

# Determination of the types of road accidents at roundabouts

Vladimir Rassokha<sup>1</sup>, Nikolai Nikitin<sup>2\*</sup>, Yulia Savina<sup>2</sup>

<sup>1</sup>Orenburg State University, Faculty of Transport, 460018, Orenburg, Victory Avenue, 13, Russia

<sup>2</sup>Immanuel Kant Baltic Federal University, Institute of Engineering and Technology, 236022, Kaliningrad, Lieut.-Gen. Ozerova Street, 57, Russia

**Abstract.** The main purpose of this study was to identify and analyze the prevailing types of accidents at roundabouts. The relationship was revealed between certain types of accidents, the place of their occurrence, and the configuration of the roundabout. The study analyzed 321 accidents at 19 ring intersections. Four predominant crash types were identified: rear-end collision, collision with vulnerable road users, side swipe collision, and entering circulate collision. The greatest number of accidents occurred at the weaving lane and at the entrances and exits of the roundabout. Dividing the ring intersections into separate sections to determine the location of the accident allows drawing conclusions on the nature of road traffic accidents and the impact of the roundabout design on safety.

## 1 Introduction

Roundabout is a type of intersection configuration strongly associated with improved road safety. International studies of intersections, which were transformed from regular ones to roundabouts, indicate significant reductions in road traffic accidents, especially with serious injuries and fatalities [1–7]. Roundabouts improve road safety by reducing the number of conflict points and traffic speed, which leads to a decrease in the severity of the consequences of road accidents [8]. According to the international studies, there are three predominant types of traffic accidents at roundabouts: collisions between vehicles entering the roundabout and those moving along it, collisions at roundabout exits, and collisions with vehicles driving ahead [9–12].

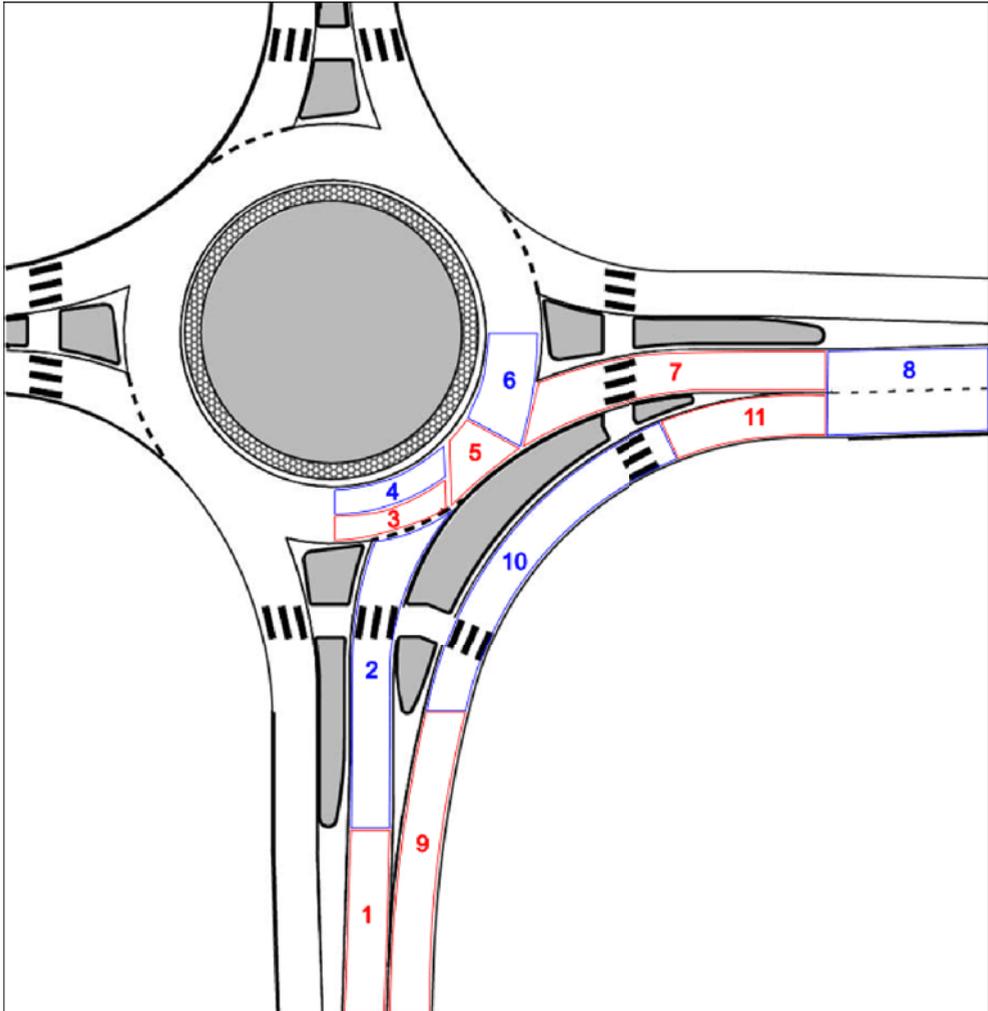
A large number of studies are focused on the characteristics of traffic safety at roundabouts, but due to the peculiarities of collecting data on road accidents in the Russian Federation, there is practically no information about the exact location of the accident. Therefore, this study is aimed at identifying and analyzing the most common types of accidents at roundabouts. Mandavilli [9] and Montella [10] analyzed accidents with consideration to their location on the ring intersection. The ideas proposed by these scientists were used by the authors to improve the accuracy of describing road traffic accidents. This study suggests distinguishing 11 sections, which makes it possible to better understand the cause of the accident, as well as to accurately take into account the location of vehicles on the roundabout. For each section, the prevailing type of accident is determined, which in turn

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\* Corresponding author: [ninikitin@kantiana.ru](mailto:ninikitin@kantiana.ru)

connects the causes of the accident with the characteristics and configuration of the ring intersection. A similar approach has already been applied to other types of intersections, such as unsignalized intersections [13,14], motorway exits [15], and service roads [16].

The analysis involved road accidents that occurred from 2015 to 2021. The data for the research was taken from open sources: the traffic police database and the car communities. In total, information was received on 321 road traffic accidents resulting in property damage or injury, including 315 road accidents at 13 multi-lane roundabouts, 5 road accidents at 5 two-lane roundabouts, and 1 road accident at 1 single-lane roundabout. To classify accidents, the conditional ring intersection was divided into a certain number of sections (Figure 1) in accordance with the data obtained from the work of other researchers [9].



**Fig. 1.** Dividing the roundabout into sections.

The division into individual sections allows for a wide variety of roundabout configurations to be considered. Figure 1 shows the intersection that includes the largest number of elements, e.g. a bypass.

Due to the large number of different roundabout designs, the general characteristics of each section were determined (Table 1).

**Table 1.** Roundabout sections and their description

<b>Roundabout section</b>	<b>Description</b>
<b>Approach and entrance to the roundabout</b>	
Section 1	25-150 meters before the roundabout. Entering traffic flows and congestion queues.
Section 2	0-25 meters before the roundabout, up to the marking. Includes pedestrian crossings.
<b>Roundabout roadway</b>	
Section 3	Located at the entrance to the roundabout roadway, right after the marking. In the case of a multi-lane roundabout, it occupies the outer and middle traffic lanes.
Section 4	Continuation of section 3. Located opposite the entrance to the roundabout. If available, includes a truck apron. In the case of a multi-lane roundabout, it occupies the inner lane.
Section 5	Located on the roundabout roadway, in the zone of conflict points of weaving lane. It is advised to locate the beginning and end of the section at 5-10 meters from the entrances and exits.
Section 6	Located on the roundabout roadway opposite to the roundabout exit.
<b>Roundabout exit</b>	
Section 7	0-25 meters after the roundabout roadway. Includes pedestrian crossings.
Section 8	25-200 meters or more. Outgoing traffic flow. The size of the zone depends on the location of the nearest intersections.
<b>Bypass</b>	
Section 9	The beginning of the lane for the bypass. Located at the widening of the roadway.
Section 10	A section that includes pedestrian crossings at the entrance and exit from the roundabout.
Section 11	The end of the lane for the bypass. Located at the narrowing of the roadway.

## 2 Methodology

### 2.1 Distribution of accidents by roundabouts and severity of consequences

To display the real situation at intersections, the official statistics, which only take into account accidents with victims, were supplemented with data on accidents with material damage, which accounted for 82% of the total number of accidents. The data were distributed with consideration to the roundabout intersections at which the accident occurred (Table 2).

**Table 2.** Distribution of road accidents by roundabouts and severity of consequences

<b>№</b>	<b>Number of accidents</b>	<b>Road accidents with victims</b>	<b>Road accidents with serious injuries</b>	<b>Road accidents with fatalities</b>	<b>Road accidents with property damage</b>
1	186	12	2	1	174
2	15	4	0	0	11
3	5	4	0	0	1

№	Number of accidents	Road accidents with victims	Road accidents with serious injuries	Road accidents with fatalities	Road accidents with property damage
4	8	8	2	0	0
5	7	7	1	0	0
6	27	10	1	1	17
7	61	2	0	0	59
8	0	0	0	0	0
9	5	3	1	0	2
10	1	1	0	0	0
11	1	1	0	1	0
12	0	0	0	0	0
13	1	1	0	0	0
14	0	0	0	0	0
15	1	1	1	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	2	2	0	0	0
19	1	1	0	0	0
Total	321	57	8	3	264
	100.00%	17.76%	2.49%	0.93%	82.24%

Roundabouts 1, 6, and 7 are characterized by the highest number of accidents, which is due to their location at the intersection of main city streets and high traffic intensity. However, it should be noted that roundabouts 2, 4, and 9 are in similar conditions, but the number of accidents on them is substantially lower. Such a difference may be due to various factors, the most likely of which can be the lack of accurate information on accidents with property damage. This fact requires additional research, which is beyond the scope of this work.

## 2.2 Distribution of accidents by sections

The largest number of accidents occurred in weaving lane on the roundabout roadway (Table 3). The sections at the entrances and exits of the roundabout are the next, with the minimum difference in the number of accidents.

**Table 3.** Distribution of road accidents by sections at circular intersections

Roundabout section	Total amount of accidents	Percentage
<b>All sections</b>	<b>321</b>	<b>100.00%</b>
Section 1	22.00	6.85%
Section 2	33.00	10.28%
Section 3	21.00	6.54%
Section 4	4.00	1.25%
Section 5	65.00	20.25%
Section 6	32.00	9.97%

Roundabout section	Total amount of accidents	Percentage
Section 7	47.00	14.64%
Section 8	9.00	2.80%
Section 9	3.00	0.93%
Section 10	1.00	0.31%
Section 11	3.00	0.93%
Total for sections		74.77%
Unknown section		25.23%

The minimum number of accidents was recorded in sections 9, 10, and 11, which may be due to the fact that only one of 19 roundabouts has a bypass.

It should also be noted that for 25% of accidents it is impossible to determine the section of the roundabout, due to the lack of an accurate road accident diagram. This problem can be solved by applying foreign experience in compiling collision diagrams to determine the nature of road accidents [9,10]. The advantage of this approach is the possibility to clearly identify the prevailing types of accidents at the roundabout, and the maneuvers of vehicles that led to the collision. Using the graphic design of the arrows, one can encode information about the time of day, weather, type of road traffic accidents, and the severity of injuries. Another approach to collecting data on road accidents is the application of neural networks that allow processing data on traffic flows in real time using video cameras located near streets and roads. The experience of collecting such information has already been applied by Russian researchers [17]. Further development of such detection systems can be the registration of road accidents with the possibility of reconstructing the road user trajectories, which will allow analyzing the causes of accidents to prevent similar accidents in the future.

### 2.3 Types of accidents

There are nine types of road traffic accidents in Russia [18]:

**Table 4.** Classification of road accidents in Russian legislation

Type of accident	Description
Collision with a stationary vehicle	An accident in which a moving vehicle collides with a stationary vehicle or trailer.
Collision with an obstacle	An accident in which a moving vehicle collides with a stationary object.
Collision with a pedestrian	An accident in which: <ul style="list-style-type: none"> <li>• a moving vehicle hits a person;</li> <li>• or a person bump into a moving vehicle;</li> <li>• or a person is injured by the cargo transported by a vehicle that protrudes beyond the dimensions of the vehicle.</li> </ul>
Collision with a cyclist	An accident in which a moving vehicle collides with a cyclist or a cyclist collides with a moving vehicle.
Collision with an animal	An accident in which a moving vehicle collides with birds, wild or domestic animals, or the animals and birds hit a moving vehicle, resulting in injury to people or property damage.
Collision with an animal-drawn vehicle	An incident in which a moving vehicle collides with draft animals or animal-drawn carts, or the draft animals or animal-drawn carts hit a moving vehicle.

Type of accident	Description
Crash	An accident in which moving vehicles crash: <ul style="list-style-type: none"> <li>• with each other;</li> <li>• or with railway rolling stock;</li> <li>• or with a suddenly stopped vehicle.</li> </ul>
Roll-over	An accident in which a moving vehicle overturns.
Other accidents	They include: <ul style="list-style-type: none"> <li>• the fall of a transported cargo on a person, an animal, or other vehicle,</li> <li>• collisions with a suddenly appeared obstacle (a dropped load, a detached wheel, etc.),</li> <li>• collisions with persons who are not road users,</li> <li>• passengers falling from or inside a moving vehicle due to sudden braking, acceleration, or a change in direction of movement, et al.</li> </ul>

The analysis of this classification showed that it does not meet the objectives of this study. In this regard, a different classification is proposed, which allows a more complete description of the types of accidents occurring at roundabouts:

**Table 5.** Road accident classification for roundabouts

Type of accident	Description
Run-off-road	A single vehicle accident in which the vehicle drives off the road and collides with an off-road object, such as a traffic sign or traffic island.
Collision with the central island	A single vehicle accident in which a vehicle collides with a center island.
Wrong way	A road user enters the roundabout in an unacceptable direction or moves along the roundabout in the wrong direction.
Rear-end collision	An accident in which a vehicle collides with the rear of a vehicle ahead.
Loss of control	An accident that occurs as a result of the loss of control by one or more road users.
Collision with vulnerable road users	A complex concept that includes collisions with pedestrians, cyclists, motorcyclists, and users of low mobility devices.
Entering circulate collision	An accident in which an entering vehicle does not give way and collides with a vehicle on a ring intersection.
Side swipe collision	An accident that occurred when changing a lane on a roundabout or at a roundabout exit.
Falling passenger	An accident in which a passenger falls in public transport.

The proposed classification was developed based on the analysis of the most common accidents. It allows classification not by the participants, but by the nature of the incident. The types of accidents can be modified, for example, «collision with the central island» can be combined with «loss of control». It should be noted that Russian studies on the identification of factors that affect road accidents [19] will make it possible to further refine this classification and to determine what information should be included in the accident diagram.

## 2.4 The relationship between the type of accident and the location on the roadway

The types of road accidents were divided into sections at the roundabout in accordance with the place of their occurrence (Table 6).

**Table 6.** Types of road accidents distributed by sections at the roundabout

Type of accident	Number of accidents	Percentage
<b>All sections</b>	<b>321</b>	<b>100.00%</b>
<b>Run-off-road</b>	<b>4</b>	<b>1.25%</b>
Section 7	2	0.62%
Section 9	1	0.31%
Section 11	1	0.31%
<b>Collision with the central island</b>	<b>3</b>	<b>0.93%</b>
Section 4	3	0.93%
<b>Wrong way</b>	<b>2</b>	<b>0.62%</b>
Section 3	2	0.62%
<b>Rear-end collision</b>	<b>57</b>	<b>17.76%</b>
Section 1	2	0.62%
Section 2	8	2.49%
Section 3	6	1.87%
Section 5	19	5.92%
Section 6	3	0.93%
Section 7	10	3.12%
Section 8	6	1.87%
Section 9	1	0.31%
Section 11	2	0.62%
<b>Loss of control</b>	<b>6</b>	<b>1.87%</b>
Section 5	2	0.62%
Section 6	1	0.31%
Section 7	2	0.62%
Section 9	1	0.31%
<b>Collision with vulnerable road users</b>	<b>26</b>	<b>8.10%</b>
Section 1	1	0.31%
Section 2	11	3.43%
Section 5	1	0.31%
Section 7	10	3.12%
Section 8	2	0.62%
Section 10	1	0.31%
<b>Entering circulate collision</b>	<b>15</b>	<b>4.67%</b>
Section 2	2	0.62%
Section 3	9	2.80%

Type of accident	Number of accidents	Percentage
Section 5	3	0.93%
<b>Side swipe collision</b>	<b>78</b>	<b>24.30%</b>
Section 1	11	3.43%
Section 2	5	1.56%
Section 3	2	0.62%
Section 4	1	0.31%
Section 5	22	6.85%
Section 6	22	6.85%
Section 7	15	4.67%
<b>Falling passenger</b>	<b>5</b>	<b>1.56%</b>
Section 1	1	0.31%
Section 3	1	0.31%
Section 5	1	0.31%
Section 6	1	0.31%
Section 7	1	0.31%

Table 6 shows that a significant number of accidents occurred in sections 5 and 7. Rear-end collisions most often occurred on the roundabout weaving lane and at the exit in section 7. Entering circulate collisions occurred in section 5 due to the characteristics of the participants and the roundabout configuration, in this case, one of the participants was a large cargo vehicle. Sections 2 and 7 are characterized by a predominance of accidents involving vulnerable road users. Side swipe collisions most often occurred in sections 1, 5, 6, and 7, which is largely due to the presence of several lanes at the approach to the roundabout and directly on the roundabout roadway. Only in section 3 there was an accident with an incorrect choice of direction of movement, but the sample size of this type of accident is too small to draw any further conclusions.

The four main types of accidents - rear-end collisions, collisions with vulnerable road users, entering circulate collisions, and side swipe collisions - account for more than half (55%) of all roundabout accidents.

### 3 Conclusion

This study was aimed at the determination of the types of accidents at roundabouts. The number of intersections studied was relatively small (19 roundabouts) and as a result, the study may have some limitations. However, the purpose of this paper was not to compare the roundabouts with each other, but to determine the types of prevailing road traffic accidents, as well as the places of their occurrence. The resulting sample of 321 accidents at ring intersections coped with this goal.

There is reason to believe that dividing the roundabouts into sections and identifying the most frequent accidents in these sections will provide new data on the nature of road accidents and the impact of the roundabout configuration on their occurrence.

The results obtained show that road accidents more often occurred at the weaving lane (section 5), entrances (sections 1-3), and exits (sections 6 and 7). The four most common types of accidents have also been identified. Side swipe collision is the most common type of crash at the intersections under study. The highest percentage of such accidents is at the weaving lane and at the exit sections, which indicates that drivers have violated the trajectory of movement and tailgated when changing lanes. Rear-end collisions most often occurred at the weaving lane of the roundabout and at the exit (section 7). From the point of view of road

safety, the study results indicate the presence of a systemic problem at multi-lane roundabouts, which manifests itself in the occurrence of accidents in the most conflict areas.

Pedestrian crossings located near roundabouts are a source of increased danger. It is noticeable by the prevalence of this type of road traffic accident in sections 2 and 7. Despite the decrease in speed on the approach to the roundabout, the complexity of the road network section forces the driver to distribute attention to many external factors, which leads to increased fatigue and inattention. Therefore, it is recommended to construct pedestrian crossings at a distance from the ring intersections to improve the safety of vulnerable road users, which is an established practice in other countries [7].

The results of this research work have identified promising areas for further research. Future studies of accidents occurring at roundabouts should explore in detail the relationship between the prevailing crash patterns, their location in terms of specific intersection sections, and roundabout characteristics such as speed limit, location (urban or regional), road geometry, multi-lane, and the presence of bypasses.

Further development of road traffic accident research depends directly on the quality and quantity of the source data, which requires a change in the approach to their collection and processing. It is proposed to make mandatory the transfer of data from insurance companies and accident managers about road accidents that have caused only material damage.

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