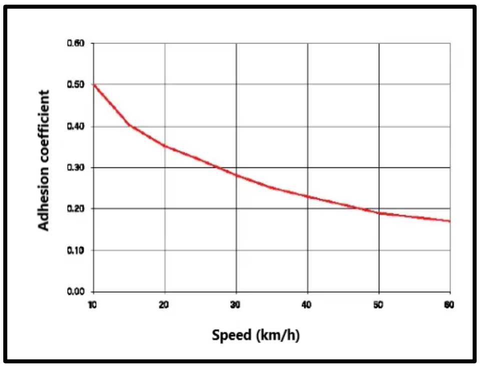

Fig. 9. Variation of coefficient of adhesion as a function of speed [3, p. 46].

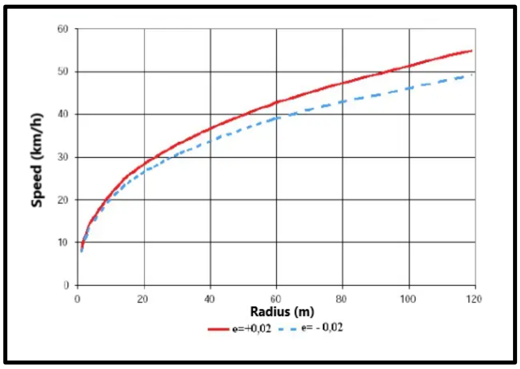

Fig. 10. Dependency between speed and minimum turning radius [3, p. 47].

- ***R_1*** - the radius of the entry path which is the minimum radius of the path leading to the priority yield line;
- ***R_2*** - the radius of the circulation path which is the minimum radius of the fastest path passing the central island;
- ***R_3*** - the radius of the exit path which is the minimum radius of the fastest path leading to the exit of the intersection;
- ***R_4*** - the left turn path radius which is the minimum radius of the path allowing the left turn;
- ***R_5*** - the right turn path radius which is the minimum right turn path radius.

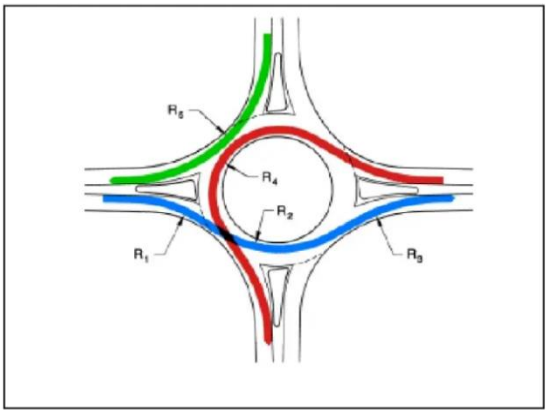

Fig. 11. Possible trajectories when crossing a roundabout intersection and their connecting radius [3, p. 48].

It is recommended on the fastest trajectory as $R_1<R_2<R_3$, conditions that reduce vehicle speed to a minimum at the entrance of the roundabout and therefore reduce and avoid loss of control of vehicles. If it is not possible by construction $R_1<R_2$, it is recommended that the speed entering the roundabout is reduced to below 20 km/h.

Table 11 shows approximate values for R_1 și R_4, to be taken into account in the design of roundabout intersections, according to the radius of the circle inscribed.

Table 11. Approximate values for R_1 and R_4 as a function of the radius of the inscribed circle [3, p. 49].

Radius of the inscribed circle (m)	Approximate value R_4		Approximate value R_1	
	Radius (m)	Speed (km/h)	Radius (m)	Speed (km/h)
One-lane roundabout intersection				
10	11	21	54	41
35	13	23	61	43
40	16	25	69	45
45	19	26	73	46
Two-lane roundabout Intersection				
45	15	24	65	44
50	17	25	69	45
55	20	27	73	47
60	23	28	83	48
65	25	29	88	49
70	28	30	93	50

- ***Traffic lights at roundabout intersections.*** As a recommendation, roundabout intersections with a radius of less than 20 m should not be signalized. The only intersections of this type where electric traffic lights may be installed are ROTOR roundabout intersections.

If traffic signals are nonetheless installed at such intersections, the recommendation is that the traffic signal should be in two distinct phases, with turn storage for left-turning vehicles on the ring road, where evacuation times for the ring road can be established between the two phases (Figure 12).

Note: If a traffic signal analysis of a roundabout intersection is to be carried out, it will not be carried out on the principle of optimizing control delays, but on the principle of queuing on the ring road. In this case, the size of the cycle and phases of the electric traffic light will also be determined according to the length of the storage space for road vehicles on the ring side.

- ***The safe visibility braking*** distance is defined as the shortest distance necessary for drivers of a road vehicle to perceive an obstacle on the roadway and to brake the vehicle to reach that obstacle. At the design stage this distance shall be predicted separately for each point within the intersection and at each entrance to the intersection. The braking distance shall be composed of two elements: 1) the distance traveled from the moment when the driver senses the obstacle until the braking process begins; 2) the braking distance required to bring the vehicle to a safe stop after the vehicle's brake pedal has been applied. As recommended by the US National Cooperative Highway Research Cooperative Program (NCHRP) [12], [13], the distance can be calculated with the mathematical relation:

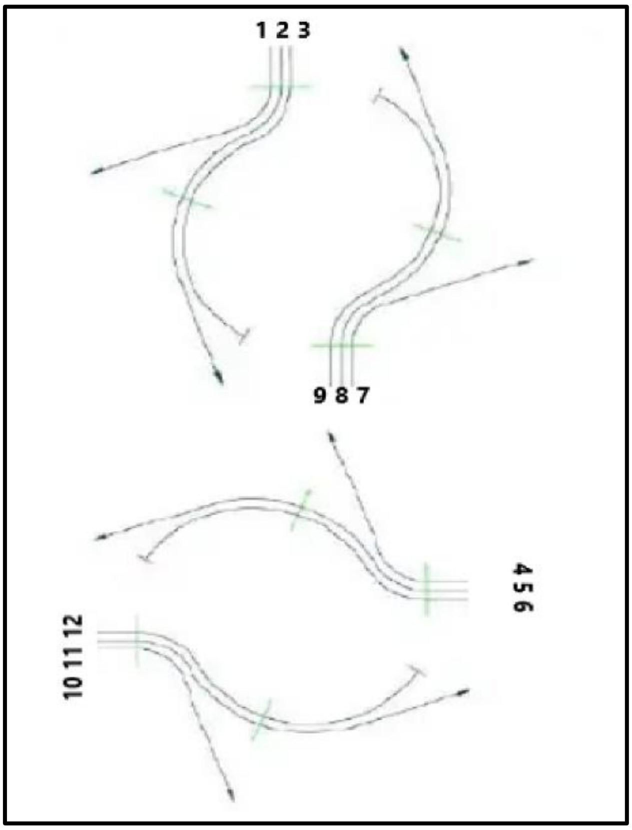

Fig. 12. Traffic signal phasing model of roundabout intersections [8, p. 11].

$$D = 0.278\ x\ t\ x\ V + \frac{V^2}{a} \tag{9}$$

where,

D is the safety stopping visibility distance (m);

t – driver reaction time estimated at 2.5 seconds;

v – initial speed (km/h);

a - vehicle deceleration estimated at 3.4 m/s^2.

Table 12 shows the recommended values to be taken into account when designing a roundabout intersection, based on relation (9)

Table 12. Recommended values to be taken into account when designing a roundabout intersection, calculated from relation (9).

Speed [km/h]	Calculated distance (m)
10	8.1
20	18.5
30	31.2
40	46.2
50	63.4
60	83
70	104.9
80	129
90	155.5
100	184.2

Note: At least three areas should be checked for safe stopping sight distance, namely: 1) the approach to the intersection; 2) the circular roadway; 3) the pedestrian crossings at the exit of the intersection. The distances are stipulated in the literature.

- The calculation of the ***length of the distance to the conflict points at a roundabout intersection*** is calculated with the mathematical relationship:

$$b = 0.278 \, x \, (V_{major}) \, x \, (t_c) \quad (10)$$

where,

b is the conflict length within the visibility triangle (m);

V_{major} - design speed of conflicting traffic (km/h);

t_c - the critical gap for entering priority *s* traffic, considered as *6.5* (seconds).

The maximum length on each arterial entering the intersection should be 15 meters, with collisions between vehicles becoming more frequent as the distance increases beyond this value. If the distance is greater than 15 meters, the attention of drivers must be directed at the same time to pedestrian crossings and vehicles having right of way, which is why, if other geometric elements lead to a greater distance, the limitation shall be achieved by means of the green zone on the dividing island. In this case, two conflicting traffic flows are taken into account [3, p. 67]:

- entering traffic composed of vehicles entering the roundabout from the left-hand arterial road. The speed taken into account is the average of the speed allowed by the entry trajectory and the speed allowed by the traffic on the roundabout;
- traffic composed of vehicles already on the circular roadway. The speed for this traffic can be approximated by the speed allowed by the trajectory for making a left turn.

The critical gap for entering priority traffic is based on the interval required to make the right turn when the reduction in speed of vehicles in traffic is no more than 30% of the initial speed. The length values for the different speeds considered are shown in Table 13.

Table 13. Length values for different speeds considered [3, p. 68].

Speed approaching the conflict point [Km/h]	Calculated distance [m]
20	36.1
25	45.2
30	54.2
35	63.2
40	72.3

Note: The braking safety sight distance in the circular roadway and the braking safety sight distance in the sight triangle impose maximum height conditions for the portion of the landscaped green area on the central island of the roundabout intersection that is included in the sight zone. At the same time it is recommended that the central area of the center island should include a higher portion as shown in Figure 13.

9. Priority and traffic rules at roundabout intersections

The ***basic traffic rules*** for roundabout intersections are:

- vehicles already in the roundabout have priority. This means that any vehicle intending to enter the roundabout must give way to vehicles already moving in the roundabout;
- all the arteries entering the roundabout are signalized with *"yield"*. This means that vehicles approaching the roundabout must reduce speed and give way to vehicles in the roundabout ring;
- none of the roads entering the roundabout has priority over the others. The difference from the general traffic rules is that the right priority rule does not apply in the roundabout;

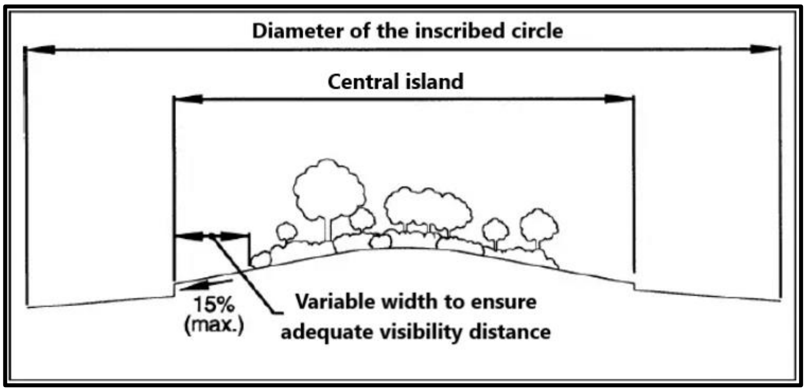

Fig. 13. Green landscaping in the central island [3, p. 68].

- the center of the intersection is bypassed on the right. This means that vehicles must follow the path from the roundabout counter-clockwise (in countries where vehicle traffic drives on the right side of the road) and clockwise (in countries where vehicle traffic drives on the left side of the road) around the center of the intersection;

➢ vehicles traveling in the first street on the right must not enter the roundabout. They shall merge as close to the right side of the roadway as possible and shall give right of way to vehicles already inside the roundabout and traveling in the same lane. The same applies to left-turning vehicles at roundabout intersections in countries where vehicle traffic travels on the left-hand side of public roads;

➢ lane changing in a roundabout must be signaled and only after giving priority to vehicles already in that lane;

➢ when entering/exiting the roundabout drivers of road vehicles are obliged to signal the direction of travel;

➢ stopping, parking and reversing within the roundabout is strictly prohibited to keep traffic flow smooth;

➢ turning into the roundabout using forward-backward maneuvers is prohibited. However, turning around the center island of the roundabout in order to return to the reverse direction of the artery from which the roundabout was originally entered is permitted.

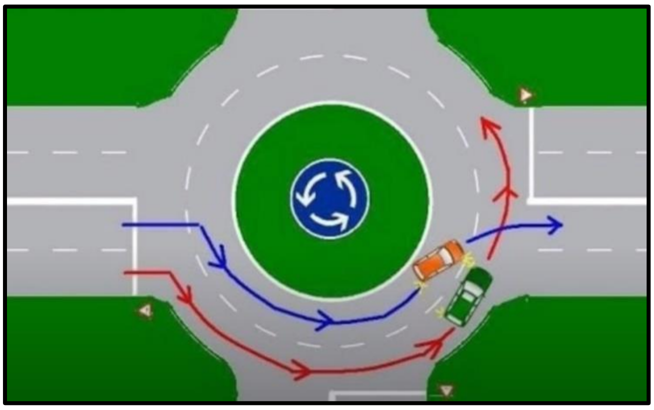

Fig. 14. New roundabout traffic rules [7].

În Romania, the rules that road vehicle drivers have to follow when driving in a roundabout have been modified since mid February 2023, and the old practice is no longer valid. In Article 107 of HG 130/2023, a new paragraph (1^1), to read as follows: (1^1) *"In the case of roundabout intersections, drivers of vehicles must comply with the rules on traffic on the lanes, and must signal in good time when leaving the intersection and ensure that they can do so without disrupting traffic or endangering the safety of other road users"* [14]. Today there are roundabouts with 2, 3, even 4 lanes. These lanes, even if they are traffic lanes, oblige drivers of road vehicles to follow the same rule as those on straight roads, even if the general rule of the roundabout has been maintained and those inside the roundabout have priority, other rules now apply. Therefore, it is no longer possible to exit directly from the 2nd or 3rd lane of the roundabout and cut in front of those in the other lanes, and if this maneuver is to be performed, it will only be done after the drivers of the vehicle have secured themselves and then signaled this maneuver. According to Figure 14, the driver of the orange colored car (blue line) is obliged to give way to the green colored car (red line) as it makes a lane change to exit the roundabout, while the green car retains its lane. Lane alignment, entry and traffic flow in a roundabout intersection is as shown in Figure 15. In Figure 16 we show the lane placement, access and vehicle movement in a three-arm roundabout by means of a *"turbo lane"*.

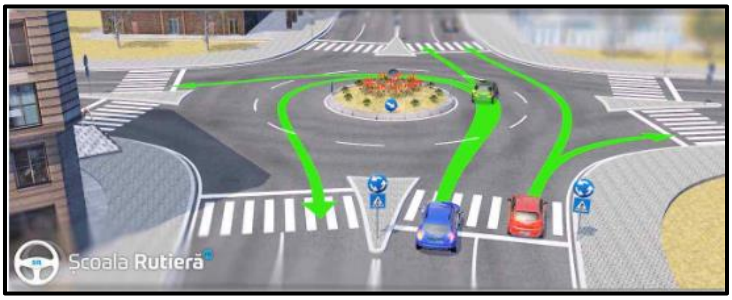

Fig. 15. Lane alignment, entry and traffic flow at a four way roundabout [16].

The recent amendment to the Highway Code for roundabout traffic means that only one lane always has priority. Specifically, once a vehicle has păt runs in the roundabout, only if it is in lane 1 can it move without giving priority to other vehicles. "It's best to stay in lane 1 when traveling in the roundabout. This makes it easier for you to leave the junction, whether you want to do it on the first exit or the fourth. Those in lane 2, for example, must give way to those in lane 1. And those in lane 3 to those in lanes 1 and 2. In any case, as a general rule, all drivers of road vehicles should take care whether they have the right of way or not, because that's the only way to prevent an accident. Even those in lane 1 should be alert to the intentions of those in lane 2, for example, who may not be aware that they need to give way" [7].

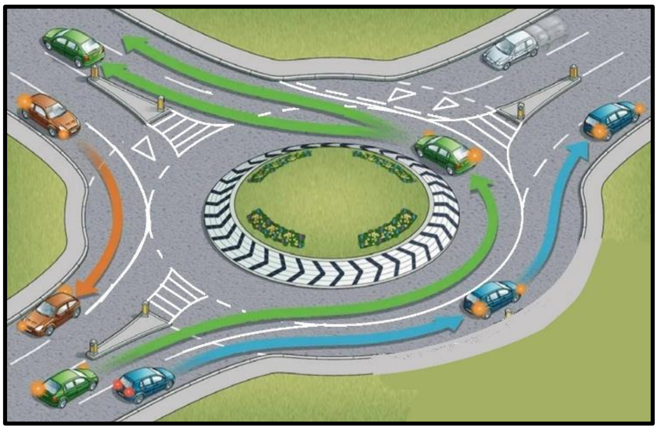

Fig. 16. Lane alignment through a "turbo lane", entry and traffic flow at a three way roundabout [7].

10. Special roundabout intersections. Case study

- ***Turboroundabout (turbogiration)*** (Figure 17), are roundabout intersections that handle a very high flow of road vehicles and provide maximum safety due to their design characteristics. They are referred to by specialists in road infrastructure design and construction as the "big brother of the roundabout". The concept of the roundabout was conceived and introduced into Dutch road infrastructure by Lambertus Fortujin in 1996.

Fig. 17. Turboroundabout [11].

The specific elements that distinguish the turboroundabout from the classic roundabout are:

- are organized with two or more traffic lanes, arranged with *a curb* separation in the form of *a spiral*;
- physical demarcation of the entry lanes into the turboroundabout with elevated kerbs (Figure 18), or by continuous longitudinal markings. In this case, the drivers of vehicles entering such an intersection have to choose in advance the lane to a particular exit, there being no possibility of entering from one lane to another inside the intersection. If this type of intersection is designed with several lanes, they can be separated by safety islands (Figure 19). In special cases, for well-founded reasons (insufficient funds, demanding architectural framework, presence of separating islands, etc), the separation of the access and traffic lanes by roundabouts can also be separated by continuous white line markings, but, as already mentioned above, this type of lane separation is not recommended;

Fig. 18. Access on pre-selected bands in turboroundabout [11].

Fig. 19. Lane separation in turboroundabout through safety islands [11].

Figure 20. Road sign to indicate that you are in the appropriate lane in a turboroundabout [11].

- the pre-signalization for the appropriate lane in which a driver of a road vehicle wishes to move shall be made in accordance with the specific road traffic regulations of each country (Figure 20). The required lane shall be chosen before entering the turboroundabout, observing road signs and markings;
- lane separation in the turborondabout can be achieved as shown in the group of Figures 21.

Fig. 21. Lane separation in the turboroundabout [11].

- the physical separation of lanes in the roundabout for specific vehicle flows in each direction of travel is done in order to direct drivers of road vehicles towards a particular exit, thereby limiting the potential for lane changing and eliminating conflict points that may occur between vehicles. This reduces the number of roadway events that can occur through collisions between vehicles and also smoothes and increases the volume of through traffic through the intersection. Turning in the direction of the turboroundabout, the driver will give priority to the vehicles in the roundabout and, if necessary, will cross one or two lanes of traffic;
- the two-lane turboroundabout, in its complexity, eliminates at least 2 conflict points compared to a classic two-lane roundabout. The conflict points in a turboroundabout and a classic roundabout intersection are materialized according to the plotted data presented in Figure 22;
- the turboroundabout creates a greater flow of road traffic, increasing the volume of vehicle traffic, compared to a classic roundabout intersection. This is shown in Figure 23;
- in the urban landscape roundabouts can only be built where space permits. They occupy a large space;

After type of construction, number of arms, volume and type of traffic, we can classify turboroundabouts as follows:

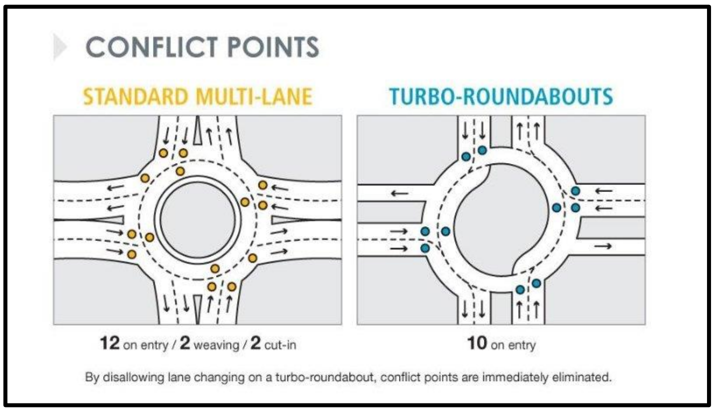

Fig. 22. Eliminating conflict points in a turboroundabout [11].

➢ ***classic*** type turboroundabout. It has a number of 4 arms, estimated capacity of 3,500 vehicles/hour, with predominantly forward movement traffic;

➢ ***knee*** type turboroundabout. It has a number of 4 arms, estimated capacity of 3,500 vehicles/hour, with predominantly right-hand traffic;

➢ ***spiral*** type turboroundabout. It has a number of 4 arms, estimated capacity of 4,400 vehicles/hour, with traffic predominantly forward movement;

➢ ***rotor*** type turboroundabout. It has a number of 4 arms, estimated capacity of 4,500 vehicles/hour, with predominantly all-directional traffic;

➢ ***wide knee*** type turbor. It has a number of 3 arms, estimated capacity of 3,800 vehicles/hour, with predominantly forward movement traffic;

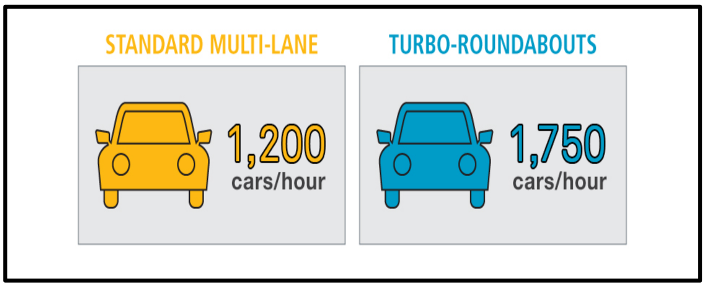

Figure 23. Traffic volume of vehicles through a turboroundabout compared to a classic roundabout [11].

star type turboroundabout. It has a number of 3 arms, estimated capacity of 5,500 vehicles/hour, with predominantly all-directional traffic. In figure 24 shows all these types of turboroundabouts.

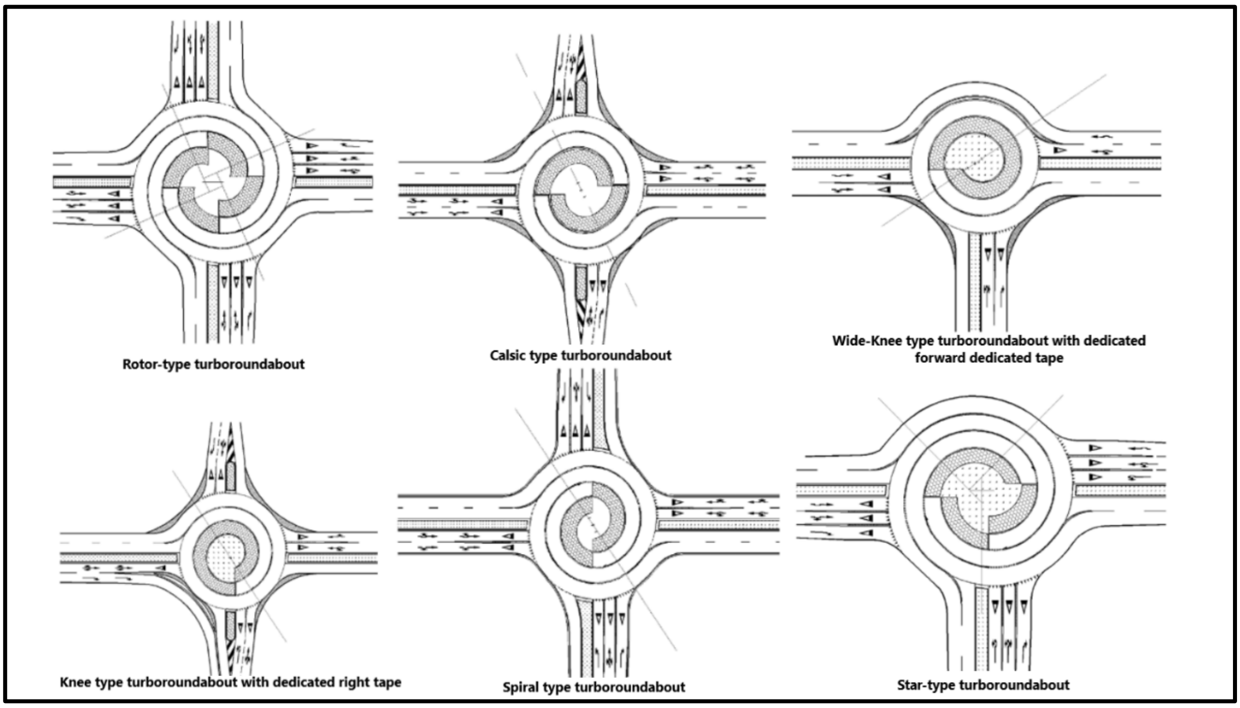

Fig. 24. Types of turboroundabout [18].

The need for a lane divider (curb or solid white line) at a turboroundabout intersection has the following functions:

➢ avoids points of conflict at the junction of road vehicle flows and the temptation for drivers to shortcut the road;

➢ it eliminates the change of the path of the vehicles in turboroundabout when traffic intensity is low;

➢ reduces the stress generated by the influence of other road vehicles traveling in parallel in the other lanes. This will increase the level of concentration on the road trajectory to be traveled by each driver according to the chosen flow;

➢ increases the ability of road vehicles to pass through the intersection due to reduced speed and increased time interval between successive vehicles, which is facilitated at the turboroundabout intersection.

Fig. 25. Tear type roundabout intersection [15].

- ***Other types of roundabout intersections that have a special design.***

➢ ***Tear*** tipe roundabout intersection (Figure 25). Provides a free-flowing left turn that flows freely to the ramps. Because of its special construction, it eliminates the need for signalization and turn lanes. Because the entrance and exit arms have a unique appearance, represented by a teardrop-shaped island. Drivers entering the roundabout from the bridge do not have to yield, and this prevents queuing on narrow, two-lane bridges [15];

➢ ***Magic*** type roundabout intersection (Figure 26).

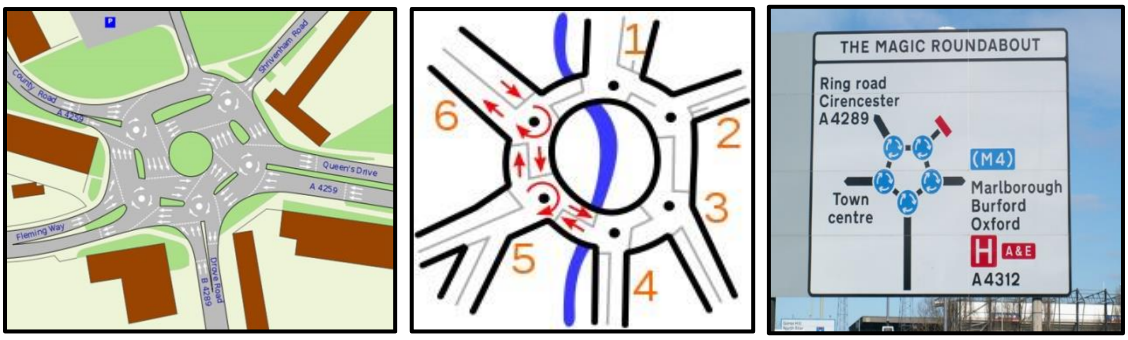

Fig. 26. Intersection with magic roundabout and how to warn drivers with pre-warning signs [15].

Analyzing the data in Figure 26 we see that at this roundabout intersection, vehicular traffic is allowed in both directions around the center island. These are officially known as *"ring junctions"*. The images in are for left side traffic. As can be seen, road traffic flows both clockwise and anticlockwise. This is accomplished by surrounding the main island with smaller roundabouts on the entrance/exit streets. The model typically directs traffic clockwise or counter-clockwise around each mini-roundabout. Exiting the miniroundabouts, road vehicle traffic can proceed around the center island either in the normal direction (through the outer loop) or in the reverse direction (inner loop). Road vehicle drivers can usually choose the shortest and smoothest route in this case. Although the safety presented by this type of itersection is high, many drivers find this system intimidating, some of them avoid them and travel long distances on detour routes.

Conclusions

Roundabout intersections treat all directions equally, as all vehicles entering the intersection yield priority and it does not matter that one artery is a primary and another a secondary. They all have the same regime for vehicle movement through them. This can be interpreted by longer delays on the main arteries, which is undesirable. This situation is common at intersections between major arterials and secondary or collector streets. It is therefore recommended to carefully analyze the categories of all intersecting streets in an interchange before deciding on the type of intersection to be built, and if appropriate, to adopt the solution of a controlled intersection with priority yield signs.

Typically, roundabout intersections require additional space compared to conventional intersections. This is why roundabouts often have a significant impact on the priority of passing at the corners of intersections especially compared to other types of intersections. The dimensions of a classic intersection are determined by the dimensions of the intersecting arterials. However, roundabout intersections gain storage space for vehicles waiting to enter the intersection by forming significantly smaller queues. While a classic intersection requires longer and multiple lanes for vehicles to wait for vehicles to enter the intersection, a roundabout intersection requires less space for vehicles to wait. It also eliminates arterials that facilitate right-turns around the intersection proper. The space thus saved can be used for a variety of purposes such as parking spaces, sidewalk widening, green spaces and bicycle paths. Another space-saving strategy is the use of funnel-shaped intersection entrances (specific to roundabout intersections), which maintains a relatively large traffic capacity despite relatively small entry and exit arteries. The speed at which the intersection can be traversed is given by the minimum radius of the turns on the shortest path. This may occur when turning around the center island of the intersection. The shortest path shall be plotted for all entries into the intersection. It is recommended that these paths should be drawn by a team of designers as there is a degree of subjectivity involved in drawing these paths and this can be reduced by involving more than one person at this stage of the design.

Roundabout intersections reduce traffic conflict points from 32 to 8. This can be interpreted as a 75% reduction of vehicle-to-vehicle intersections at a typical road junction. Fewer conflict points mean fewer road events. The severity of accidents depends largely on the speed of the vehicles at the moment of impact and the angle of impact. As speed increases, the severity of road traffic accidents also increases. Reducing speed reduces the consequences of a possible road event, and the angle at which collisions can occur in a roundabout is also conducive to reducing their consequences.

In the case of intersections with more than four arms, a roundabout intersection or a simultaneous group of roundabout intersections is a very good possibility to reduce conflict points.

Pedestrians crossing a roundabout intersection with two or more lanes in each direction are at greater risk of being hit by vehicles traveling at higher speeds at this type of intersection. In addition, they may not be noticed by drivers approaching from the far lane, if another vehicle is parked in the lane next to them to give way. Children, people in wheelchairs and the visually impaired are most at risk in this case.

Roundabout intersections streamline the movement of vehicles through the intersection, increasing safety, traffic volume, reducing conflict points and therefore road events, favoring an increase in the speed of movement through the intersection and fluidizing traffic.

Statistically speaking, roundabouts are safer for pedestrians and drivers than traditional intersections because they require low speeds when entering the roundabout. They are not designed for freeways or expressways. However, when these types of roads are connected to roundabouts, a few steps are taken to reduce the speed of cars before the intersection.

Roundabouts are not placed on arteries with more than 40% heavy traffic.

Reducing the speed at the roundabout intersection is also beneficial for cyclists traveling at average speeds of 20-25 km/h because the smaller the speed difference between them and motor vehicles, the safer the entry into traffic for this category of road users. In this way, the difficulty of delays caused by reduced traffic speeds is offset by their safety.

Whereas in a classic roundabout, the traffic flow is on a circular ring and vehicles can go round and round the intersection endlessly, in a roundabout the traffic flow is spiral. Regardless of which lane you enter the slipstream, after the first turn, the shape of the slipstream directs drivers towards the exit of the intersection.

Roundabout intersections are in principle much safer than other types of intersections. Although minor road traffic events (collisions between vehicles) may be higher in number, accidents resulting in injuries to occupants of the vehicle seats are much lower. Pedestrians and cyclists, however, are involved in a much higher number of accidents resulting in fatalities.

The correct choice of the correct type of turbocharger is extremely important, as it crucially affects the ability to pass the intersection.

Given that vehicles must position themselves in the entry lane corresponding to the direction of travel, the road signs at the entrance to the roundabout must be properly positioned so that they can be observed in good time by drivers in order to ensure that they are in the correct lane according to the direction of travel. For this reason, it is also the regulatory road signs that will inform the driver of the type of intersection and the maneuvers he has to perform.

Although better than the classic roundabout, turbo-turns cannot be used in all situations. In conditions where the intersection design space is limited, the classical roundabout may be the only option, as turbo-gyratory requires larger design radii for the center island.

It is recommended that at turboroundabouts, the markings should not be made with paint on the roadway but with uneven kerbs. In this type of intersection, markings can also be made by painting on the roadway when high volumes of agabaritic vehicles are likely to pass through the intersection, but for high efficiency, this type of marking should be avoided. The paint markings should be continuous line markings and only in the area of the entrance to the gyratory should broken line markings be provided.

Roundabouts also have a positive influence in areas where there is a change of traffic from out-of-town to in-town traffic, which involves a significant change in vehicle speed. In these cases, the speed reduction imposed by the roundabout entry is beneficial for the subsequent adjustment of travel speed.

Roundabout intersections offer great opportunities for the aesthetic design of area centers or entrances to areas. However, the presence of serious solid obstacles in the direction of entry to the intersection can be a safety hazard. The central island and to some extent the splitter islands offer extensive possibilities for design from an aesthetic point of view. A positive effect can also be achieved by the texture used to create the inner belt of the central island. Some roundabout intersections can even be used as a calling card for the area by being featured on tourist brochures, advertisements or postcards.

At two-lane roundabout intersections the design and realization of a reduced radius of the entry curve may lead to overlapping of the intersection crossing paths of vehicles in adjacent lanes which increases the number of conflict points. Overlap occurs when a vehicle in the left lane on the approach to the intersection moves into the right lane before reaching the yield line to pass the center island, or when a vehicle in the right lane on the approach to the intersection on entering the circular roadway approaches the center island by moving into the left laneThis overlapping of paths results in reduced traffic capacity and an increased likelihood of traffic accidents. For this reason the design of the three radii at these intersections needs to be very careful.

Turboroundabouts can hold 46% more mainstream traffic than normal roundabouts. Turboroundabout intersections are an excellent opportunity for improved traffic management, reducing accidents (Figure 27).

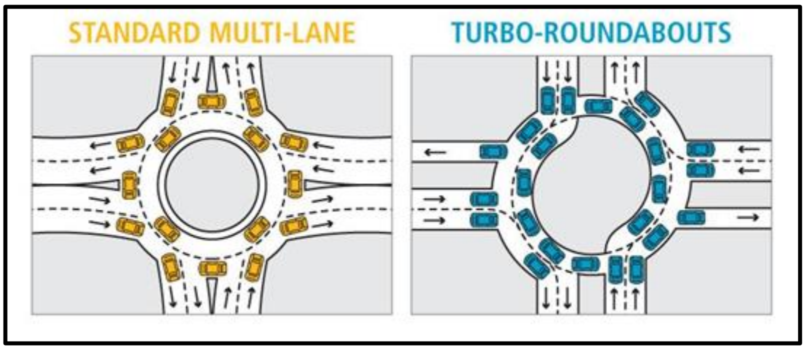

Fig. 27. Turbo-roundabouts can hold 46% more mainstream traffic than normal roundabouts [17].

In turboroundabouts, flow interchanges or lane-to-lane maneuvers are not permitted and are not possible because of the curb.

In contrast to traditional roundabouts, it is no longer possible to rectify an incorrect lane choice (a maneuver considered to be an accident-generating maneuver) by completely crossing the roundabout equipped with lane splitters.

Even if the costs of turboroundabouts are somewhat higher than in the case of ordinary roundabouts, these investments are operationally recovered due to the significant increase in traffic safety (by 75%) and minimization of the number of accidents, the resulting financial and material losses, and the saving of human lives. For this reason, turbogrids are characterized by two distinct functional elements: they have a high degree of safety and functionality in terms of road traffic. Both of these elements are achieved by channeling traffic in separate lanes separated by median dividers.

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