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№ 10270

Research on the Safety of the Intersection with Circular Traffic

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May 26, 2023

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Abstract. The Motor roads ensure continuous, safe and convenient movement of vehicles. In terms of capacity, level of service and safety, intersections play a critical role in the road network. They differ in type, regulatory priority and design features. Special attention is paid to the intersection with circular traffic (roundabout), as it is safer compared to other types because vehicles approaching the intersection must give way to vehicles that are already on it. Intersections with circular traffic are designed in different sizes for different purposes and conditions and have their own defining characteristics that can affect their safety and convenience.
The article presents the results of the study of the intersection with circular traffic in the city of Dubno (Rivne region, Ukraine). The research describes the geometric construction features, organization of traffic, and evaluates its safety.

Keywords: Roundabout Designs, Geometric Elements, Safety Assessment, Safety Performance, Traffic Safety.

1 Introduction

Motor roads are extremely important for the economic development of Ukraine and the whole world. Road intersections are critical elements of the road network in terms of capacity, service level and safety (Pan et al., 2021). They are places where opposing

traffic flows are constantly changing, thereby changing the road situation (Stevanovic and Mitrovic, 2019; Renkas et al., 2021).

In the general provisions of the Road Traffic Code of Ukraine (Fomenko et al., 2023), the term intersection is defined as "the place of crossing, meeting or branching of roads on the same level, the boundary of which is the imaginary line between the beginning of the rounding of the edges of the carriageway of each of the roads".

There are two main groups of intersections: intersections without priority traffic and ones with priority traffic. At intersections without priority traffic, drivers moving to the right have the right of passage. Intersections can have three, four or more levels and can be designed with different layout solutions. At intersections with priority traffic, the right of passage is regulated by road signs, road markings, and traffic lights regulation.

The intersection with circular traffic is one of several types of intersections where traffic slows down and turns into a one-way flow around a central island. They are sometimes called roundabouts.

Considerations regarding safety and high capacity of roundabouts have led to a significant increase in their number. Conversely, when the growing demand for transport services leads to the fact that the existing intersections no longer cope with the task, then they are converted to other types.

In practice, there are many variations of intersection types. Therefore, the unification of intersections is limited, often due to the traffic situation at the site, the necessary costs for their construction, the available space and the social impact of their implementation.

Depending on the type of intersection of road sections (geometric configuration that best describes their intersection), 8 main types are distinguished. They are presented in Fig. 1

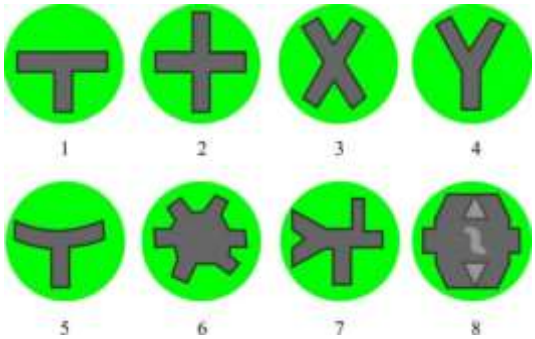

Fig. 1. Types of intersections:
1 – T-intersection; 2 – four-way intersection; 3 – X-intersection; 4 – Y-intersection; 5 – вилоподібне; 6 – roundabout; 7 – mixed; 8 – with a switch (Lianzhen et al., 2021; SWOV, 2022)

The Traffic Code of Ukraine (Fomenko et al., 2023) stipulates that “the main condition for ensuring safety when driving through an intersection is the determination by the driver of priority in traffic, that is, the right to priority movement in relation to other road users”.

The sequence of actions for safe passage of an intersection is as follows:

- take the appropriate traffic lane, taking into account markings and road signs;
- reduce the speed of the vehicle;
- determine the type of intersection, presence of traffic light regulation, etc.;
- evaluate the road situation for crossing the intersection;
- determine the presence of an advantage in traffic (necessity to give way to other road users);
- stop the vehicle in the appropriate lane, taking into account a possible change in the situation;
- make a safe passage of the intersection.

An important condition for the safe passage of an intersection is its visibility, which is affected by the technical structures, fencing elements, geometric (relief) features of the road, the presence of vehicles on the roadside, natural and climatic conditions, the presence of lighting, etc.

Each intersection has its own geometric boundaries, which must be easily recognizable (it is especially relevant in cases when there are no horizontal markings or technical means of traffic management).

The widespread use of intersections with circular traffic was launched in the mid-1960s by British engineers to overcome capacity constraints and for safety reasons (Pumphrey). Today, such intersections are usual everywhere.

The physical configuration of a modern roundabout, with its deflected entrance and speed limit at the entrance, forces the driver to reduce speed on the approach, entrance and while traveling within the roundabout (this is in contrast to the traditional intersection, which drivers try to pass faster or “skip the prohibition signal”).

The general rules for driving through an intersection with circular traffic are as follows. When approaching the intersection, it is necessary to occupy the appropriate lane, give way to vehicles that are already at the intersection, and enter it, making sure to have a safe maneuver (in a safe interval of traffic flow).

If it is necessary to change the traffic lane, the corresponding signal is given, and after passing the vehicles that are going in the adjacent lane, to change the lane (the traffic lane can only be changed in places with a broken white line). It is necessary to pay attention to cyclists, who also have the right to a full traffic lane.

It is recommended to keep a low, steady speed while continuing to drive around the circle. When approaching the desired exit, turn on the turn signal so that other drivers know about your intention. Exiting an intersection usually does not require additional slowing down or stopping (the only exception is pedestrians in a crosswalk or approaching emergency vehicles).

Intersections with circular traffic are usually designed for the movement of vehicles with a speed of up to 40 km/h, which is ensured by (Pilko et al., 2014):

1. the regulation of the speed of traffic approaching the intersection, pre-established signs, road markings and a given change of the traffic trajectory;

2. the required radius of the central island and its shape (as a rule, the diameter is from 20 to 50 meters);

3. the number and width of traffic lanes (the higher the traffic intensity, the larger the size of the intersection);

4. larger radii on exits to speed up traffic;

5. the installation of pedestrian crossings at different levels.

Access capacity at the entrance is an equally important operational factor of a modern intersection. It is determined by the organization of traffic and its geometric configuration (Fig. 2)..

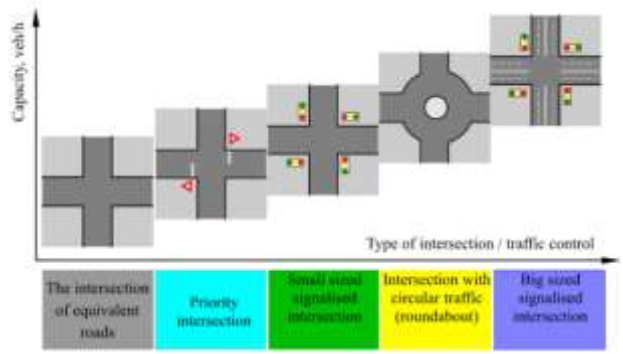

Fig. 2. Capacity of the intersection by its type and organization of traffic (Koren et al., 2010)

2 Literature Review

Roundabout intersections are designed in different sizes for specific purposes and operating conditions. For example, mini-roundabouts (up to 25 m in diameter) effectively reduce speed and increase safety, while larger roundabouts (over 40 m in diameter) provide more capacity (Pratelli et al., 2020).

Conflict situations at the intersection may arise due to a significant difference in the speed of traffic flow and traffic intensity, direction priority. That is why, from the point of view of traffic safety, it is necessary to take measures to regulate (reduce) speed at intersections (or near them) (SWOV 2022).

It was proved that intersections with circular traffic reduce traffic jams due to the cancellation of left turns, thus drivers are not delayed in the traffic flow and make a right turn to exit it (TEA).

For example, in the state of Indiana, starting in 2016, 256 roundabouts were installed instead of traffic light regulation, which led to a decrease in the number of accidents, delays, fuel consumption, and air pollution. Overall, the number of fatalities decreased by 90%, the number of pedestrian accidents by 30-40%, and the traffic capacity increased by 50% (Broom).

Dr. ir. Atze Dijkstra (2014) points out that the safest intersections are the intersections with circular traffic. They reduce the possibility of angular and head-on collisions, contribute to the reduction of speed due to the change of the traffic trajectory (accidents at roundabouts occur at a much lower speed than at traditional intersections, and, accordingly, with less consequences).

Design Engineer Amarnath Acharya (2018) describes the following advantages and disadvantages of a roundabout. Roundabouts are considered safer than traffic-controlled intersections for the following reasons: lower speed of approaching and circling vehicles; speed is regulated both by road geometry and regulatory signs. Disadvantages of an intersection with circular traffic include the need for a larger area compared to an intersection with regulated traffic, an excessive number of maneuvers and speed changes during its passage

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3 Purpose of the Research, Data and Methodology

The Safety at the intersection is primarily determined by the number of conflict points, as well as the amount of conflicting flows at each conflict point.

The degree of complexity m of an intersection with circular traffic according to conflict points and geometric features of the construction is defined as (Kashkanov and Kuzhel, 2017)

$$m = n_b + 3 \cdot n_z + 5 \cdot n_p \quad (1)$$

where n_b is the number of conflict points of divergence (deviation) at an intersection with circular traffic; n_z is the number of conflicting merging points at a roundabout intersection; n_p is the number of conflicting crossing points at a roundabout.

An important characteristic of a roundabout is the intensity of traffic (the more vehicles pass, the better, but at the same time the risk of an accident increases). The degree of complexity of an intersection with circular traffic according to the traffic flow intensity index m_{σ_N} is calculated with the formula (Lobashov and Prasolenko, 2011)

$$m_{\sigma_N} = \sum_{i=1}^{n_b} \sigma_{Nib} + 3 \sum_{i=1}^{n_z} \sigma_{Niz} + 5 \sum_{i=1}^{n_p} \sigma_{Nip}, \quad (2)$$

where σ_{Ni} are coefficients that take into account the influence of the intensity of traffic flows in conflict situations: deviation, merging, crossing.

The degree of danger of each conflict point q_i of an intersection with circular traffic is calculated as follows (Lobashov and Prasolenko, 2011)

$$q_i = K_i \cdot N_i \cdot N_j \cdot 25 \cdot 10^{-7} / K_n \cdot K_r, \quad (3)$$

where N_i, N_j is intensity of interacting flows of the conflict point, cars/hour; K_i is the coefficient of the relative accident rate of the conflict point (the number of road accidents per 10 million vehicles); K_n is the coefficient of the transition from hourly to daily traffic flow intensity; K_r is the coefficient of annual unevenness of the traffic flow.

A probable accident rate G_p (annual number of road accidents at the intersection) is calculated using the formula (Lobashov and Prasolenko, 2011)

$$G_p = -0{,}468 + q_a + \sum_{i=1}^{n} q_i, \quad (4)$$

where q_a is the number of possible emergency situations on the approach to the intersection.

The level of ensuring traffic safety K_a at the intersection is calculated with formula (Lobashov and Prasolenko, 2011)

$$K_a = G_p \cdot K_r \cdot 10^7 \,/\, 25 \cdot N_s, \qquad (5)$$

where N_s is total daily intensity of traffic at the intersection in all directions, cars/day

4 Research results

The city of Dubno (Rivne region, Ukraine) is a small town with a specific transport network. There are classical intersections of various types for crossing streets there.

On-the-spot observations of the main roads and city streets showed that in the city of Dubno, there are 95 unregulated intersections and 3 intersections with regulated traffic (Fig. 3), most of which are of the "T(Y)-shape" type. There is also one intersection with circular traffic (Fig. 4).

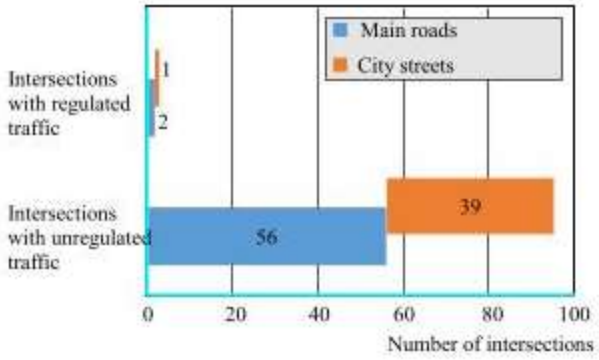

Fig. 3. The number of intersections in the city of Dubno by the method of traffic regulation

Since 2016, various projects have been actively implemented in the city of Dubno aimed at modernizing the road network, intersections, arranging bicycle lanes, and improving transport and communication infrastructure. Such changes will increase traffic safety and capacity of the road network, and will improve traffic conditions for the annually growing traffic flow.

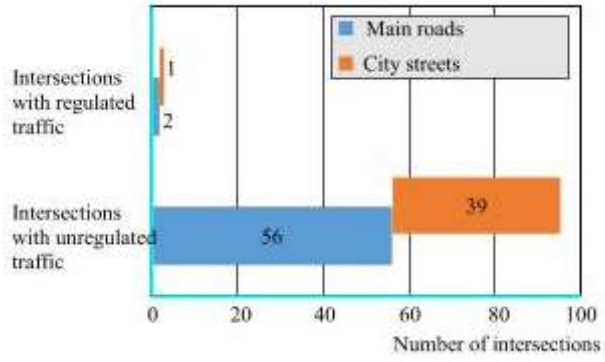

Fig. 4. The number of intersections in Dubno by their type

Special attention was paid to the regulated intersection of Semydubska, Mykhailo Hrushevskyi, Myrohoshchanska and Surmychi streets. The mayor of the city of Dubno, Vasyl Antoniuk (IPCD), explained that "the capacity of this intersection will soon be exhausted, and its operational indicators do not meet the requirements of the existing and projected traffic intensity; this situation is dangerous and may lead to an increase in the number of traffic accidents... (at this intersection, road accidents most often occur, mainly related to violation of traffic rules by pedestrians)". In 2018, this intersection with traffic light regulation was re-planned into a circular one, in which traffic flows move counterclockwise around the central island, and traffic entering the intersection must give way to traffic flows moving around it in a circle (Fig. 5).

Fig. 5. Design peculiarities of the intersection with circular traffic in the city of Dubno: 1 – pedestrian crossing; 2 – splitter island; 3 – apron; 4 – circulatory roadway; 5 – sidewalk; 6 – landscape design (gardening); 7 – central island; 8 – entry width; 9 – exit width

Technical means used to organize and regulate road traffic (traffic and pedestrian flows) include road signs, information boards, road markings, signal posts, traffic and pedestrian fences of various types, traffic light equipment, video surveillance, etc. The scheme of traffic organization of this intersection with circular traffic in the form of

placement and interconnection of technical means of traffic organization can be presented as follows (Fig. 6).

At the entrance to the intersection with circular traffic in Dubno, there is a solid white dividing line to separate the flows of vehicles moving in opposite directions. There is also a broken white line, which divides two lanes of traffic at the intersection. It can be crossed to change the lane and the direction of traffic.

Fig. 6. The scheme of traffic organization of the intersection with circular traffic in the city of Dubno

Different types of road signs of different groups are provided for the organization of the passage of the intersection: priority, mandatory, informative and indicative ones.

For the convenient movement of pedestrians around the intersection, sidewalks and special places for crossing the road are provided.

Traffic monitoring is carried out using a video surveillance system (four cameras are installed at the intersection). The cameras are equipped with panning and zooming functions, as well as with the possibility of remote control from the Control Center).

Although traffic control devices are aimed at reducing the number of conflicts, they cannot completely eliminate them because of the deliberate violation of traffic rules by drivers and pedestrians.

The obtained results regarding the safety of the selected intersection with circular traffic are summarized in Fig. 7.

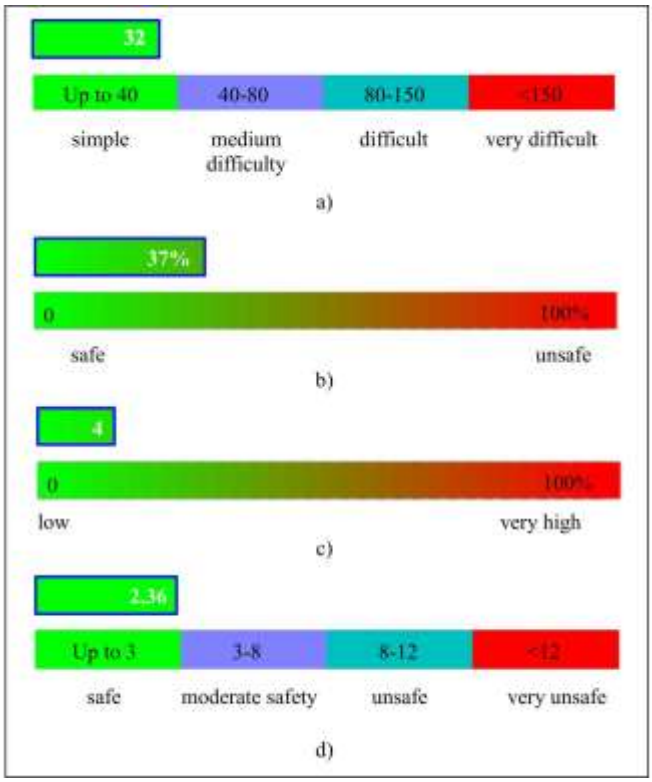

Fig. 7. The results regarding the safety of the intersection with circular traffic in the city of Dubno: a – the degree of complexity of the intersection; b – general level of danger by conflict points; c – probable annual number of traffic accidents; d - general traffic safety at the intersection

5 Conclusions

Thus, each intersection with circular traffic has its own defining characteristics that can affect its safety and convenience of travel, which was confirmed by the research of different scientists. Such intersections require careful planning taking into account specific road conditions and future operation.

According to the conducted research, the intersection in the city of Dubno is simple in terms of the organization of crossing and is quite safe.

Acknowledgement

The research reported in this article was conducted at the National University of Water and Environmental Engineering with the support of the Department of Economy and Property of the Dubno City Council

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