Journal of Engineering Science *Vol. XXXII, no. 2 (2025), pp. 7 - 25*
Fascicle *Industrial Engineering* *ISSN 2587-3474*
Topic *Applied Engineering Sciences and Management* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2025.32(2).01
UDC 656.11.053.3

ROUNDABOUT – ELEMENT OF SAFETY, ECOLOGY AND ECONOMY

Olivian Pădure *, ORCID: 0000-0002-6024-3763,
Vasile Plămădeală, ORCID ID: 0000-0003-1722-2649,
Vladimir Goian, ORCID: 0000-0002-0031-0389

Technical University of Moldova, 168 Stefan cel Mare Blvd., Chisinau, Republic of Moldova
* Corresponding author: Olivian Pădure, *olivian.padure@tran.utm.md*

Received: 05. 15. 2025
Accepted: 06. 12. 2025

Abstract. Statistical analysis reinforces the conclusion that road accidents are not random and even more unpredictable or unavoidable, although their occurrence is random. The concentration of road accidents at intersections is high, around 25-30% of the total number of road accidents. The intersection itself is an area of concentration of conflict points, where the occurrence of road accidents is both theoretically and practically possible due to the contact of vehicle flows from three different directions: intersecting, separating and merging. Increasing the safety of intersections therefore boils down to taking measures to reduce the number of conflict points and the degree of their potential danger. The article describes the purpose, advantages and disadvantages, conflict points, classification and types of roundabouts. The benefits of roundabout organization in terms of road traffic safety, environmental safety and increasing the road's passing capacity, thus reducing waiting time at intersections, are also analyzed.

Keywords: *roundabout, intersection, conflict points, road accidents, road traffic safety, environmental safety, roundabout capacity.*

Rezumat. Analizele statistice întăresc concluzia, că accidentele rutiere nu sunt întâmplătoare şi cu atât mai mult imprevizibile sau inevitabile, cu toate că apariţia lor este aleatoare. Concentrația accidentelor rutiere la intersecții este una mare, circa 25-30% din numărul total de accidente de circulație. Intersecția prezintă în sine o zonă de concentrare a punctelor de conflict, unde apariția accidentului rutier atât teoretic, cât și practic este posibilă datorită contactului fluxurilor de vehicule din trei direcții diferite: de intersectare, separare și fuzionare. Prin urmare, creșterea siguranței intersecțiilor se reduce la întreprinderea unor măsuri de reducere a numărului punctelor de conflict și gradului de pericol potențial al acestora. În articol sunt descrise destinația, avantajele și dezavantajele, punctele de conflict, clasificarea și tipurile de sensuri giratorii. De asemenea, sunt analizate beneficiile organizării sensului giratoriu privind siguranța traficului rutier, securitatea ecologică și ridicarea capacității de trecere a drumului, astfel reducând timpul de așteptare la intersecții.

Cuvinte cheie*: sens giratoriu, intersecție, puncte de conflict, accidente rutiere, siguranța circulației rutiere, siguranța ecologică, capacitate de trecere a intersecției.*

1. Introduction

In global road traffic management practices, one of the most effective methods of reducing traffic accidents is considered to be roundabout intersections [1]. In many countries in Western Europe, North America and Australia, the effectiveness of using roundabouts is convincingly confirmed by the reduction of all crash indicators, in particular by the reduction in crash severity and the decrease in the number of road traffic accidents with fatalities.

Roundabout intersection or ***roundabout*** is the intersection, where approaching vehicles decelerate and begin to circle around the central „*island*" counterclockwise on roads with traffic on the right side of the road, or clockwise on roads with traffic on the left side of the road, until exiting onto a roundabout arterial (convergence) [2].

Roundabouts are intersections formed by a one-way circular path around a central island. Thus, the roundabout can be compared as a one-way road with a sequence of T-intersections (Figure 1) [3-5].

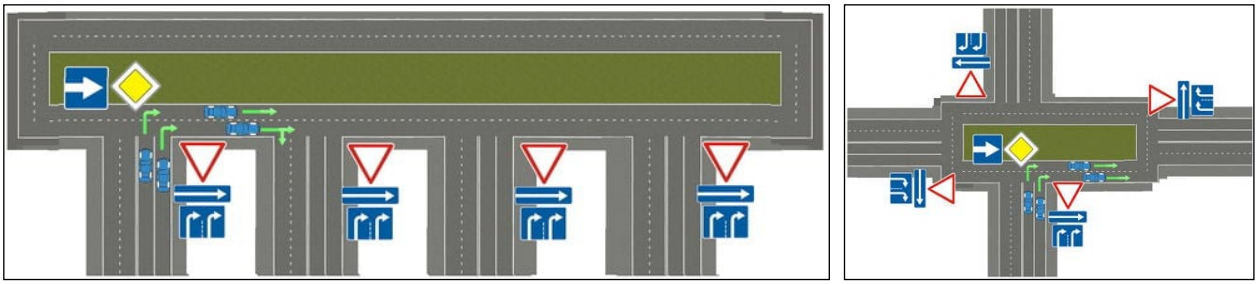


Figure 1. Roundabout intersection shown as a one-way road with a sequence of T-junctions [3,4].

In the literature, roundabouts are attached to a broad class of circular road junctions (circular intersections). However, not every circular road junction is considered to be a roundabout. There are three types of circular road junctions [1].

Rotaries are an old type of circular road junctions, characterized by a large diameter, sometimes exceeding 100 m. The large diameter is due to the high projected traffic speeds, which exceed 50 km/h. Such junctions provide a slight deviation from linear traffic and may operate according to the „*right obstruction*" rule (in countries with right-hand traffic), i.e. traffic entering the circle has priority over traffic moving in the circle.

Neighborhood traffic circles are circular road junctions usually located on local streets in residential areas for traffic calming. The entrances to such junctions may be undirected or accompanied by signs and road markings, which indicate the priority of traffic on the circle. Such intersections are usually not accompanied by flow channelization (i.e. no separation islands are created at the entrance along the roadway axis). Lately, this type of roundabout intersection is becoming more widespread and is used as a means of traffic calming.

Roundabouts are circular road nodes with established geometrical parameters and form of organization of the flow of road traffic, including [1]:

- „*Yield*" or „*Mandatory stop*" road signs at circle entrances [6];
- geometry of the intersection in plan – radii of the roadway side of the circle, of the unimmediate entrances to and exits from the roadway side of the circle, of the approaches to the intersection, which do not allow the development of a speed greater than 50 km/h;
- mandatory canalization of road flows at the entrances to the circle, while the separation islands at the entrances are used as safety islands for pedestrians.

The term ***roundabouts*** originated in the United Kingdom as early as 1929 with the Ministry of Transportation and the Institute of Town and Country Planning. It should be noted that Florida's Roundabout Intersection Guidelines (FRG 1996) introduced a new term ***„modern roundabout"***, which has come to be commonly used in technical literature.

The first roundabout was organized in Paris around the Arc de Triomphe in 1901. Columbus Circle in New York was built in 1904. The first British roundabout followed in 1909 (Letchworth Garden City) – originally planned as a pedestrian island. Later, during 1925-1926 in the UK, several roundabout intersections were built in different parts of London. At that time, when designing intersections, they were guided only by accumulated experience and intuition. Widespread use began in the mid-1960s, when English engineers perfected the system for guiding the flow of cars [1].

In fact, in 1966, the UK adopted a new priority rule – the main road flow moving around the circle has priority over the main road flow entering the circle. With the introduction of this innovation (modification) to roundabouts, the through capacity (by 10-40%, according to a study by the Road Research Laboratory) and traffic safety levels increased significantly. The success of the introduction of modern roundabouts has revived interest in this type of intersections worldwide, especially in Europe.

Since the late 1980s, roundabouts have become a widespread solution for road intersections in several countries, including the Netherlands, Norway, France, Switzerland, Sweden, Switzerland, the United States of America, Australia etc. In the Netherlands, about 400 roundabouts were built in just six years, due to their advantages such as reduced accidents and the absence of the need for traffic lights. In Norway, the number increased significantly between 1990 and 1992, reaching 500 roundabout intersections. France has seen a rapid increase, reaching about 12080 roundabouts at the end of 1994 and more than 27000 in 2005. In Sweden, there has been a significant increase in the number of roundabouts (more than 1000 in 2000), with studies showing that single-lane circles with a central island diameter of 10 to 20 m are the safest, reducing speed and accidents, especially those involving cyclists. The United States began building modern roundabouts in the 1990s with excellent results in reducing accidents, and by 2002 the number had exceeded 600. In the meantime, roundabouts have become very popular in many countries. In Australia, for example, the number has risen to over 10000, in the UK to over 25000 and in France to over 32000 [7].

At busy intersections, waiting times for yielding transportation can be quite long. This would create opportunities for some road users to use all sorts of time-saving tricks. Intersection points and frequent turning conditions create dangerous situations, thus the overall traffic picture becomes seemingly uncontrollable.

The traffic conditions at an intersection have a specific character, due to the existence of points where vehicle flows intersect with each other and vehicle flows with pedestrian flows. These points of contact are called „*conflict points*", as they are where collisions are most likely to occur. In the case of the intersection of two roads with X-shaped two-way traffic (Figure 2a), 32 possible „*vehicle-vehicle*" conflict points can be determined [5-11], of which 16 intersection points (red color), 8 separation points (green color) and 8 merging points (blue color), as well as 8 possible „*vehicle-pedestrian*" conflict points (white color) [12].

As a rule, intersection points represent the greatest potential hazard, since the severity of the consequences of a road accident is greater than in the case of a road accident at the

points where the flows separate or merge. The number of conflict points and the potential danger of the intersection increases [12]:

- as traffic intensity increases;
- in the absence of direction restrictions;
- when the number of traffic lanes increases;
- when the width of the roadway increases;
- in the absence of restrictions on the choice of lanes for the intersection of vehicle and pedestrian flows etc.

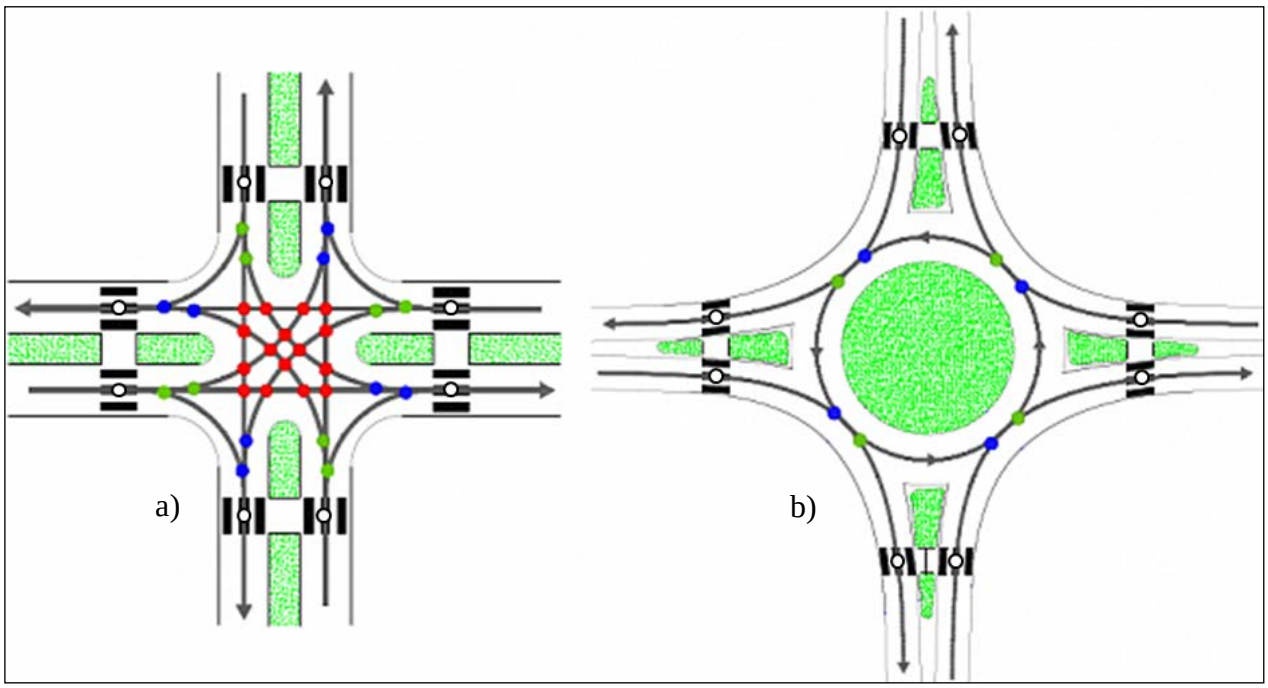


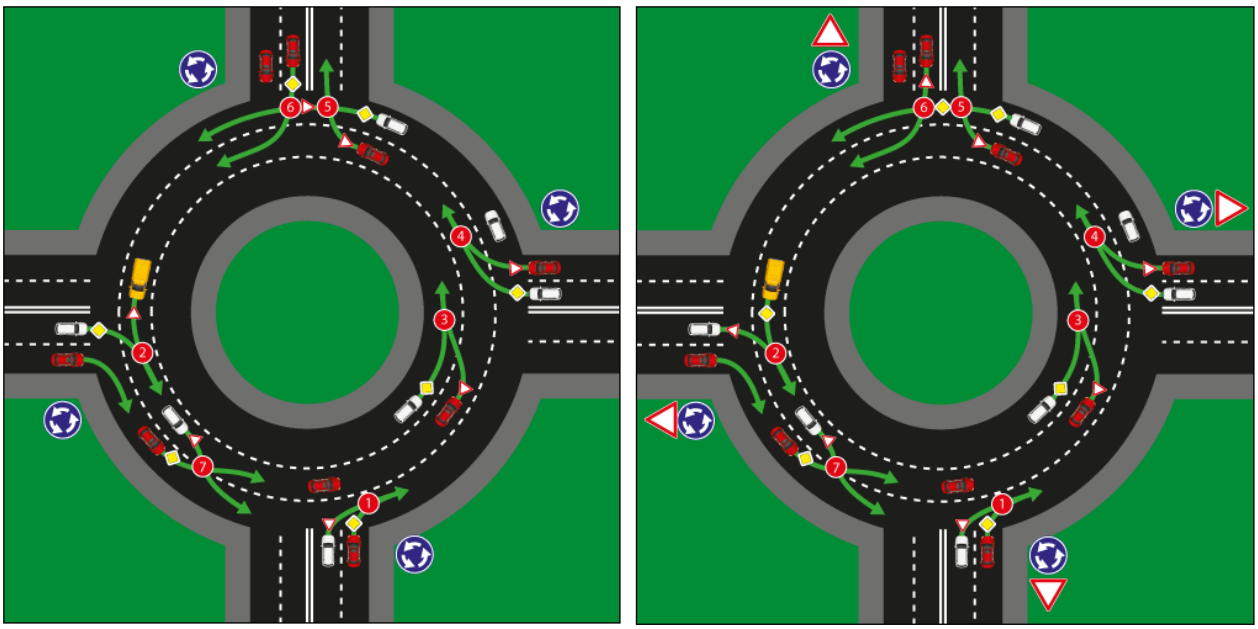
Figure 2. Possible conflict points in an intersection [8]:
a) X-shaped intersection; b) roundabout intersection.

Frequent intersections and junctions of secondary roads with the main road hinder the smooth flow of traffic on the main road, increasing the potential risk of road accidents along its entire length.

The risk of a traffic accident increases, in particular, when traffic intensity on secondary roads increases. In the absence of means of directing traffic, the waiting time at the entrance from the secondary road to the main road can be quite long. This causes drivers on the secondary road to take dangerous actions to reduce the waiting time, e.g. speeding up in order to „*squeeze through*".

Multi-lane roundabouts, although they can increase traffic handling capacity, can create new conflict points between traffic participants (Figure 3). When a roundabout has only one traffic lane, traffic usually flows smoothly. However, in the case of multi-lane roundabouts, vehicles choose different paths based on their intentions to accelerate, which can lead to path intersections.

At the same time, drivers crossing a roundabout tend to travel in the most direct and shortest path. These intersections are not always foreseen in the original design and can create conflicts which, during periods of freer traffic, can be even more frequent, thus increasing the risk of accidents.



a) b)

Figure 3. Possible conflict points at a roundabout intersection multi-lane roundabout [13]: a) equivalent intersection; b) non-equivalent intersection.

Another negative aspect is that widening the roundabout does not always bring a proportional increase in traffic capacity. In multi-lane roundabouts, the center lanes are often less used, which leads to an inefficient use of the whole infrastructure and can cause congestion in the peripheral sections with a higher flow of vehicles. Thus the total capacity of the roundabout does not always align with traffic requirements.

2. Solutions to improve road traffic flow and safety

In order to improve traffic flow and reduce the risk of road accidents on high-traffic priority roads, it is usually recommended to design intersections in two or more levels. Various variants of such intersections are used, but they require large capital investments.

The rich experience of some countries shows that less costly solutions can be used on public roads with low traffic intensity, which successfully improve traffic flow and safety. Proven and effective solutions include [9-11]:

- dividing the X-shaped intersection into two T-shaped ones;
- application of speed limiting measures by raising the intersection area, pedestrian crossing or applying artificial speed bumps;
- channelization (routing) through the space in the form of markings of separating and merging flows;
- channelization of flows by means of graded spaces (islands);
- the organization of additional lanes in order not to hinder the movement of vehicles entering and exiting the intersection when turning right;
- organization of the additional lanes in order not to hinder traffic in the intersection by vehicles turning left;
- organization of the left-turn manoeuvre at right-turning intersections;
- reorganizing the Y- or X-shaped intersection into a roundabout intersection etc.

It is often proposed to build additional traffic lanes to increase the through capacity of busy intersections. Practice in many countries shows that increasing the number of lanes

at intersections leads to an increase in the number of road accidents. Norwegian studies show that after widening the intersection, the number of road accidents with injuries increases on average by 10% and the number of road accidents with property damage doubles. This phenomenon is explained by the following [11]:

- the wider road in the intersection causes drivers to increase speed to cross the intersection faster;
- the wider roadway increases the length of the pedestrian crossing, therefore also the length of time pedestrians is on the roadway side;
- additional traffic lanes increase the willingness and possibilities to change lanes in the vicinity of the intersection, which increases the risk of road accidents not only at the intersection itself but also in the vicinity of the intersection.

Therefore, in order to increase the passing capacity of congested intersections, nowadays more and more often, the reorganization of these intersections into roundabouts is applied. The aim and purpose of roundabout intersections are the following [14]:

- distribution of road flows in nodes with a complex structure and a large number of intersecting roads;
- increasing the through capacity of the intersection and reducing waiting time in front of the intersection;
- increase road traffic safety;
- traffic calming;
- creating an architectural style specific to the urban environment;
- introducing convenient forms of traffic management for left-turning and turning traffic flows;
- reducing noise and traffic speed when locating junctions in close proximity to medical and educational institutions etc.

The organization of roundabouts is not recommended: on road sections with a longitudinal gradient of more than 4%; at the beginning and end of road sections with long slopes and ramps; in the immediate vicinity of railway level crossings; when vehicles with an increased gauge size of more than 25% are present in the traffic flow.

3. Advantages and disadvantages of organizing roundabouts

Roundabout organization has the following advantages [3,7,11,14,15]:

✓ reducing the theoretical number of „*vehicle-vehicle*" conflict points from 32 to 8 (Figure 2b), of which 4 separation points (green color) and 4 merging points (blue color), as well as 8 possible vehicle-pedestrian conflict points (white color);

✓ eliminating the area, where the most serious road accidents occur, with the help of the central island, which „*covers*" the area of the most dangerous intersection conflict points;

✓ the complete elimination of the risk of serious head-on collision road crashes, with only the less dangerous conflict points of separation and merging of road flows, which reduce the likelihood and severity of road crashes;

✓ low speed forcing by design, which forces drivers to slow down on entry, reducing the risk of serious crashes;

✓ achieving the self-regulating property inherent to roundabouts, which ensures a constant uninterrupted flow of traffic at low speed, as opposed to traffic light routing;

✓ one-way routing of traffic inside the circle, which does not cause psychological stress on the driver's part due to the need to monitor traffic from other directions when waiting for the intersection entry interval;

✓ exclusion of left-turn situation and turning maneuver from oncoming traffic;

✓ low traffic speed, due to the smooth and calm rotation around the center island, which allows drivers to adequately assess the traffic situation and respond quickly, and in case of a road accident, the consequences, as a rule, do not become serious for the occupants of the car, being limited only to damage to the vehicle body;

✓ the slow deceleration of the traffic flow on the circle, which reduces the number of braking – stopping – acceleration, helps to reduce the negative impact of transport on the environment (emissions, noise);

✓ achieving more efficient traffic organization when passing through a junction with 4 or more roads;

✓ reduced capital costs compared to multi-level junctions;

✓ reduced maintenance compared to signalized intersections, which require constant electricity, repairs and calibration;

✓ lower long-term costs; once built, a roundabout can operate for decades with minimal intervention;

✓ adaptability, which allows the effective use of roundabouts in various types of intersections: from urban, moderately trafficked intersections to major highway intersections;

✓ increase traffic safety by 1.5-3 times compared to other types of intersections at the same level;

✓ the organization of roundabouts helps to reduce the number of road accidents and the severity of their consequences etc.

Among the disadvantages of the roundabout are [3,14,15]:

➢ need in large areas of land compared to classic intersections, which can be a problem in dense urban areas with old infrastructure or buildings close to intersections;

➢ reduced average traffic speed;

➢ difficulties in organizing the crossing of pedestrians and cyclists in the absence of special infrastructure;

➢ waiting time at the entrance to the circle during rush hours, when priority is given to vehicles traveling on the circle;

➢ difficulties in organizing priority for passing vehicles;

➢ confusion for inexperienced or unfamiliar drivers, roundabouts, which can cause uncertainty or hesitation;

➢ inefficiency in heavy traffic when roundabouts can become congested, requiring additional interventions such as temporary traffic lights;

➢ high upfront costs for design, construction and relocation of existing infrastructure;

➢ increased risk of tipping of vehicles with high center of gravity as traffic speeds increase;

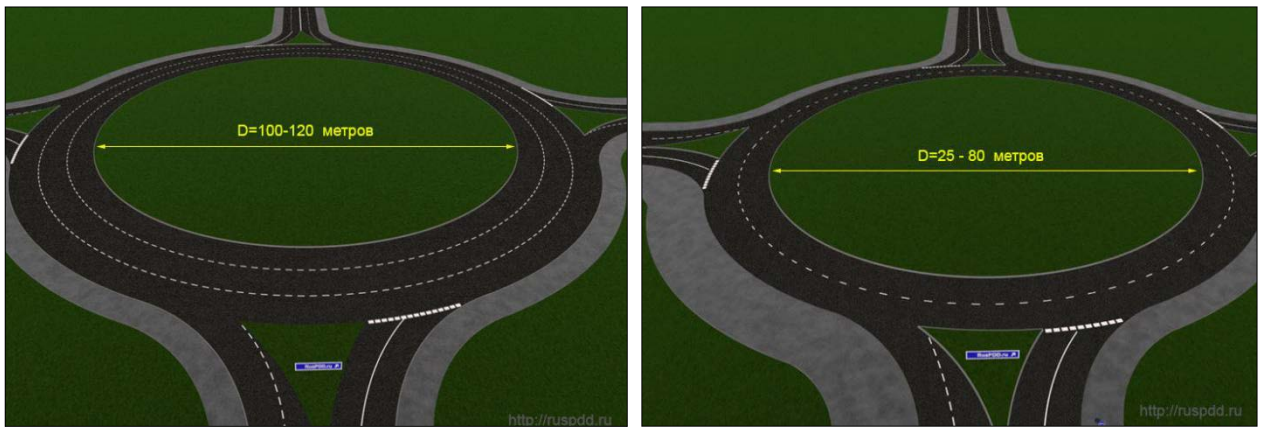
➢ maneuvering difficulties for large vehicles, particularly at small roundabouts, requiring special solutions such as traversable center islands;

➢ the need to create a fairly complex system of information assistance for drivers on traffic conditions etc.

4. Types of roundabouts

In order to ensure a unified approach to the purpose, scope, geometric parameters, design and traffic organization, roundabout intersections are classified as follows [3,12,14]:

Large roundabouts. They are primarily used on roads outside settlements with high design speeds. Entering the roundabout is performed with right turn, driving on the roundabout forward and exiting the roundabout with right turn. The outer diameter of the middle island of these circles is 100-120 m (Figure 4a), the estimated design speed – 50 km/h, the number of converging roads ⩽ 4, the estimated intensity – up to 70 thousand vehicles/24 h, the number of lanes on the entrance/exit – 2/2-3/3 and the number of lanes on the circle roadway – 2-3.



a) b)

Figure 4. Roundabout intersection [3, 12]:
a) large roundabout; b) medium roundabout.

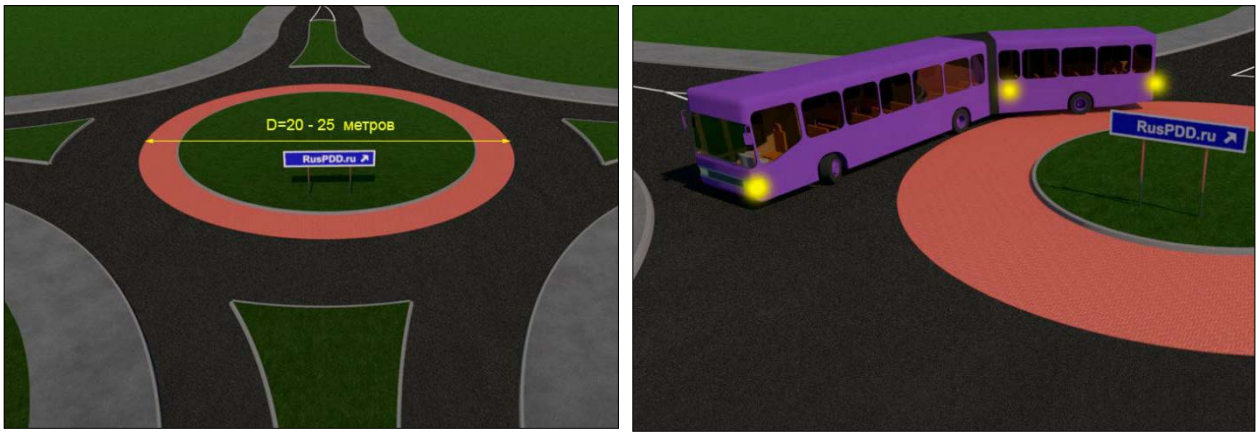
Medium roundabouts. These are the most common intersections of this type for urban and non-urban roads. They possess a fairly high through capacity at a small node area. The outer diameter of the middle island of these circles is 25-80 m (Figure 4b), estimated design speed – 35-40 km/h, number of converging roads ⩽ 5, estimated intensity – up to 35-40 thousand vehicles/24 h, number of lanes on the entrance/exit – 2/2-3/3 and number of lanes on the circle roadway – 2-3.

Small roundabouts. Abroad, this type of intersection is called compact. It is recommended to be used at the nodes of the local road network and trunk road network of regional significance. The outside diameter of the middle island of such circles is 20-25 m (Figure 5a), the outside diameter of the roadway – not more than 30 m, the width of the 4,5-5,5 m, design speed – 25 km/h, number of convergent roads ⩽ 4, estimated intensity – up to 20-25 thousand vehicles/24 h, number of lanes on entry/exit – 1/1 and number of lanes on the circle – 1.

At intersections with small roundabouts it is possible to organize a marginal lane of the middle island for large vehicles (Figure 5b). At such intersections it is no longer logical to apply the „*classical*" maneuvering scheme to the roundabout. Here, the right turn is passed through the circle in a single maneuver, and the entry onto the circle takes place from the steering island tangentially to the middle island.

Mini roundabouts. These are used on local road networks for traffic calming. The outside diameter of the middle island of these circles is 13-18 m (Figure 6a), estimated design speed – 15-25 km/h, number of converging roads ⩽ 4, estimated intensity – up to 15-20

thousand vehicles/24 h, number of lanes on the entry/exit – 1/1 and number of lanes on the circle roadway – 1.



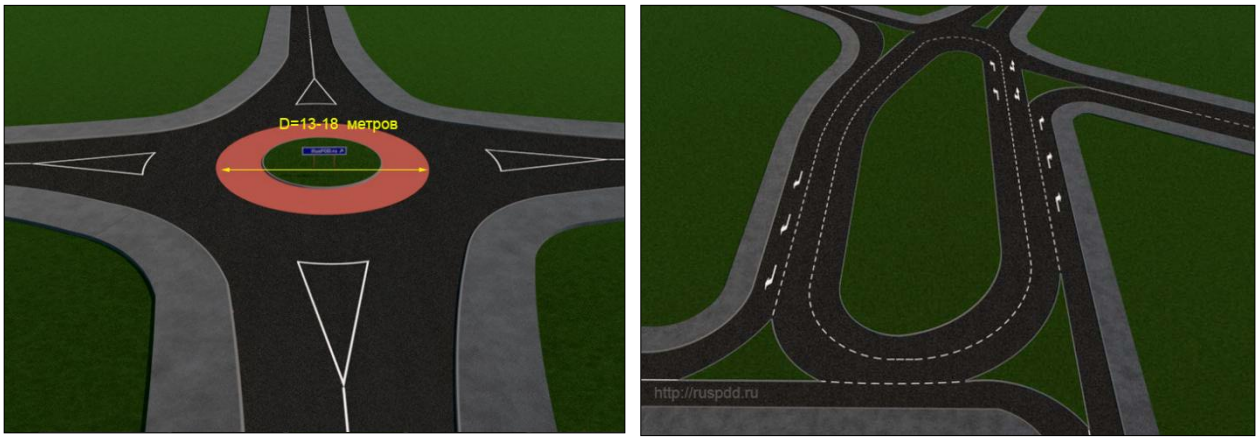
a) b)

Figure 5. Roundabout [3, 12]:
a) small roundabout; b) marginal lane of the middle island for large vehicles.

At intersections with mini roundabouts, as well as at intersections with small roundabouts, a marginal lane of the middle island is organized for large vehicles (Figure 4b). The right turn and the entrance to the circle are identical.

Roundabout road surfaces. These (Figure 6b) represent nodes formed in the process of historical development and organized for roundabout traffic. Road surfaces, when organizing the roundabout on them, are not subject to systematization and classification. The parameters of these intersections are determined by calculation or modeling methods.

The main initial data, in this case, are the dimensions of the road surface, the intensity and composition of road flows, the correspondence matrix, the traffic management schemes on converging streets. At these intersections also the „classical" circular movement does not fit. Traveling in the circle at some exits might continue straight ahead in the right direction, at others go left. The entry on the circle, too, can be performed both in the forward direction and turning right. Estimated design speed – 20-40 km/h, number of converging roads ⩾ 3, estimated intensity – up to 60 thousand vehicles/24 h, number of lanes on the entrance/exit – 1/1-3/3 and number of lanes on the circle roadway – 2-3.



a) b)

Figure 6. Roundabout [3,12]:
a) mini roundabout; b) road surface with roundabout.

Simple roundabout intersections. Undirected intersections and junctions of local roads shall be equipped only with a guide island in the middle with a particularly small diameter, without changing the geometric parameters of the intersection. Travel in the intersection is carried out on the circle, which is provided with priority. It is applied in priority localities for the purpose of traffic calming. The use of central guide islands for traffic guidance is permitted. Simple roundabout intersections are organized under restricted traffic conditions. The central guiding island shall be in the form of a marker or construction with a slight bump for the passage of large vehicles (Figure 7). The outer diameter of the middle island of such circles is 4-10 m, the estimated design speed – 10-15 km/h, the number of converging roads ⩽ 4, the estimated intensity – up to 15 thousand vehicles/24 h, the number of lanes on the entrance/exit – 1/1 and the number of lanes on the circle roadway – 1. Such a roundabout can be organized practically at any intersection of two-lane roads without changing the intersection boundaries.

Figure 7. Simple junction with roundabout [3, 12].

Auxiliary and incomplete roundabout intersections. This category includes intersections with roundabout elements, nodes with a transverse-circular circulation pattern. This type of intersections are designed as traffic nodes (Figure 8). Estimated design speed – 15-30 km/h, number of converging roads ⩽ 5, the estimated intensity – up to 50 thousand vehicles/24 h, the number of lanes on the entry/exit – 1/1-3/3 and the number of lanes on the circle road – 1-3. Roundabouts with complex (non-standard) planning.

Figure 8. Auxiliary and incomplete roundabout intersections [3,16,17].

Turbo-turn intersections, intersections with dual center-guide island, intersections with mini-islands at entrances, intersections with central divided and segmented guide islands. Estimated design speed – 10-20 km/h, number of converging roads ⩽ 5, estimated intensity – 15-50 thousand vehicles/24 h, number of lanes on the entrance/exit – 1/1-3/3 and number of lanes on the circle road – 1-3.

5. Roundabouts with complex planning

Turbo-turned intersections (Figure 9) are multi-lane signalized intersections highlighted by a low curb stone in a spiral. They are formed by the arrangement of a central guiding island with a particularly complex shape and channelization of traffic. Their organization is due to the need to exclude additional conflict points at the intersection of vehicle traffic paths in the case of a two-lane roundabout. The throughput capacity of turbo-roundabout intersections is 3 to 5.5 thousand vehicles/h.

Pioneers in the development and implementation of turbo-turns are traffic engineers from the Netherlands. The main reason for the implementation of the new type of roundabout is the unsatisfactory traffic safety results in multi-lane roundabouts under high traffic intensity conditions**.**

In the Netherlands, multi-lane roundabouts are no longer built and those that are built are reorganized as turbo-roundabouts. The application of turbo-roundabouts is permitted by British design standards and it is recommended that the management of vehicle flows in the roundabout should be achieved by road markings only. In the Netherlands low kerbs are used to separate the lanes of the roundabout. Roundabouts have become the subject of research and analysis in Germany.

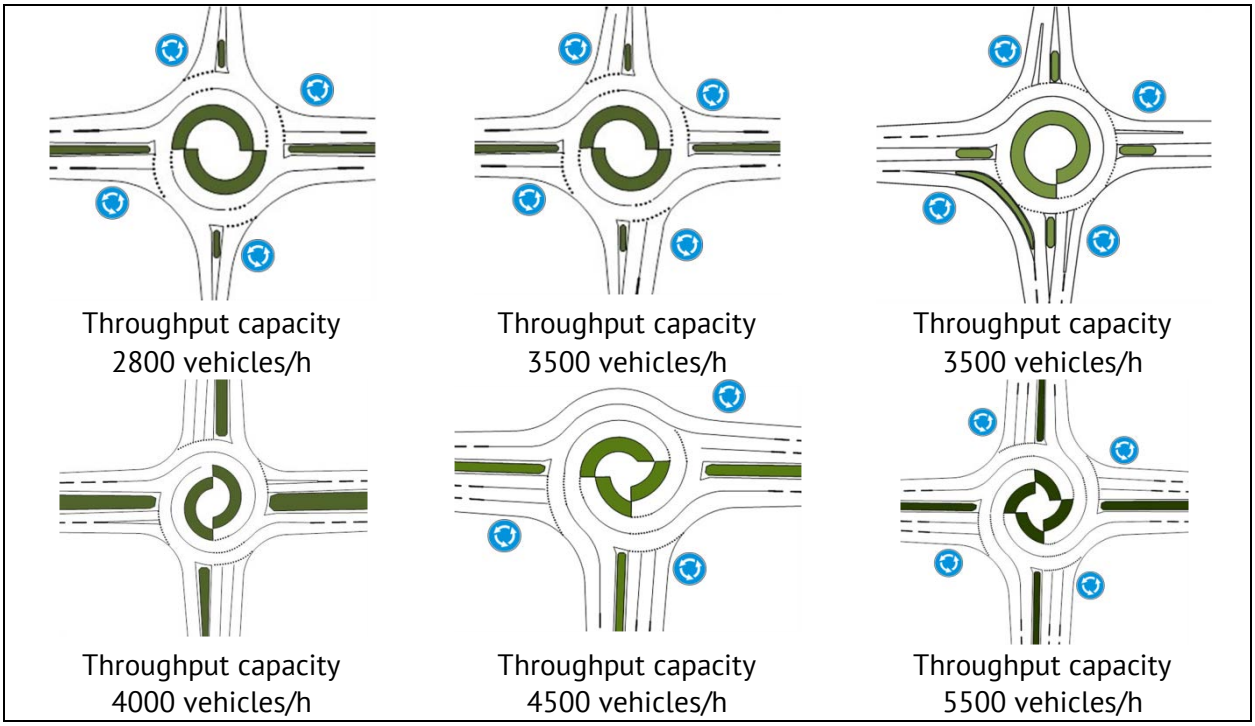


Figure 9. Turbo-turn junctions [3,14].

Turbo-turn intersections work on the principle of an uncoiled spiral, which extends outwards. Entering the outer ring of the turbo-turn, the vehicle moves in the same way as in a normal roundabout. The innovative element of the roundabout is the principle of moving

the vehicle, which has entered the roundabout on the inside lane. Travelling in the inside lane, the vehicle travels in a very clearly delimited strip by curbs, so that on exiting it will be on the outer ring, without colliding with vehicles in other lanes.

The main features of turbo-turn are the following [18]:

- two or more traffic lanes are organized, arranged by separation with a spiral curb;
- the required lane must be chosen before entering the roundabout, consulting the signs and road markings;
- when entering the roundabout, the driver shall give priority to vehicles in the roundabout and, if necessary, cross one or two traffic lanes;
- in the turbo roundabout, flow crossings or lane-to-lane maneuvers are not permitted and are not possible because of the curb.

The advantages of turbo-turn are the following:

✓ simple and clear roundabout entry situation, when the driver gives priority to the vehicles traveling in the roundabout;

✓ traffic fluidity and prevention of bottlenecks due to better organized traffic flow, thus reducing the risk of congestion;

✓ the risk of road accidents due to lane changing is excluded;

✓ the need for careful speed control due to lane dividers etc.

The traffic lanes in turbo-turn roundabouts are separated by a low kerb. Thanks to this separation, the vehicle moves only within its own separate lane without the risk of colliding with another vehicle while maneuvering.

At present, specialists in the Netherlands distinguish five types of four-input turbo-turns (Figure 9). The Dutch classification of the roundabout is based on the criterion of the number of lanes into and out of the roundabout. The need to change the number of entry/exit lanes is determined by the actual traffic distribution picture in the roundabout. The safety of traffic flow at intersections is determined not only by the number of conflict points but also by the type of conflict. In turbo-roundabout roundabouts there are no intersection and narrowing conflicts, the only conflict is generated by the need to give priority to the vehicles on the roundabout. In this situation driver behavior is easily

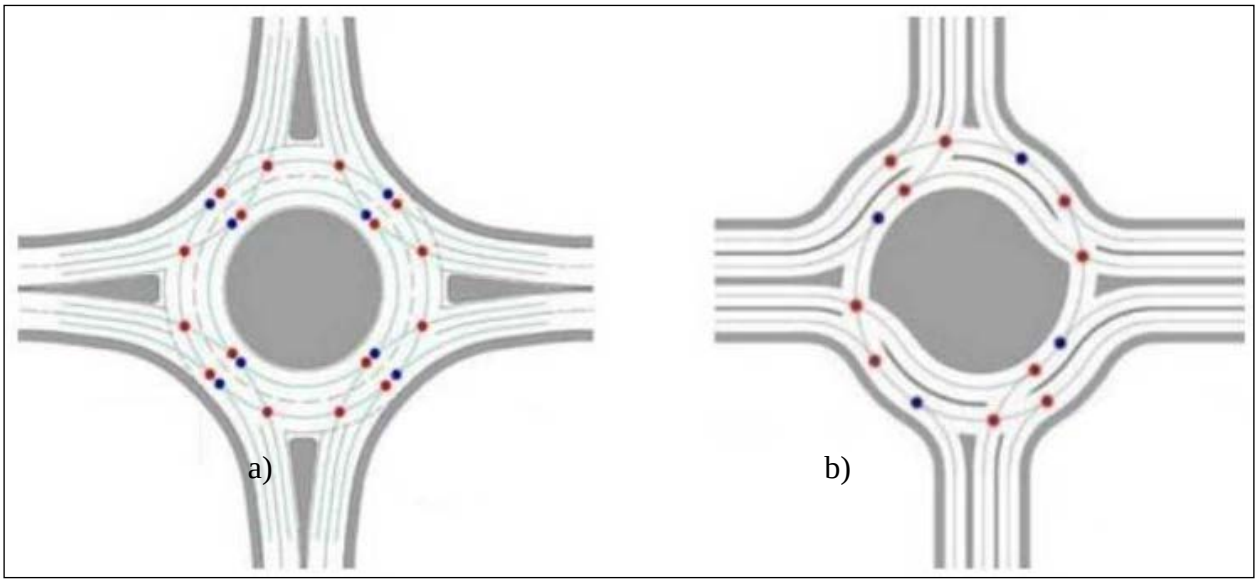


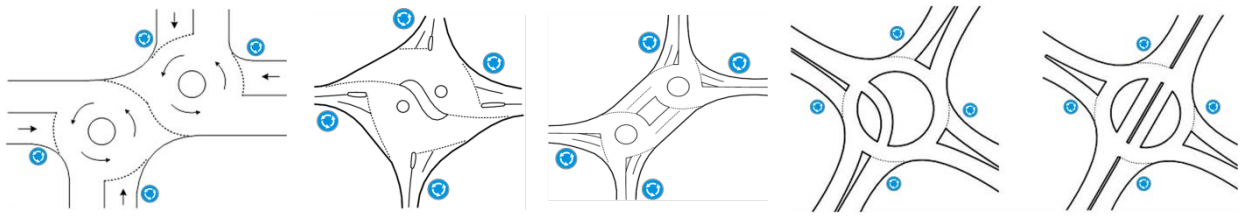
Figure 10. Points of conflict in a roundabout intersection [3, 19]:
a) classic; b) turbo-turn.

predictable as the vehicles travel in separate lanes. The separation of the traffic lanes helps to reduce the traveling speed, which reduces the risks.

The reorganization of the four-entry multi-lane roundabout into a turbo-roundabout reduces the number of conflict points from 24 to 14 (Figure 10), where the red marked points are the points of merging or intersection of road flows, and the blue marked points are the points of separation of road flows.

The problem of organization of roundabouts with turbo-roundabouts is more complex than the design of modern classical roundabouts. However, even if the costs of arranging roundabouts with turbo-turns are slightly higher than in the case of ordinary roundabouts, these investments are operationally recovered due to the significant increase in traffic safety and minimization of the number of road accidents, including financial and material losses, as well as saving lives.

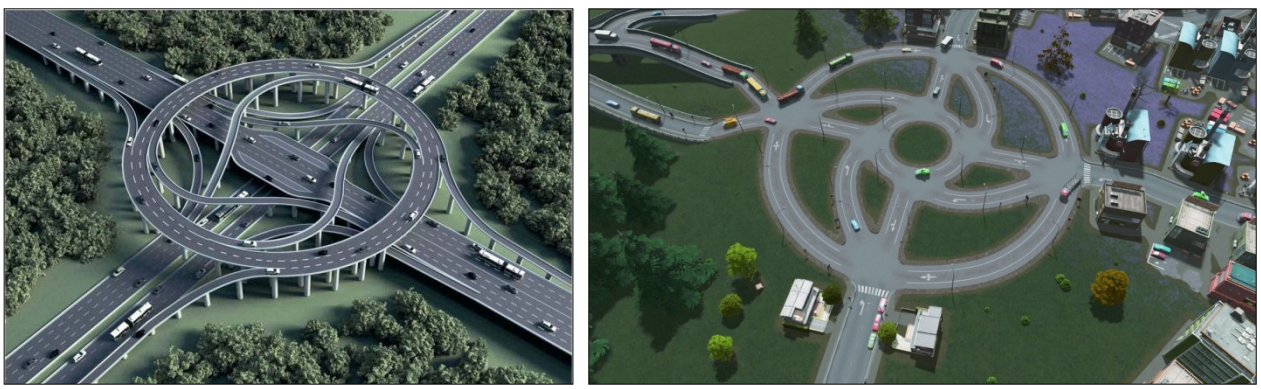
On the local road network, where it is not possible to create regular intersections, it is recommended to use roundabout intersections, using a number of organizational solutions (Figures 11a and 11b), in order to ensure the self-regulation of the traffic process. In order to facilitate the passage of other types of vehicles, e.g. trams and other routing vehicles on the lane specially reserved for them, intersections with split and segmented central guide islands are organized (Figure 11c) [14].



a) b) c)

Figure 11. Roundabout intersections with complex planning [3, 14]:
a) roundabout at a displaced intersection; b) roundabout at a complex junction with sewers; c) intersections with split and segmented central guidance islands.

Technical solutions, which considerably reduce the number of conflict points and increase the crossing capacity of the intersection, but require huge capital investments, are roundabout intersections with turbine-turn (Figure 12a). A simpler and lower-cost solution are turbo-turn intersections of a special design (Figure 12b).



a) b)

Figure 12. Intersections with turbo and turbo-turn [3, 20]:
a) with turbo-spin; b) with turbo-spin.

„Magic roundabout" intersections. This complex intersection (Figure 13) consists of five smaller roundabouts that direct traffic clockwise around a central circle that operates counter-clockwise [21]. Despite its strange appearance, this configuration is much more efficient than the classic roundabouts. Each of the outer circles serves for the entry and exit of cars on the corresponding road.

Experienced drivers can cross the intersection more efficiently (yellow line), thus saving time, and less experienced drivers can go with the flow, bypassing the edges on the large outer circle (red line).

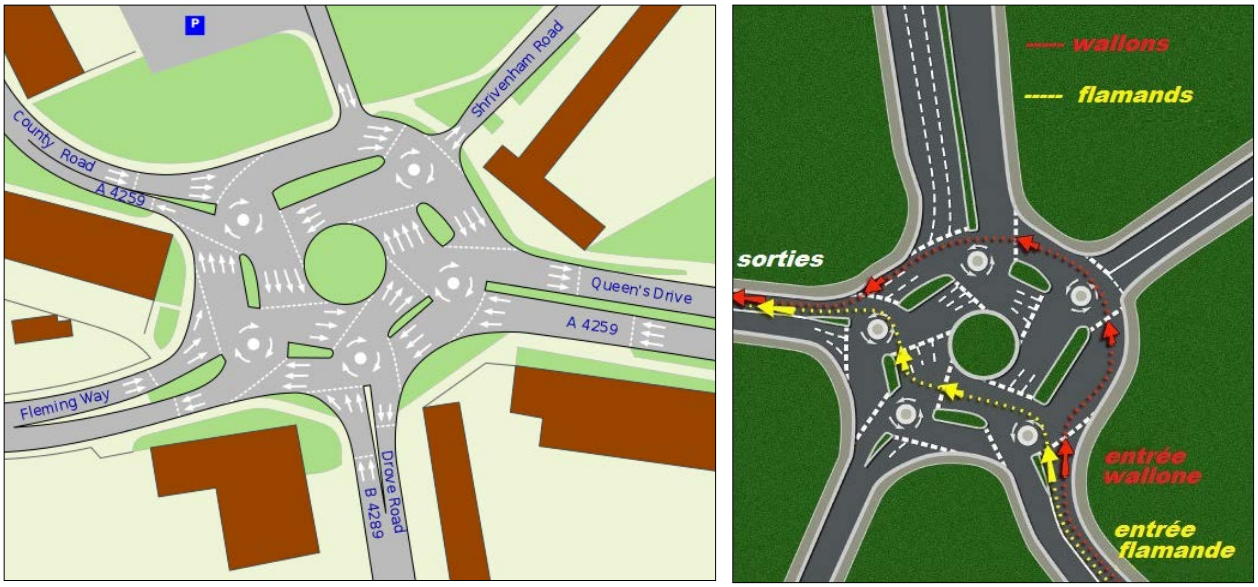


Figure 13. Intersection with „magic roundabout" [3,21].

The junction was designed by engineer Frank Blackmore, who worked at the British Transportation and Road Research Laboratory. Swindon's famous junction came into being in 1972. It was originally called the County Isles, but was quickly renamed the „*magic roundabout*", eventually becoming the official name.

Despite negative comments in the press, the Swindon junction has surprisingly good safety and efficiency indicators. The main property of the junction is the simplicity of the rules. Efficiency is achieved by reducing traffic speeds and increasing driver attention.

6. Benefits of roundabout organization

The roundabout intersection with regard to traffic safety occupies an intermediate position between a simple undirected and a directed intersection. Research in the UK, Denmark, Sweden, Norway, Australia, the Netherlands, Switzerland, Germany, the Netherlands, Norway, Australia, Switzerland etc. has shown the following [14,21,22]: roundabout intersections generally reduce total road accidents by 35%, road accidents with fatalities by 90%, road accidents with injuries by 75%, road accidents involving pedestrians by 35% and road accidents involving cyclists by 10%. According to the road accident severity index, roundabout intersections are more effective on roads outside settlements, where the number of road fatalities is reduced by more than 2 times. At roundabout intersections in built-up areas this index is 18-20%.

Roundabout intersections provide a higher through capacity than regular X-shaped intersections, both directed and undirected. This is explained, by transforming the flow of

intersecting or turning flows, which are usually related to waiting periods and can create obstacles to other flows, into decelerated traffic on the circle. Although, the circular path reduces the speed of movement, the total intersection crossing time decreases, as the need for a complete stop of vehicles occurs quite rarely.

The magnitude of the time gain depends on the traffic intensity, the variations in traffic intensity during the day and the distribution of transportation flows on the side roads entering the circle, therefore it is difficult to present general figures. In a study in Germany it was observed that the waiting time for a car at a roundabout intersection is on average 15 s shorter than at a traffic-light controlled intersection with a traffic intensity of 500 to 2000 cars/h. A study in Sweden of 20 non-equivalent undirected intersections that were reorganized into roundabout intersections showed that cars entering from the main road lost an average of 2.3 s/car, while cars entering from the secondary road gained 4.4 s/car [21].

Recently, in Western European countries (especially Germany and France), active X-shaped intersections are being actively replaced by roundabout intersections. Prerequisites for the implementation of such measures, serve the high content of toxic gases in the area of intersections and their reduced passing capacity. The controlled traffic flow requires the transport flow to move in a stop-brake-accelerate mode. This traffic regime is accompanied by an increase in harmful emissions into the atmosphere. The reorganization of the X-shaped intersection transforms the polluting transport flow regime into a cleaner and more fluidized regime of continuous circular motion.

In a study in Denmark it was observed that the emission of hydrocarbons (HC), carbon oxides (CO) and nitrogen oxides (NO_x), calculated in grams/km travelled, is on average 5-10% lower when driving through a roundabout than when driving through a traffic light controlled intersection. A study in Sweden showed a 29% reduction in carbon monoxide emissions and a 21% reduction in nitrogen oxides emissions after reorganizing the traffic-light controlled intersection into a roundabout [20].

A group of researchers at Kansas State University (USA) carried out an experiment, recording vehicle emissions at six locations: three classic intersections and three roundabouts. Twice a day (morning and evening), the scientists measured the amount of pollutants in the air and recorded them. The results confirm that vehicles at roundabouts emit significantly less harmful substances than vehicles at regular intersections. On average, carbon monoxide emissions fell by 33% and carbon dioxide, which is America's most polluting pollutant, by 46%. Other gases, such as nitrogen oxides and hydrocarbons, fell by a third and a half respectively.

The social and aesthetic benefits are to improve the pedestrian appearance and can serve as community landmarks. Roundabouts can be landscaped with green spaces, fountains or works of art, contributing to the aesthetics of the city. They can also be used at urban and rural intersections, highways and parking lots. Mini and turbo roundabouts are ideal for improving safety and flow in busy neighborhoods.

While roundabout intersections offer many advantages, they are not without their critics and challenges. One of the main complaints is related to driver confusion, especially among inexperienced drivers and those unfamiliar with the rules of the road at such intersections.

Another aspect criticized is the space needed to build a roundabout. In densely populated urban areas, the creation of such a roundabout may require the demolition of

buildings or significant changes to existing road infrastructure. These modifications can be costly and may be resisted by the local community.

Also, roundabouts are not always the best solution for all intersections. In the case of extremely busy intersections, they can become overloaded and cause bottlenecks, especially during rush hours. In such situations, alternative solutions, such as intelligent traffic lights or zebra crossings, may be more effective.

7. International road accident statistics after roundabout implementation [1]

Australia. In 1981 the results of the implementation of 73 roundabouts were evaluated. There was a 74% decrease in the rate of road accidents, while property damage from road accidents decreased by 32% and the number of road accidents involving pedestrians decreased by 68%. For 3 years there were no fatal road accidents.

In 1990, at the 15th Australian Road Research Board conference, an analysis of road accident statistics at 230 intersections in New Wales before and after their conversion to roundabouts was presented. The average number of road accidents at an intersection per year fell by 41.5% from 3.910 to 2.289, the average number of road accidents with persons injured at an intersection per year – by 45.4% from 1.045 to 0.571 and the average number of persons killed at an intersection per year – by 62.5% from 0.024 to 0.009.

Belgium. In Wallonia in the 90s of the last century, the number of roundabouts increased 10-fold, while the total number of road accidents at roundabouts increased only 2-fold. In the period 1992-2000, the experience of converting 122 undirected intersections into roundabouts was studied, while it was found that:

✓ the average number of road accidents with traumatized persons at an intersection per year after the transformation was reduced by 41.6%, from 1.352 to 0.789;

✓ the average number of serious road crashes at an intersection per year was reduced by 48% from 0.373 to 0.194.

UK. During research in 1984, it was found that the annual number of road accidents at roundabout intersections averaged 3.31, of which only 16% were road accidents with injuries and fatalities, and the average number of road accidents per 100 million vehicles passing through roundabouts was 27.5. Studies carried out in this country indicate that roundabouts have led to a decrease in waiting times by up to 20% and a reduction in road accidents by up to 50% in some regions [23].

Repeated studies on the evaluation of road accidents at different roundabouts have been carried out between 1999 and 2003. It was established, that the average number of road accidents at a roundabout per year was 1.77, of these only up to 7% were road accidents with traumatized and fatalities. Compared to 1984, the rate of road accidents at roundabouts has decreased by 46.5%.

Netherlands. At the end of 1992, 181 roundabouts were surveyed in the Netherlands. The intersections were previously undirected, but due to the high rate of traffic accidents, they were converted into roundabouts as a result:

✓ the average number of road traffic accidents at an intersection per year after the transformation was reduced by 51% from 4.9 to 2.4;

✓ the average number of people traumatized at one intersection per year has been reduced by 71.5% from 1.3 to 0.37.

USA. According to a report by the Federal Highway Administration, there are more than 7000 roundabouts in the United States and the number is growing. This expansion is

supported by data showing that, on average, roundabouts reduce fatal crashes by 90% and total crashes by 75% compared to traditional signalized intersections [23].

According to a federal source in 2000 a study was conducted at 24 intersections converted to modern roundabouts in the states: California, Colorado, Florida, Kansas, Kansas, Maryland, South Carolina and Vermont. The effect was as follows: reduction in the number of road accidents – 39%; reduction in the number of road accidents with injured persons – 76%.

The above-mentioned source reported that a study of 15 small, single-lane roundabouts on the roadway side of a circle in Maryland (2002) showed their exceptional effectiveness. The following results were obtained: reduction in the number of accidents road accidents – 60%; reduction in the number of road accidents with traumatized persons – 82%; number of fatalities – 100%; reduction in property damage only – 27%.

A more recent study of 8 intersections in Maryland published the following data:

✓ the average number of traffic crashes at an intersection per year after the transformation was reduced by 75.8%, from 5.9 to 1.43;

✓ the average number of traffic crashes per 100 million vehicles passing through the intersection decreased by 76.7%, from 1.59 to 0.37 after the transformation.

Another interesting fact: 60 roundabouts have been built in the city of Carmel, Indiana (more than in any other city in the United States) and, as a result, there has been an 80% reduction in injuries and a 40% reduction in road accidents [7].

According to the Institute for Highway Safety, modern roundabouts generally show a reduction in American practice:

- of road accidents with fatalities of 90%;
- 76% of road accidents with trauma;
- 30-40% of road accidents involving pedestrians;
- 10% of road accidents involving cyclists.

A 2004 study estimated that converting 10% of classic intersections in the US to roundabouts would have prevented 51000 traffic crashes in 2018, including 231 fatalities and approximately 34000 road crashes with trauma. It notes that the study covers single-lane intersections. Meanwhile, a 2019 Insurance Institute for Highway Safety study also found that the safety of two-lane roundabouts also improves over time as drivers get used to the new roundabout. Researchers analyzed roundabout intersections built in Washington State between 2009-2015 and found that traffic crashes at two-lane roundabouts decreased by an average of 9%/year [24].

France. An analysis of the results of the implementation of 83 roundabout intersections in France in 1986 showed the following indicators:

✓ the average number of road accidents with traumatized persons at an intersection per year after the conversion was reduced by 78.2%, from 1.42 to 0.31;

✓ the average number of fatalities per intersection per year has decreased by 82.4% from 2.78 to 0.49;

✓ the average number of persons killed at an intersection per year decreased by 87.5% from 0.16 to 0.02.

Germany. In 1995, an experiment was carried out in Germany in which 13 ordinary undirected intersections were converted into mini roundabouts. It was established that the use of a mini roundabout instead of a regular intersection in an urban environment leads to a significant reduction in accidents and average road accident damage:

✓ The average number of road accidents per 1 million vehicles passing through the intersection decreased by 29.1% from 0.79 to 0.56 after the transformation;

✓ The average number of serious road accidents per intersection per year decreased by 48% from 0.373 to 0.194.

8. Conclusion

According to road accident statistics at roundabout intersections, unlike traditional roundabouts, there are almost no head-on, right-turn and left-turn collisions. The reasons are speed reduction and one-way traffic. These characteristics of roundabouts generally reduce total road crashes by 35%, road crashes with fatalities by 90%, road crashes with injuries by 75%, road crashes involving pedestrians by 35% and road crashes involving cyclists by 10%.

In conclusion, it is safe to say that, with the stated aim of increasing road traffic safety, improving environmental safety and increasing road capacity, which reduces waiting times at intersections and subsequently translates into savings, roundabout intersections are a great solution. The organization of roundabouts from every technical and architectural point of view is of major practical interest for many countries, including the Republic of Moldova.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Modern roundabouts, Irkutsk, 2009. Available online: http://transport.istu.edu/downloads/books/deponent_3.pdf (accessed on 24.09.2024) [in Russian].
2. Ukaderov, V.V. Improving the organization of traffic through intersections. Master's thesis, Krasnoyarsk, 2022, 80 p. [in Russian].
3. Goian, V.; Plămădeală, V.; Beiu, I. Organization and safety of road traffic. Volume 4. Organization and safety of vehicle traffic in various conditions and traffic situations. University course. Tehnica-UTM, Chisinau, RM, 2021, 306 p. ISBN 978-9975-45-721-7, ISBN 978-9975-45-724-8 (PDF) [in Romanian].
4. Intersections. Roundabouts. Available online: https://wiki.zr.ru/Перекрестки._Круговое_движение (accessed on 26.09.2024) [in Russian].
5. Onceanu, V.; Voleac, P. Roundabout design considerations. Available online: https://ibn.idsi.md/sites/default/files/imag_file/352-359_2.pdf (accessed on 26.09.2024) [in Romanian].
6. Plămădeală, V.; Goian, V.; Beiu, I. *Organization and safety of road traffic. Technical means of organizing and directing road traffic*. Volume 3. University course. Tehnica-UTM, Chisinau, RMN, 2021, 450 p. ISBN 978-9975-45-721-7, ISBN 978-9975-45-728-6 (PDF) [in Romanian].
7. Road Usability: Roundabouts. Available online: https://lpgenerator.ru/blog/2015/12/21/yuzabiliti-dorozhnogo-dvizheniya-krugovye-razvyazki/ (accessed on 26.09.2024) [in Russian].
8. Goian, V.; Plămădeală, V.; Beiu, I. Organization and safety of road traffic. Normative acts, safety elements and characteristics of road traffic. Volume 1. University course. Tehnica-UTM, Chisinau, RM, 2021, 341 p. ISBN 978-9975-45-721-7, ISBN 978-9975-45-722-4 (PDF) [in Romanian].
9. Onceanu, V. *Organization and safety of road traffic*. Elena VI, Chisinau, Republic of Moldova, 2006, 273 p. ISBN 978-9975-935-94-4 [in Romanian].
10. Onceanu, V.; Armașu, S. *Road traffic safety management and audit*. Tehnica-UTM, Chisinau, Republic of Moldova, 2011, 240 p. ISBN 978-9975-45-175-8 [in Romanian].
11. Operating principles of a roundabout and its advantages over an X-shaped intersection. Available online: http://www.ador.ru/data/files/static/audit_16.pdf (accessed on 26.09.2024) [in Russian].
12. Roundabouts in the Russian Federation. Available online: https://zen.yandex.ru/media/ruspdd/krugovoe-dvijenie-v-rf-5c1bd62bb7cd5100aad3a9d2 (accessed on 27.09.2024) [in Russian].
13. How to determine priority at a roundabout? Available online: https://ruspdd.ru/journal/62-krugovoe-dvizhenie-prioritet/ (accessed on 27.09.2024) [in Russian].
14. Methodological recommendations for the development and implementation of measures to organize traffic. Increasing the efficiency of using roundabouts. Available online: https://files.stroyinf.ru/Data2/1/4293734/4293734704.pdf (accessed on 28.09.2024) [in Russian].

15. Roundabouts: pros, cons, accident statistics. Available online: https://avtoshkolamost.ru/articles/krugovye-perekrestki (accessed on 28.09.2024) [in Russian].
16. The second stage of the Piskarevskaya interchange has opened in St. Petersburg. Available online: https://topdialog.ru/2014/11/29/v-peterburge-otkrylas-vtoraya-ochered-piskarevskoj-razvyazki/ (accessed on 28.09.2024) [in Russian].
17. The Hippodrome intersection has taken away the Haabersti Circle's title as a traffic jam magnet. Available online: https://rus.postimees.ee/6244032/perekrestok-u-ippodroma-otobral-u-kruga-haabersti-titul-magnita-probok (accessed on 27.09.2024) [in Russian].
18. Ambrosi, Gr.; Ambrosi, E. Turbo-gyration as a method of improving road traffic safety. In: *Materials of the national scientific-practical conference „Transport: engineering, economics and management"*, Chisinau TUM, 2017, p. 59-62. ISBN 978-9975-45-511-4 [in Romanian].
19. Draft new standard for roundabouts. Available online: http://transspot.ru/2017/09/25/proekt-novogo-standarta-na-kolcevye-peresecheniya/ (accessed on 25.09.2024) [in Russian].
20. Turbine-ring interchanges: the end of traffic jams! Available online: https://hodor.lol/post/159468/ (accessed on 30.09.2024) [in Russian].
21. England's „Magic Roundabout" lets cars navigate six circles. Available online: https://cfts.org.ua/news/2016/08/05/volshebnaya_krugovaya_razvyazka_v_anglii_propuskaet_avtomobili_cherez_shest_kolets_video_35620 (accessed on 30.09.2024) [in Russian].
22. Capsky, D.V. *Traffic management. Accident rate: analysis, assessment, forecasting. Study guide for students majoring in 1-44 01 02*. Traffic management, Minsk, Belarus, 2023, 439 p. ISBN 978-985-583-849-5 [in Russian].
23. Roundabout speed limit. Available online: https://www.topgear.ro/sens-giratoriu-viteza-legala/?utm_source=chatgpt.com (accessed on 30.09.2024) [in Romanian].
24. Why we need roundabouts: studying accident statistics. Available online: https://110km.ru/art/krugovye-perekrestki-udobno-voditelyam-bezopasno-peshehodam-134693.html (accessed on 26.09.2024) [in Russian].

Citation: Pădure, O.; Plămădeală, V.; Goian, V. Roundabout – element of safety, ecology and economy. *Journal of Engineering Science*. 2025, XXXII (2), pp. 7-25. https://doi.org/10.52326/jes.utm.2025.32(2).01.

Submission of manuscripts: jes@meridian.utm.md