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MODERN ROUNDABOUTS: GLOBAL EXPERIENCE AND IMPLEMENTATION IN UKRAINE

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Abstract. The article analyzes modern solutions for the design of roundabouts that have been developed in Europe in the last decades, briefly provides a history of the development of such elements of road infrastructure. The three main newly developed types of such intersections that are most common are considered: turbo roundabout, «flower» roundabout (or a roundabout with «depressed lanes») and mini-roundabout. Key features of the geometric and physical structure of turbo roundabout intersections are given, as well as information on their impact on traffic safety and the capacity of the intersection, recommendations on traffic flow parameters. The main inherent elements of the «flower» roundabout are given, the results of computer modeling of its bandwidth with the help of specialized software are given, the characteristics of traffic that make this solution the most appropriate are shown. The article also briefly examines the history of the development of mini-roundabout intersections in the United Kingdom, provides general information about their structure, variants of the design and principles of functioning. The results of empirical observations on the efficiency, safety and appropriateness of such intersections conducted in the United Kingdom, Germany and Croatia in the 1970s and 2000s are presented. For each type of the intersection the conditions that substantiate use of the solution, the schemes of geometrical design and an example of implementation are given.

The implementation of similar solutions in Ukraine, which has taken place in recent years, is analyzed also. Both the existing example of a turbo roundabout and the domestic theoretical and regulatory framework for the implementation of such solutions are analyzed. The analysis showed that building codes provide almost no explanations for the physical and geometric structure of turbo roundabouts and their elements, and there are no significant recommendations on the conditions under which it is advisable to use one or another type of intersection. The directions in which the theoretical and regulatory base should be improved in order to ensure the successful implementation of modern more advanced types of roundabout traffic in Ukraine have been identified.

Keywords: intersection, roundabout, modern roundabout, traffic, road safety, streets, turbo roundabout, mini-roundabout.

Statement of the problem. Crossroads are vital part of the transport infrastructure, on which the overall capacity and safety of the transport network largely depemds. One of the common types of intersections are roundabouts. Today in Ukraine, the street and road network are dominated by traditional for urban planning large-radius roundabouts with one or more lanes, which does not provide maximum efficiency in terms of safety and capacity of the intersection compared to more modern planning solutions.

New types of roundabout intersections are also being introduced in Ukraine, the structure of which is organized according to modern European models, but such solutions are insufficiently covered in the Ukrainian scientific literature. Therefore, there is a need to compare them with European (because European countries are leaders in the development and implementation of safe road infrastructure) prototypes to identify differences in the implementation and impact of these differences on the functioning of the intersection, it is essential due to very high traffic deaths rate in Ukraine (13.7 deaths per 100,000 people comparing to 4.1 in Germany, 3.8 in Netherland, 3.1 in the UK, 2.8 in Sweden) [13].

Analysis of lastest researches and publications. Since introduction in 1990’s in Netherlands, new types of roundabouts were researched in many countries. One of the first works covering this new experience in this sphere was made by Dr. it. L. G. H. Fortuijn, who invented and implemented the new type of roundabouts also some guidelines on design and principles of turbo roundabouts were developed by Overkamp, Wijk (2009) and National Academies of Sciences, Engineering, and Medicine (2010).

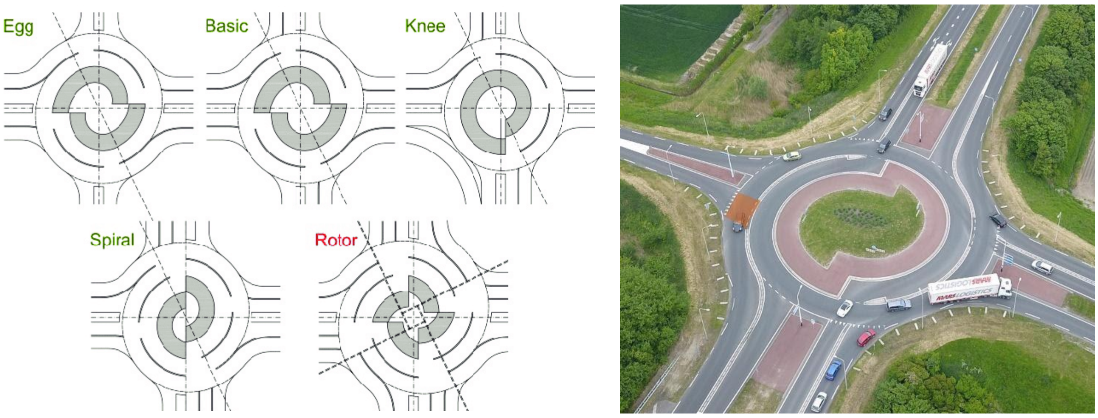
Further analysis was made by S. Babić, M. Cuculić, S. Šurdonja (2012), D. Ciampa, M. Diomedi, S. Olita (2020), A. Pratelli, S. Casella, A. Farina, M. Lupi (2017), T. Džambas, S. Ahac, V. Dragčević (2017) covering the possibility and peculiarities of implementation of Dutch experience in other countries like Italia and Croatia.

Aim of the research. Modern roundabouts: global experience and implementation in Ukraine. Therefore, this paper has following tasks: to make a brief overview of the existing latest structural schemes of roundabouts, to make a review of the Ukrainian experience in the implementation of such intersections; to study determination the impact of design features on the efficiency and safety of operation; to make a brief formulation of differences between the Ukrainian experience and the experience of leading European countries in the implementation of modern types of roundabouts.

Main body. Rounded roads existed long before roundabouts, but one of the first modern-typed roundabouts was designed by French architect Eugene Enard, who designed one-way roundabouts in 1877. American architect William Phelps Ino preferred small circles. He Columbus Circle in 1905. The first British roundabout was built City in 1909. In the United States, large-diameter roundabouts were built to maneuver mergers and intersections at high speeds [11].

Since the 1960s, both large and small roundabouts have become more common in Europe. Since the 1980s, there has been active construction of roundabouts in European countries with the introduction of new types, so that in the early 2010s there were ~30,000 roundabouts in France, ~25,000 in the UK and ~4,000 in the Netherlands [14].

In 1990 in Delft University of Technology Dr. ir. Fortuijn has developed new type of roundabout – turbo roundabout, a specific kind of spiral circular motion. As the introduction of turbo roundabouts in the late 1990s proved effective, standard two-lane road roundabout are no longer being built in the Netherlands [5].



a) b)

Fig. 1. a) Examples of the geometric structure of turbo roundabout; b) implemented turbo roundabout in the Netherlands

In the Western professional literature, this term refers to intersections with a circular motion, which is not circular in geometric shape, but spiral, consists of circular sectors with a

center offset approximately the width of the lane. Such intersections usually have physically separated lanes, which leads to the following advantages over traditional roundabouts [3,4,6,10]:
- there is no change of lanes during traffic at intersections;
- reducing the number of conflict points (a roundabout at the intersection of 4 roads reduces the number of conflict points from 32 to 16 compared to a normal intersection, and the turbo roundabout reduces their number to 10);
- reducing the speed of traffic at intersections, which reduces the likelihood of accidents and the severity of the consequences of a potential accident;
- increase the capacity of intersections by an average of 15% with a decrease in waiting time at each branch of the intersection.

In particular, turbo roundabout intersections are characterized by the following features (Fig. 1):
- entrance lanes are divided according to direction, physically limited by curbs;
- users approaching the intersection must choose a lane along the entrance shoulder to maneuver (through and left movements, turns to the right);
- after choosing their own lane, their path is partially limited by the presence of curbs installed along the circulating lanes to the exit;
- all vehicles entering the roundabout, even if they follow different patterns of behavior, must give priority to vehicles moving though the roundabout;
- through turns and maneuvers with a left turn come into conflict with vehicles moving in the roundabout; in order for incoming vehicles to enter the relevant lane, incoming vehicles must wait for a combination of two clearances to pass;
- in contrast to the above, right-turn maneuvers occur in the same way as at traditional roundabouts [7].

In recent years there is a question among transport engineers: is it possible to combine the positive characteristics of different types of circular intersections, while eliminating their negative characteristics, or whether you can to eliminate intersections and intertwining of contradictory points in existing «normal» roundabouts and thus achieve a high level of traffic safety without reducing the bandwidth of the roundabout?

Some researchers have found a solution in a roundabout with «depressed» lanes for right turns, which is also called a flower intersection.

One of the main characteristics of the roundabout with «depressed» lanes for right-hand traffic is the same as at the turbo-roundabout - physically separated lanes in the carriageway.

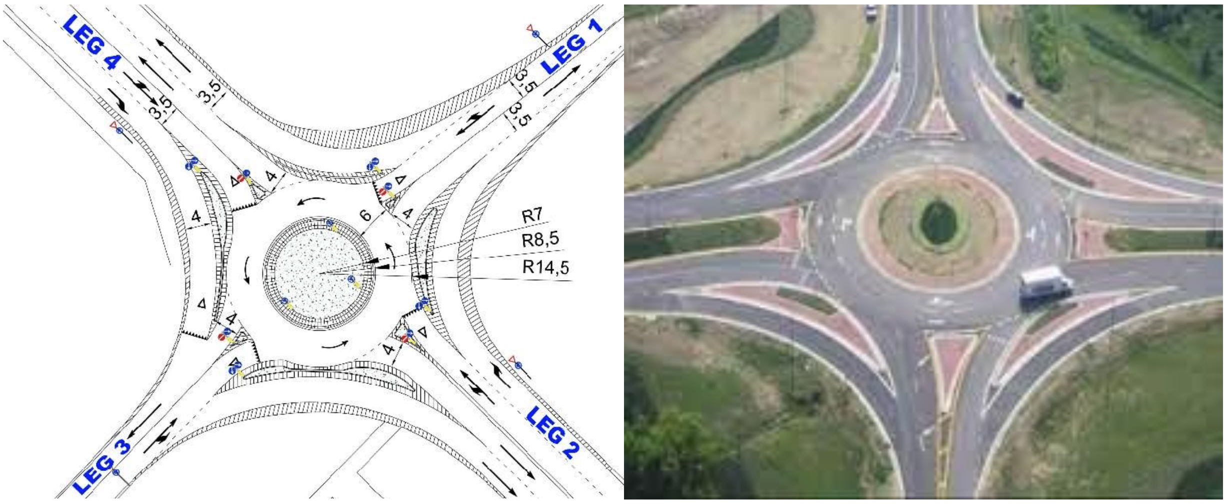
The second characteristic of a roundabout with «lowered» lanes for a right turn is that a separate lane is created for a right turn. This means that the inner lane is only used by vehicles traveling directly through the roundabout (180°) or turning left (270°).

Physically separating the right turning movement, a single-lane roundabout is obtained, where (unlike in the case of turbo-circular) there are no intersections of different flow directions; however, (unlike the case of «normal» two-lane roundabouts) there is also no intersection of conflict points when moving from one lane to another.

Moving the intersection points from the roundabout (in the curve) to the section of the road in front of this roundabout (usually a straight line) is a safer solution in terms of traffic safety.

However, perhaps the best feature of a roundabout with «depressed» lanes for turning right is that it is implemented within size of traditional (and even existing) two-lane roundabouts. Unlike turbo roundabout, there is no need to move the outer curbs of the roadway, and therefore additional usage of the surrounding land is not required. With the reconstruction of the «normal» two-lane roundabout into a roundabout with «depressed» lanes for right-hand traffic, all curbs of the circular carriageway, splitter islands and exit roads remain in the same position.

The effectiveness of such a solution was analyzed using micromodeling software. It included congestion and queue lengths for four variants of loading at intersections (750, 1000, 1250 and 1500 vehicles in the main direction of peak traffic) and for four variants of the proportion of vehicles turning right (40%, 60% and 80%) of the traffic). In all scenarios, 10% of the main traffic flow in the secondary directions was added.



a) b)

Fig. 2. a) geometric arrangement of a flower roundabout;
b) example of an embodied intersection of this type

The results of micromodeling show that there are no significant differences between the small roundabout, normal and turbo roundabouts, at low levels of transport load. Congestion and queue length are approximately the same.

At higher traffic loads, differences in favor of the flower roundabout occur when the percentage of age of right-hand drive vehicles approaches 60% of the total number of vehicles in the main direction of travel.

Compared to the usual two-lane and turbo roundabout intersections, the flower type of intersection shows its advantages when most of the traffic in the main direction is moving to the right. Under such conditions, such an intersection loses its effectiveness when the capacity of single-lane roundabout traffic is exceeded. [12]

Anter modern roundabout solution is mini-roundabout. Mini-roundabouts are a subtype of conventional single-lane roundabouts, but they deserve to be considered as a separate type due to the design, execution and bandwidth of these intersections. For this reason, these intersections have a separate section in the design guidelines of many countries.

Although it was to be expected that such intersections would be common, this type of intersection has only recently begun to develop actively and is still quite unexplored. The first mini roundabout appeared in the United States in the early 20th century. The first such intersection, made by engineer Hainaut, had a «target» in the middle, which consisted of a white circle 60 cm in diameter and 2 concentric circles 30 cm wide at a distance of 30 cm, so the diameter of all together was 3m. This was the beginning of mini-circular movements, which are still used today in many countries.

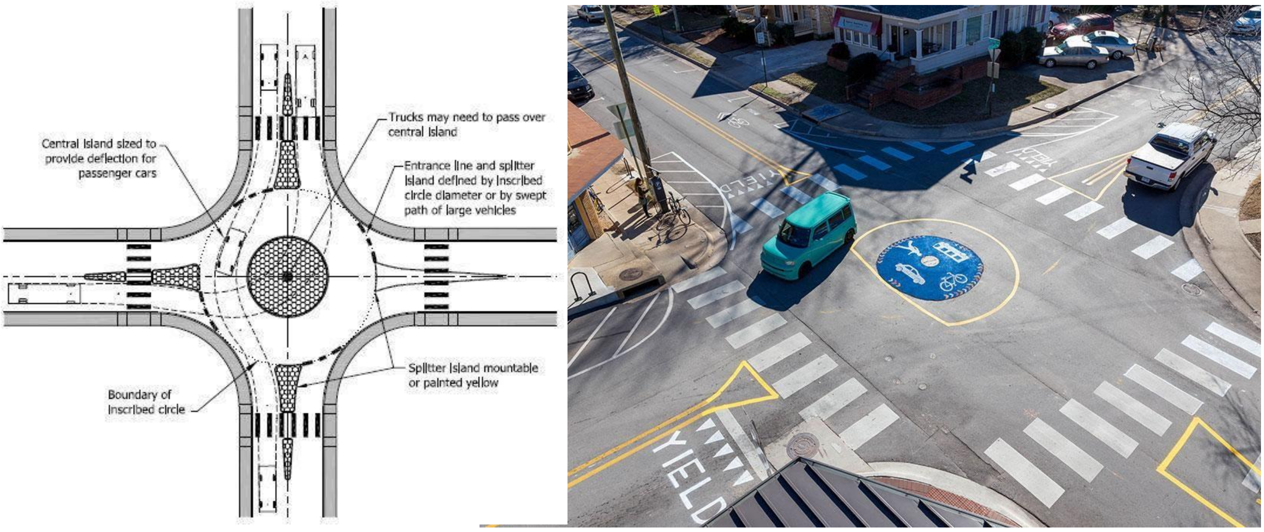
Mini-roundabout intersections in the UK were developed in the 1960s and 1970s. The rule of priority for roundabout vehicles was extensively tested and proven during the period from 1962 to 1966. The roundabout was able to become smaller because they were no longer blocked by vehicles on them.

Subsequent tests at smaller three-lane roundabouts have shown that the mini-roundabout with its nominal central island will operate in the relevant sections and provide much more throughput than a similarly sized intersection with traffic light regulation.

The period between 1966 and 1974 in England was a time of extensive research at roundabouts with small and very small diameter central islands and at roundabouts without a raised central island. The low cost allowed us to test many ideas and requirements for their operation and use. It is interesting to note that in England all research at that time was conducted at real intersections, not at landfills, or using computer simulations of the real environment. During this period of extensive analysis, other, lesser-known forms of circular motion have also appeared. Only recently have they begun to acquire their significance and application.

Since the introduction of mini-roundabouts in England, three extensive and comprehensive safety analyzes have been carried out at these roundabouts (1974, 1980 and 1993), which included almost all previously built mini-roundabouts. The last one (1993) covered 85% of all mini-circular movements. The main conclusions of this analysis were the following:

- mini- (and ordinary) roundabouts have lower accident rate than other types of detours;
- the mini-roundabouts have the highest number of accidents in which one participant was a pedestrian;
- there were no accidents during the U-turn,
- with a traffic load of 15,000-25,000 vehicles/day, the level of road accidents at the mini-roundabout was 2.5 accidents/year, and at the "normal" roundabout 1.5 accidents/year.



a) b)

Fig. 3. a) geometric structure of the mini-roundabout; b) example of a the mini-roundabout in the US

Professor Werner Brilon's research team (from the Ruhr University in Bochum, Germany) conducted research at 18 intersections in the centers of large cities or in their suburbs (residential areas), which were reconstructed over four years in mini-roundabouts. The volume of traffic at these intersections ranged from 2,000 to 17,000 vehicles/day. These intersections were chosen for reconstruction into mini-roundabout intersections due to low level of traffic safety, high speed of vehicles, high conflict, long waiting time from less congested areas [3].

The results of a German study show that the volume of traffic of up to 15,000 cars per day for a mini-roundabout is not a problem. In particularly good conditions (traffic load is evenly distributed on all approaches, and the percentage of vehicles turning left is very small), these intersections can withstand transport loads of up to 20,000 vehicles/day without complications and deteriorating safety.

The results of the study confirmed that mini-roundabouts in German residential areas are not only a better solution than classic intersections, but also better than ordinary (small and medium) roundabouts. It was also concluded that for German conditions, the mini-roundabout is a much cheaper solution than the reconstruction with the reorganization of the classic intersection.

The first mini-roundabout in Croatia was built in Zagreb in 2002. After that, a double mini-roundabout was built on the island of Rab in 2003, and this was the beginning of the development of this type of intersections in Zagreb and Istria, especially in Porec. The first prefabricated mini-roundabout was built in 2006 near Opatija, which in the first summer season after the performance (with very low costs) confirmed the expected increase in capacity and decrease in speed at the intersection [8].

In recent years, new types of roundabouts have begun to appear in Ukraine, developed on the basis of modern European models. Relevant changes were made by Industry building codes B.2.3-37641918-555: 2016 “At-grade intersections”. It should be noted that the new schemes of these intersections in the Industry building codes were presented without significant detail, which complicates their implementation, as no recommendations and detailed schemes on the geometric and physical parameters of such intersections.

Domestic building code indicate only spiraling lanes, increased capacity and reduced accidents, as well as the recommendation to use this type of interchange when turning left for more than 50% of the main road flow [8]. Other features and details of the device are not given.

One of the first examples of such a solution in Ukraine is the intersection of Hetman Mazepa and Oleksandra Dovzhenko streets in Ivano-Frankivsk. This is a large roundabout with a radius of about 80 meters (according to Google Maps), which was redesigned in 2018.

There were separate lanes for traffic in the specified directions, but they are made in graphic layout, which allows drivers to rearrange between traffic lanes and violate the requirements of marking, as seen in the storyboard video surveillance of this intersection.

This somewhat reduces the safety of the roundabout, as road users will rely on other road users to comply with traffic rules. Based on this, maneuvers are performed, but if such requirements are violated, conflict situations may arise, including traffic accidents.

Conclusion. Analysis of scientific sources that considering the operation and development of new types of roundabouts allows us to conclude that new types of such intersections, actively implemented in European countries, have significant advantages in terms of efficiency, capacity and traffic safety.

These two types (turbo-roundabout and flower- roundabout) are a replacement for roundabout intersections with two or more lanes. The flower roundabout is effective when a significant number of road users turn right. With a significant number of vehicles moving straight or left, it is more appropriate to use turbo roundabout.

The mini-roundabout is effective for lightly loaded intersections with a traffic intensity of up to 15,000 vehicles per day.

Ukraine's experience in designing such intersections is currently insignificant: the first such intersections were built in 2018. The design and construction of such interchanges is hampered by the low intensity of reconstruction of streets and roads and outdated design standards, which have the following shortcomings:

- Ukrainian standards for the design of roundabouts require both excessive width of the carriageway and excessive radius of the intersection. construction of these facilities, but does not reduce their efficiency and safety.
- The relevant building code are not sufficiently detailed in the organization of traffic at such intersections, as well as in terms of details and elements of such intersections.
- The building code does not provide detailed drawings and descriptions of different types of intersections, which hinders the effective design of safe road infrastructure.

In order to accelerate the development of modern roundabouts in Ukraine, it is necessary to develop more detailed building codes that will regulate the organization of such intersections and encourage the design of modern intersections, as well as intensify the reconstruction of intersections instead of conventional repairs.

References

[1] World Health Organization. (2019). *Global status report on road safety 2018.* Geneva: World Health Organization. [in English]

[2] Roundabouts: An Informational Guide – Second Edition. (2010). *National Academies of Sciences, Engineering, and Medicine.* Washington, DC: The National Academies Press.

[3] Wylie, Ian. (2015). *Traffic lights are so dictatorial, but are roundabouts on the way out?* The Guardian. Retrieved from: https://www.theguardian.com/cities/2015/oct/19/traffic-lights-roundabouts-way-out.

[4] Engelsman, JC, Uken, M. (2007). Turbo roundabouts as an alternative to two lane roundabouts. Pretoria: 26th Annual Southern African Transport Conference 2007. URL: https://repository.up.ac.za/handle/2263/5909.

[5] Delft University of Technology. (2013). Turborotonde en turboplein: ontwerp, capaciteit en veiligheid. DOI: 10.4233/uuid:e01364ce-78de-465b-a8c8-39e28a4585dd.

[6] Ciampa D., Diomedi M., Olita S. (2020). Effectiveness of unconventional roundabouts in the design of suburban intersections. European Transport\Trasporti Europei. DOI:10.48295/ET.2020.80.6 [in English].

[7] Džambas T., Ahac S., Dragčević V. (2017). Geometric design of turbo roundabouts. Tehnicki Vjesnik. DOI:10.17559/TV-20151012162141 [in English].

[8] Fortuijn, L. (2009). Turbo Roundabouts: Design Principles and Safety Performance. Journal of the Transportation Research Board. DOI:10.3141/2096-03.

[9] Overkamp, DP, Wijk, van der, W. (2009). Roundabouts - Application and design. A practical manual. Ministry of Transport, Public Works and Water Management Partners for Roads.

[10] Pratelli A., Casella S., Farina A., Lupi M. (2017). Conventional and unconventional roundabouts: A review of geometric features and capacity models. International Journal of Transport Development and Integration. DOI:10.2495/TDI-V2-N3-225-239

[11] Giuffrè O., Guerrieri M., Granà A. (2009). Evaluating capacity and efficiency of turbo-roundabout. URL: https://www.researchgate.net/publication/263965250_EVALUATING_CAPACITY_AND_EFFICIENCY_OF_TURBO-ROUNDABOUTS

[12] Tollazzi, T., Rencelj, M., Turnsek, S. (2011). New Type of Roundabout: Roundabout with 'Depressed' Lanes for Right Turning – 'Flower Roundabout. Promet-Traffic & Transportation. DOI:10.7307/ptt. v23i5.153

[13] Babić, S., Cuculić, M., Šurdonja, S. (2012). Mini-roundabouts in urban areas. Retrieved from: https://www.researchgate.net/publication/281637401_Mini-roundabouts_in_urban_areas

[14] Industry building codes B.2.3-37641918-555:2016. At-grade intersections. (2016). Kyiv: Ministry of infrastructure of Ukraine. Ministry of Transport, Public Works and Water management. Partners for Roads [in Ukrainian].

СУЧАСНІ КІЛЬЦЕВІ ПЕРЕХРЕСТЯ: СВІТОВИЙ ДОСВІД ТА ІМПЛЕМЕНТАЦІЯ В УКРАЇНІ

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Анотація. В статті проаналізовано сучасні рішення з устрою кільцевих перехресть, що були розвинені в Європі в останні десятиліття, стисло надано історію розвитку кільцевих перехсреть. Розглядаються три основні типи таких перехресть, що отримали найбільше поширення: турбокільце, «квіткове» кільце та мінікільце. Надано характерні риси геометричного та фізичного устрою турбокільцевих перехресть, а також інформацію щодо їх впливу на безпеку руху так пропускну здатність перехрестя. Приведено притаманні елементі «квіткового» кільцевого перехрестя, надано результати комп'ютерного моделювання його пропускної здатності за допомогою спеціалізованого програмного забезпечення, показано характеристики дорожнього руху на ділянці, коли є найбільш доцільним використання такого типу кільцевого перехрестя. В статті стисло розглядається також історія розвитку мінікільцевих перехресть у Сполученому Королівстві, подано загальну інформацію щодо їх устрою. Окремо наведено результати емпіричних спостережень за ефективністю, безпекою та доцільністю застосування таких перехресть, що проводилися у Великій Британії, Німеччині та Хорватії у 1970-2000-х роках. До кожного типу перехресть надано схеми геометричного устрою та приклад імплементації рішень.

Окремо проаналізовано впровадження подібних рішень в Україні, що мало місце в останні роки. Проаналізовано як існуючий приклад турбокільця, так й вітчизняна теоретична та нормативна база для впровадження таких рішень. Аналіз показав, що галузеві будівельні норми майже не надають істотних пояснень щодо фізичного та геометричного устрою турбокільцевих перехресть, також немає значних рекомендацій щодо умов за яких доцільно застосувати той чи інший тип перехрестя. Виявлено напрямки, за якими слід вдосконалювати теоретичну та нормативну бази задля забезпечення вдалої імплементації сучасних більш досконалих типів кільцевого руху в Україні.

Ключові слова: перехрестя, кільцеве перехрестя, сучасне кільцеве перехрестя, дорожній рух, дорожня безпека, вулиці, турбокільце, мінікільце.