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DOI: 10.35117/A_ENG_23_02_02

Improving the traffic safety by converting an existing conventional multilane traffic roundabout to a look-a-like turbine roundabout (case study)

Abstract: The article addresses the issue of converting existing conventional multilane roundabout to a look-a-like turbine traffic roundabout. A case has been proposed by reviewing different solutions of traffic control devices on existing conventional multilane roundabouts with a circular central island. Four different variants of traffic control devices has been presented, which take into consideration the availability of land and analysis of projected traffic volumes at individual entrances and routes. In addition, three Szczecin multilane roundabouts were characterized, where the existing traffic control devices was changed in 2019 and a look-a-like traffic roundabout was introduced. The roundabouts has been changed by introducing only horizontal markings without any reconstruction of the existing entrances. An analysis of the state of traffic safety was carried out for these traffic roundabouts, confirming that significant improvements have been achieved.

Keywords: Conventional roundabout; Turbine look-a-like roundabouts; Vehicle path; Traffic safety

Introduction

Recently, many roundabouts have been constructed in our country, or older intersections have been converted into roundabouts, due to their higher traffic safety parameters. Additionally, the rapidly increasing traffic intensity requires the use of intersections in transportation systems that ensure high capacity. These requirements are met by intersections with traffic lights and turbo roundabouts. Turbo roundabouts provide both greater capacity and increased traffic safety, which is associated with fewer collision points due to the segregation of traffic at the entries and within the roundabout.

Turbo roundabouts began to be implemented at the end of the 20th century. The first turbo roundabout was built in 1996 in the Netherlands. Its creator and designer was L.G.H. Fortuijn, a lecturer at Delft University of Technology [1, 13, 14, 37]. The fundamental principle and distinguishing feature of turbo roundabouts is channelizing traffic in such a way that the driver must decide on the correct traffic lane corresponding to the desired direction of travel before entering the roundabout. A classical turbo roundabout should meet four basic principles:

a) At entries with high traffic intensity, there should be two traffic lanes, with a clear division of traffic consistent with specific directions.

b) Within the roundabout, clear traffic separation using a separating lane should be implemented to avoid the need for lane changes.

c) The direction of traffic within the roundabout must be ensured and clearly marked, consistent with the signs and traffic separation at the entries, so that the driver selects the appropriate lane before entering.
d) From the outer lane, a driver can turn right at the nearest exit or continue along the outer lane of the roundabout, while from the inner lane, only left turns or straight movements can be made.

The Dutch guidelines [34] distinguish the following basic types of four-entry turbo roundabouts: basic, egg, spiral, knee, and rotor. Another essential feature of turbo roundabouts is the use of separating lanes dividing individual traffic lanes at the entries, exits, and within the roundabout. (Separating lanes should have a width of 0.7 m or 1 m). A separating lane typically consists of raised concrete traffic separators, continuous road markings, and, in the case of a 1 m width, LED road markers [1, 34].

In the Netherlands, most turbo roundabouts built adhere to the classical design; however, depending on traffic conditions and, primarily, the availability of land, partially turbo roundabouts (known in Dutch as Partiële turborotonde, with some deviations from the principles mentioned above) and "look-a-like" roundabouts have also been constructed. On these, instead of the typical separating lane, only road markings or, in some cases, a classical U-25 traffic separator is used (Figures **1** and **2**). Turbo roundabouts must meet all four principles outlined above. If any principle is not maintained, the roundabout is not a classical turbo roundabout. It may instead be a Partiële turborotonde or a "look-a-like" roundabout [2, 3, 14, 34].

1. An example of a roundabout in Dziwnówek – a "Partiële turborotonde" type with three traffic lanes on the western section of the roundabout roadway (Photo by A. Sołowczuk)

2. An example of a roundabout in Dziwnówek – a "Partiële turborotonde" type with two traffic lanes on the eastern section of the roundabout roadway (Photo by A. Sołowczuk)

"Look-a-like" roundabouts are being built more frequently, both in Europe and on other continents. However, they do not strictly adhere to the principles mentioned earlier. Various modifications of "look-a-like" roundabouts exist, with traffic segregation marked only by road lines and varying numbers of traffic lanes within the roundabout and at the entries and exits, depending on traffic needs and terrain conditions (Figure **3**). Figure **3** highlights the profiling of dividing islands, which are usually irregularly shaped, based on curvilinear stylized triangles, and surrounded by road markings. Another notable feature is the drivable section of the roundabouts shown in Figure **3**, separated from the roundabout roadway by a rounded curb with a recessed channel (Figure **3b**). The height of the curb relative to the roadway level, according to American guidelines NCHRP 672 [33], is 7–10 cm (Figure **3c**). The method of shaping the curvilinear dividing islands is provided in the guidelines [33] and aims to ensure speed reduction to match the allowable speed for navigating the roundabout based on the specific traffic relation. The design and width of traffic lanes at the entries, exits, and along the length of dividing islands, as well as within the roundabout, are determined based on an analysis of ensuring the traffic corridors for the design vehicle.

a) b) c)

3. "Look-a-like" roundabout at the intersection of State Road 41 with Breezewood Ln and W Bell St in Neenah, USA:
a) Plan of the four roundabouts;
b) Curb ramp and adapted stormwater inlets matching its rounded shape;
c) View of the curb separating the drivable part of the roundabout from the roundabout roadway

(Source: Google Earth [18] – geographical coordinates 44°9'22.55"N, 88°29'8.49"W)

A Peculiarity Among Partially Turbo Roundabouts

A unique example of a partially turbo roundabout with an atypical separating lane design (consisting solely of a concrete U-25 separator) is the roundabout built in 2021 in Zululand, South Africa (Figure **4**) [11, 23]. In addition to the unusual curb design replacing the classical separating lane, the surface design of the drivable part of the roundabout is particularly distinctive, featuring symmetrically placed transverse concrete traffic separators. These design features of the drivable part of the roundabout and the separating lane are likely tied to local drivers' habits and driving styles.

a) b)

4. The first partially turbo roundabout built in the suburbs of Khandisa in Zululand, South Africa, at the intersection of roads R102/P535/P743:
a) Separating lane with a raised curb,
b) Drivable section
(Source: Google Earth [18] – geographical coordinates 28°51'50.32"S, 31°51'15.75"E)

As previously mentioned, when designing a turbo roundabout, partially turbo roundabouts (Partiële turborotonde), or "look-a-like" roundabouts, the starting point is projected traffic volumes. Based on the projected traffic volumes for specific movements, the designer determines the required number of traffic lanes at entries, exits, and on the roundabout itself, which forms the basis for selecting the roundabout type. The decision to include two or three lanes in the roundabout design is directly linked to its capacity and the achievable speed on the roundabout roadway [16]. The issue of turbo roundabout capacity, using various traffic simulation scenarios for different types of roundabouts, has been analyzed in [12, 15, 17, 25]. These studies demonstrated that varying scenarios can result in different queue lengths at individual entries, improved capacity, and varying numbers of potential conflicts. Although the studies described in [15] were limited to a single example roundabout with variable traffic scenarios, the results of the simulation programs used indicate that when designing a turbo roundabout, it is crucial to consider traffic intensity not only at the entries but also for specific movements. This analysis may reveal the need for two or three traffic lanes at entries or certain sections of the roundabout roadway. Another conclusion from the studies in [15] is that turbo roundabouts can differ from classical designs while still increasing capacity and improving traffic safety.

The issue of classical turbo roundabout capacity is primarily addressed in the doctoral dissertation of turbo roundabout creator L.G.H. Fortuijn [14]. In his work, the author explains the principles and reasons for the increased capacity of turbo roundabouts compared to conventional roundabouts with a traditional circular central island. The undeniable fact of improved traffic safety at turbo roundabouts compared to classical roundabouts is attributed to traffic segregation. The issue of improved safety at classical turbo roundabouts has been discussed in numerous publications [1, 3, 4, 6, 7, 8, 12, 16, 19, 26]. Regarding "look-a-like" roundabouts, many studies and analyses addressing traffic safety are described in [4, 9, 13, 15, 16, 20, 27, 30, 35].

Other Considerations for Roundabout Design

Another issue to analyze when designing classical turbo roundabouts and "look-a-like" roundabouts is ensuring drivability and defining traffic corridors. At classical turbo roundabouts, traffic corridors are primarily defined by separating lanes. At "look-a-like" roundabouts, traffic corridors must be verified during the design process, and variable road marking boundaries must be determined based on these corridors.

This literature review shows that the Polish literature lacks analysis of feasible "look-a-like" roundabouts, which could be highly useful and helpful when planning the reconstruction of existing multi-lane roundabouts into this type of roundabout. Given financial constraints and the need to improve traffic safety, converting existing multi-lane conventional roundabouts into "look-a-like" roundabouts with traffic segregation achieved solely through road markings offers many possibilities. These issues are the focus of this article. The article utilizes a case study presented in Table 1, ensuring intentional control over external factors being analyzed. The selected roundabout cases were determined by external factors beyond the researcher's control. According to case study theory, a single case reflects a unique set of factors and empirical data, and conclusions drawn from it can be generalized to other similar cases.

In this article, cases of reconstructing an existing three-lane conventional roundabout into a roundabout with traffic segregation marked solely by road markings were first analyzed. These roundabouts, however, required broader reconstruction plans, primarily involving the widening of entries. In the latter part of the article, another approach is presented, focusing on transforming an existing three-lane conventional roundabout into a "look-a-like" roundabout with traffic segregation achieved through special road markings on the roundabout roadway itself, without reconstructing the entries. Additionally, the article discusses the necessity of detailed analyses of traffic corridors and the specifics of defining transition points for changing road markings on the roundabout roadway. The article concludes with findings from the analyses conducted.

Analysis of Potential Cases of "Look-a-Like" Turbo Roundabouts

The design of "look-a-like" turbo roundabouts is gaining popularity not only in the Netherlands but also in Germany [9, 15], Poland [37], and the USA [32, 33]. The primary reasons for their popularity include low reconstruction costs, increased capacity, and enhanced traffic safety compared to conventional roundabouts with traditional circular central islands. Moreover, "look-a-like" turbo roundabouts occupy slightly more space than existing conventional roundabouts, which is a significant economic advantage when compared to classical turbo roundabouts with a similar number of lanes and constructed separating lanes. Examples of such roundabouts in Poland include, for instance, the Zgrupowania AK "Radosław" roundabout ([18] – geographic coordinates 52°15'16.96"N, 20°58'58.00"E) in Warsaw. This roundabout features a variable number of traffic lanes between entries, a distinctive "Egg"-shaped central island, and uses only road markings on both the roundabout and its entries. Another example is the roundabout at the intersection of Płowiecka, Ostrobramska, and Marsa streets ([18] – geographic coordinates 52°14'1.74"N, 21°7'37.79"E). This roundabout includes directional arrows on the road surface, areas excluded from traffic opposite the entries near the non-drivable part of the roundabout, and U-25 separators along the edges of the excluded zones. It mimics a rotor-type turbo roundabout, not only due to the four characteristic "noses" opposite the entries but also due to the inclusion of traffic lights.

Design Guidelines for "Look-a-Like" Turbo Roundabouts

"Look-a-like" roundabouts, as recommended in the NCHRP 672 guidelines [33], often require modifications to dividing islands or adjustments to the central island's location relative to the existing conventional roundabout. According to Dutch guidelines for turbo roundabouts [34], separating lanes or, alternatively, continuous road markings should begin at least 20 meters before the roundabout's outer diameter or the edge of pedestrian crossings marked with line P-10. At exits, the end of the separating lane or continuous markings should be at least 15 meters beyond the outer diameter or the edge of pedestrian crossings. Widening or narrowing of entry and exit lanes can only be implemented beyond these boundaries. However, designing a "look-a-like" turbo roundabout is not merely a matter of applying new road markings. The design should incorporate the fundamental principles of shaping traffic corridors, and vehicle traversability must be thoroughly evaluated.

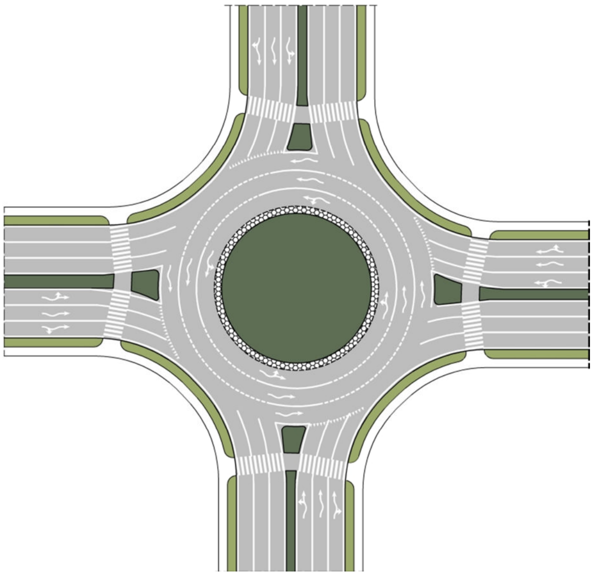
Examples of "Look-a-Like" Roundabout Designs

- Roundabout in Figure **5:** This roundabout was transformed from a conventional three-lane roundabout by applying new road markings on the roundabout roadway and making minor adjustments to the dividing islands within approximately 20 meters from the roundabout's outer diameter or the end of the pedestrian crossings. The roundabout retains the general shape of the conventional layout, with traffic segregation achieved through road markings and reconstructed channelized lanes at the entries and exits. The only significant increase in land use compared to a conventional roundabout with a circular central island and parallel dividing islands (2.5 meters wide) occurs at the widened entries.
- Flattened Roundabout in Figure **6:** This example features two traffic lanes along two opposing sections of the roundabout, resulting in a flattened shape along opposing entries. While this design provides cost savings when compared to constructing a three-lane conventional or classical turbo roundabout, it requires substantial reconstruction of the entries, leading to increased overall costs. This flattened "look-a-like" roundabout is particularly suitable for locations with limited space available for constructing a conventional three-lane roundabout with a circular central island or a classical turbo roundabout.
- Roundabout in Figure **7:** This design accommodates dual left-turn lanes on one of the entries with high traffic volumes by partially restricting the middle lane and creating two left-turn lanes along a section of the roundabout roadway. This approach is particularly useful in cases of high left-turn traffic volumes.
- Roundabout in Figure **8:** This example incorporates dual left-turn lanes at all entries. Based on the findings of studies cited in [12, 15], the authors believe this type of "look-a-like" roundabout is well-suited for reconstruction scenarios where significant vehicle queues and high left-turn traffic volumes are observed at entries.

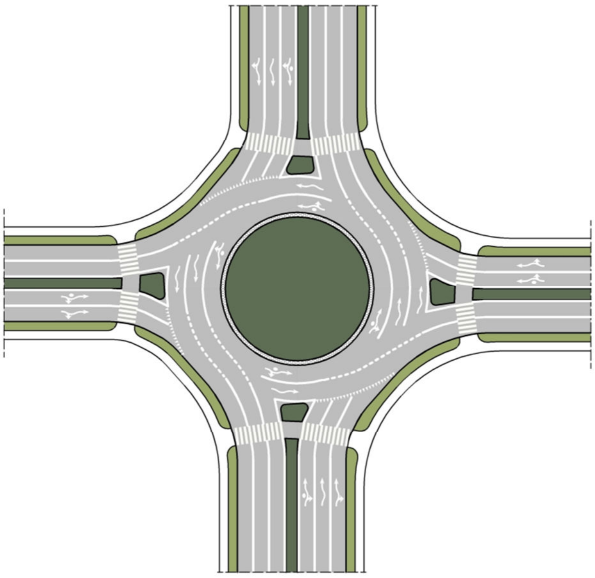
General Observations

Figures **5-8** present different ways to reorganize traffic at existing three-lane conventional roundabouts, depending on projected traffic volumes at entries and for specific movements. Each "look-a-like" roundabout example features unique central island shapes and varying dividing island widths, reflecting traffic corridor analyses for the assumed design vehicle.

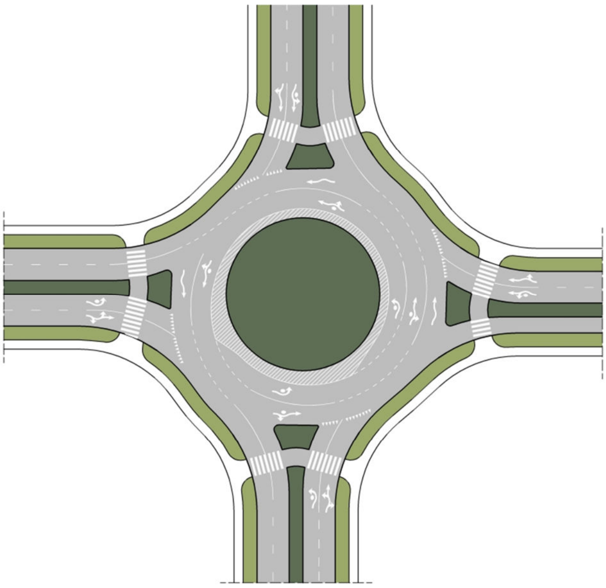
Depending on the projected traffic volumes, these roundabouts can feature either three or two lanes at entries and roadways, with permitted movements marked solely by road markings.



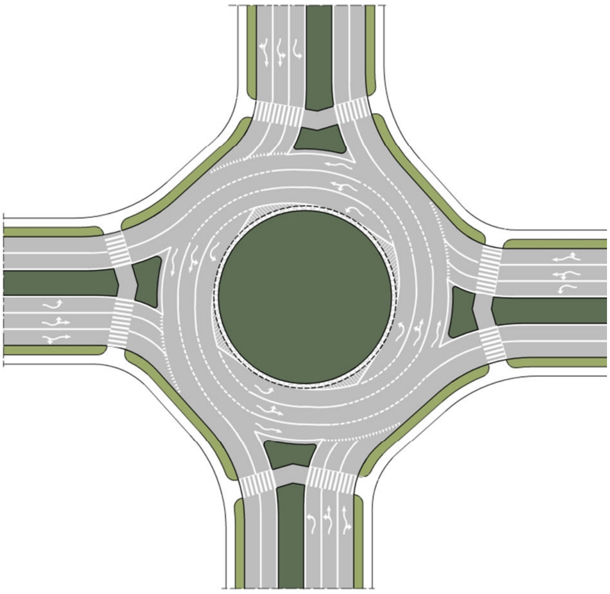
5. An example of a three-lane "look-a-like" roundabout with three traffic lanes at the entries and exits (Source: Authors' own work).



6. An example of a flattened "look-a-like" roundabout with two traffic lanes at the side entries (Source: Authors' own work).



7. An example of a "look-a-like" roundabout with two consecutive left-turn lanes (Source: Authors' own work).



8. An example of a "look-a-like" roundabout with two traffic lanes at the exits and double left-turn lanes (Source: Authors' own work).

Geometric and Spatial Considerations

To select an appropriate "look-a-like" turbo roundabout type for a specific location, designers should primarily analyze projected traffic volumes at entries and for specific movements. Additionally, geometric parameters such as available land and the degree of "roundabout flattening" must be considered. For comparative purposes, Table **1** presents selected parameters for the roundabouts in Figures **5-8**, assuming an outer diameter of 62 meters. Table **2** provides percentage comparisons of land use and other parameters relative to the base roundabout in Figure **5**. The analysis indicates that the roundabout in Figure **7** uses the least land and exhibits the greatest degree of flattening.

Tab. 1. Three stages of the case study on the analysis of the "look-a-like" type roundabout design (Source: authors' own work).

Methods of Induction and Deduction	Stage I	Stage II	Stage III
Logic of Replication	Analytical Replication (Four Different Cases)	Analytical Replication (Three Different Cases)	Analytical Replication (Single Set of Circumstances)
Sampling Selection	Purposeful: Consideration of Land Availability and Forecasted Traffic Volumes at Entries and Relationships	Purposeful: Roundabouts with Different Numbers of Entries, Diameters, and Land Use	Random: A Single Case Selected for the Analysis of Road Marking Line Design
Type of Generalization	Analytical (Graphically Illustrated)	Analytical: (Analysis of Graphic and Photographic Documentation) and Statistical (Statistical Tests)	Graphical Analysis of a Single Case
A strong point	Richness of Information	Richness of Information	analysis of the transposition of data on traffic corridors

Tab. 2. Comparison of the basic geometric parameters characterizing the roundabouts presented in Figures 5-7 (Source: authors' own work).

Compared parameter	Look-a-like roundabouts shown in:			
	Fig. **5**	Fig. **6**	Fig. **7**	Fig. **8**
Area of land occupation	100%	95,2%	79,7%	92,6%
The distance between the heads of the dividing islands, measured along the vertical axis, characterizing the so-called "flattening of the brim"	100%	88,8%	88,0%	93,3%

Using "Look-a-Like" Roundabouts to Define Traffic Lanes

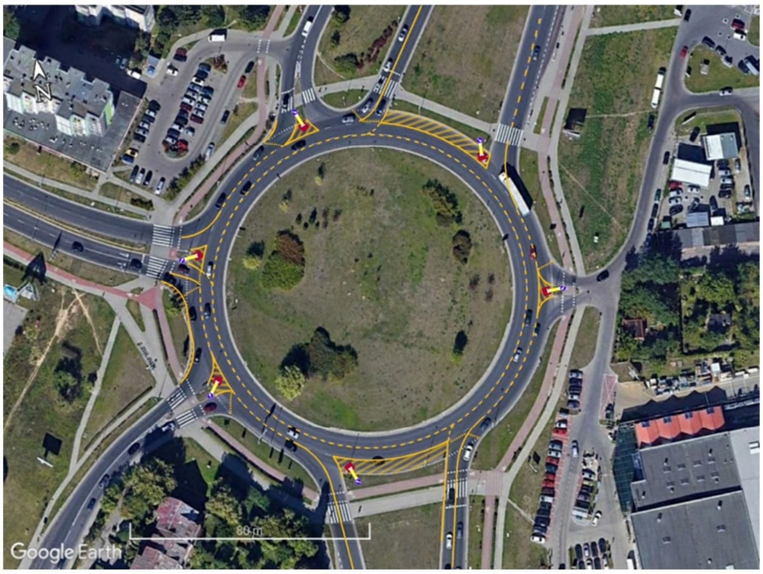
In "look-a-like" roundabouts, traffic lanes are primarily delineated by road markings. According to traffic management principles, vehicles should not change lanes when separated by a continuous segregation line [24]. Experience with classical turbo roundabouts shows that raised curbs (concrete separators) on separating lanes contribute significantly to traffic safety. In many cases, particularly in Poland, U-25 traffic separators are used in "look-a-like" turbo roundabouts (Figures **1** and **2**). The individual segments of the U-25 separator are slightly spaced to allow efficient rainwater drainage during rainfall. However, there are no national studies yet on snow removal for such roundabouts. Nevertheless, as with classical turbo roundabouts, the height of the U-25 separator should not pose significant issues during snow removal.

A key issue for such roundabouts is determining the start and end points of continuous lines on the roundabout roadway or the optimal start and end points of U-25 traffic separators. To address this, each roundabout design (as illustrated in Figures **5–8**) requires an analysis of vehicle traversability, defining traffic corridors, and, based on this analysis, determining the precise locations of road markings (e.g., transitions between continuous and dashed lines). Some "look-a-like" roundabout designs in Figures **5–8** allow exiting from the middle lane, which complies with traffic regulations [24] because such exits follow a designated path using a traffic separator and do not interfere with outer-lane exits. However, if no U-25 separator is used, the location becomes a collision point where traffic streams intersect. In such cases, "look-a-like" roundabouts relying solely on road markings do not contribute to increased traffic safety.

Case Study: Three-Lane "Look-a-Like" Roundabouts in Szczecin

The final example discussed in this article involves reconstructing existing three-lane conventional roundabouts in Szczecin without altering the dividing islands or the roundabout roadway. Szczecin's three-lane roundabouts date back to the 19th century, with several constructed in recent years. The city authorities decided to reconstruct three conventional three-lane roundabouts into "look-a-like" roundabouts using only road markings [5, 10, 21, 22, 28, 31]. Examples of these roundabouts are shown in Figures **9–11**. Figure **9** presents the road markings on a five-entry roundabout, while Figures **10** and **11** highlight selected fragments of traffic organization applied to three-entry and eight-entry roundabouts.

At Grunwald Square, additional modifications included shortening pedestrian crossings on the roundabout roadway from three to two traffic lanes (Figure **11**). This unique eight-entry square was initially designed in the 1860s by James Hobrecht and constructed in the 1880s. From the beginning, the main dual-carriageway arterial road and the central island featured a two-track tram line. The square was modeled on similar roundabouts built in Paris and Berlin. Today, the central island still includes tram stops, green areas, recreational spaces with chess tables, and multiple pedestrian crossings.



9. The five-entry University Roundabout with an outer diameter of 125 m (Source: road marking visualization created by the authors based on a satellite image from the program [18] – geographical coordinates 53°24'12.18"N, 14°30'5.00"E).

10. The three-entry Haken Roundabout with an outer diameter of 141 m (Source: road marking visualization created by the authors based on a satellite image from the program [18] – geographical coordinates 53°23'30.00"N, 14°30'8.43"E).

a) Extension of the dividing lane at a dual-carriageway entry with a double-track tram line.

b) Extension of the dividing island at the entry of a two-lane, two-way street.

c) Allocation of the outer lane on the roundabout roadway exclusively for right-turn movements.

d) Shortening the pedestrian crossing to only two traffic lanes.

11. The eight-entry Grunwaldzki Square with pedestrian access to the central island (Photo by Alicja Sołowczuk).

Statistical Analysis of Safety Improvements

To verify the effectiveness of converting three-lane roundabouts into "look-a-like" roundabouts for enhancing traffic safety, the authors conducted a statistical analysis using data from the SEWIK program [36]. This analysis evaluated the reduction in traffic incidents following the reorganization of roundabout traffic. The results are shown in Figure **12** and Table **3**. SEWIK data covered 2015–2018 (before the reorganization) and 2019–2021 (after the reorganization). A statistical analysis was performed under two conditions of the test, with the results summarized in Table **3**.

Tab. 3. Data and results of statistical analysis for the three analyzed "look-a-like" turbo roundabouts in Szczecin (Source: authors' own work based on data presented in the SEWIK program [36])

Year	Grunwaldzki Square		University Roundabout		Haken Roundabout	
	Total road accidents	Pedestrian accidents	Total road accidents	Pedestrian accidents	Total road accidents	Pedestrian accidents
Dane przed zmianą organizacji ruchu						
2015	46	3	85	–	43	–
2016	46	5	79	–	33	–
2017	38	1	110	1	49	–
2018	65	4	123	–	56	–
Total	**226**	**13**	**459**	**1**	**244**	**–**
Data after changing the traffic organization						
2019	19	1	37	–	18	–
2020	26	1	60	1	38	–
2021	34	2	70	–	34	–
Total	**79**	**4**	**167**	**1**	**90**	**–**
Result of the significance test of the identified differences in the safety status χ^2 (chi-square): $\chi^2 = (n_1 t_2 – n_2 t_1)^2/(t_1 t_2 (n_1+n_2)) > \chi_\alpha^2 = 3{,}84$, confidence level 0,95, $\chi_\alpha^2 = 2{,}71$, confidence level 0,90						
$\chi^2 =$	**36,0 > 3,84**	3,0 < 3,84	**67,0 > 3,84**	0,04 < 3,84	**35,0 > 3,84**	–
The effectiveness of the applied change in traffic organization is confirmed when, together with a positive result of the significance test, there is also an inequality: $n_1/t_1 > n_2/t_2$						
$n_1/t_1 > n_2/t_2$	56,5 > 26,3	3,25 > 1,33	114,8 > 55,7	0,25 < 0,33	61,0 > 30,0	–

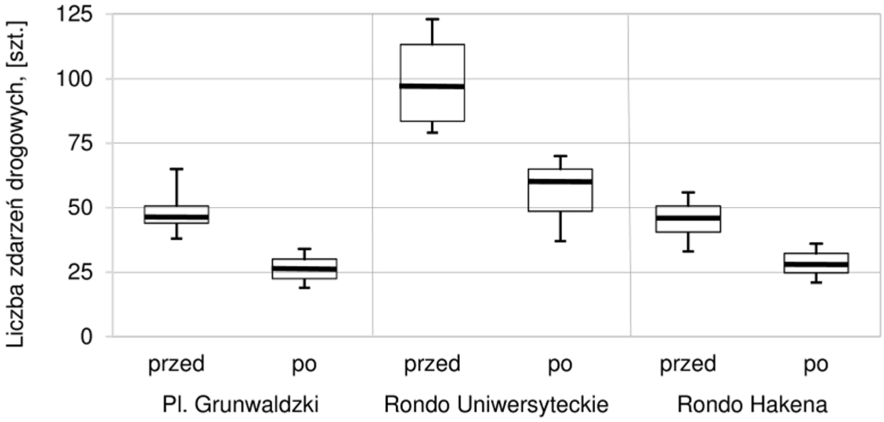
Markings:

n_1 – number of road incidents/accidents “before”,

n_2 – number of road accidents "after" the introduction of changes,

t_1 – length of the observation period "before" the changes were introduced (years),

t_2 – length of the observation period "after" the changes were introduced (years).



12. Box plot (box-and-whisker) of the number of road incidents before and after the change in traffic organization at the analyzed roundabouts in Szczecin (Source: own research based on data presented in the SEWIK program) [36])

The analysis of data and statistical tests in Table **3** confirmed the high effectiveness of traffic reorganization in reducing traffic incidents across all analyzed roundabouts. However, for pedestrian-related accidents, only Grunwald Square showed significant improvements due to the changes in traffic organization. At University Roundabout, no conclusive results were obtained for pedestrian-related accidents, as only one accident involving a pedestrian was recorded in each of the compared periods. It should be noted that pedestrian traffic intensity at University Roundabout (located on the outskirts of the city) is much lower than at Grunwald Square in the city center. Field observations revealed that pedestrians at University Roundabout typically use only one pedestrian crossing, with no pedestrian traffic observed at other crossings during multiple visits.

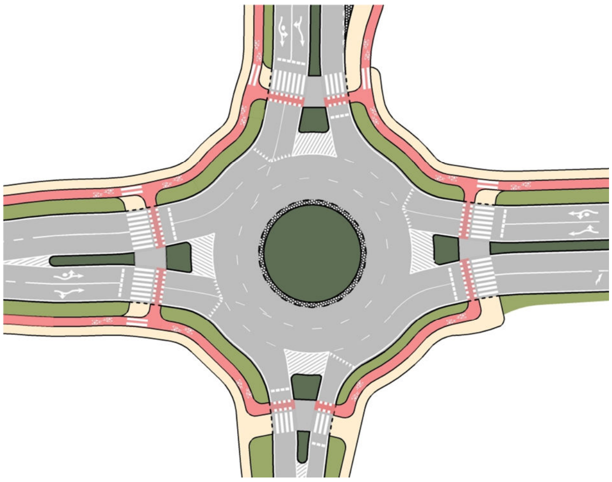
Conclusion

The study confirms that reconstructing three-lane conventional roundabouts into "look-a-like" roundabouts using road markings can effectively reduce traffic incidents and enhance safety, especially in urban areas with high pedestrian activity. However, the degree of safety improvement varies depending on the specific roundabout location, traffic intensity, and design adjustments.

Case Study: Defining Road Marking Boundaries on a "Look-a-Like" Roundabout

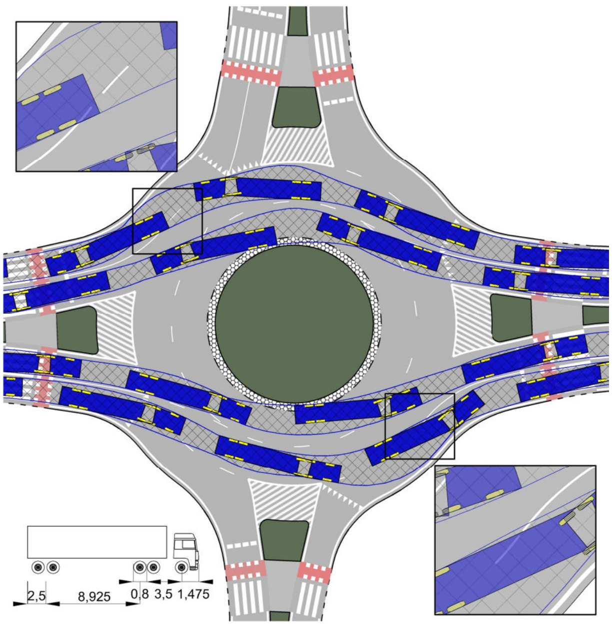
As previously mentioned, defining the boundaries of road markings on a roundabout roadway requires an analysis of vehicle traversability and the determination of potential traffic corridors for design vehicles as part of the reconstruction project for an existing three-lane roundabout. Design vehicles should be identified based on in-situ studies for existing roundabouts and standard vehicles for newly designed ones. Considering that different countries may use vehicles with non-standard lengths, the design should account for vehicles characteristic of the specific country. To diversify the traversability analysis, the article adopts varying side entries (i.e., northern and southern), differing in the number of traffic lanes [29]. In the analyzed example, three lanes remain on the roundabout roadway between entries, while only two lanes are allocated opposite the dividing islands.

To showcase diverse solutions, two entries feature elongated dividing islands (western and southern entries), while the remaining entries (eastern and northern) incorporate dividing lanes. Following the recommendations of the American NCHRP 672 guidelines [33], continuous lines were placed 0.3 m from the curb face along the entries at the outer curb and the dividing island curb. A 1 m wide ring was applied at the central island. The conversion of the conventional three-lane roundabout into a "look-a-like" roundabout was achieved solely through road markings. Figure **13** illustrates the roundabout plan and resulting road markings. Considering that the reconstruction of an existing three-lane roundabout might occur in an urban area with existing pedestrian crossings and bicycle paths, the example roundabout in Figure **13** includes such elements.

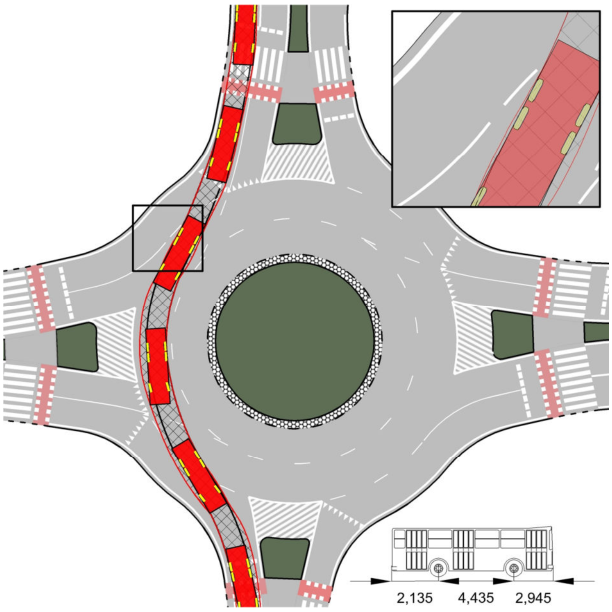


13. Plan of the analyzed "look-a-like" type roundabout (Source: authors' own work).

The design assumes that the main entries (western and eastern) accommodate a design vehicle of a 16.5 m long semi-trailer truck (Figure **14**), while the side entries (northern and southern) accommodate a 9.5 m long solo bus (Figure **15**). Figure **14** presents the results of the traversability analysis and the determination of continuous line boundaries for the western and eastern entries and exits. Figure **15** shows the results of the traffic corridor analysis for a bus navigating the northern and southern entries and the location of the dashed line extensions on the roundabout roadway.



14. Analysis of the passability of the design vehicle at the main entries and the determination of the junction of segregation lines on the roundabout roadway (Source: authors' own work).



15. Analysis of the passability of the design vehicle at the secondary entries and the determination of the junction of segregation lines on the roundabout roadway (Source: authors' own work).

Summary

The literature review conducted in this article demonstrates that existing three-lane roundabouts with circular central islands can be reconstructed into "look-a-like" turbo roundabouts to achieve improved traffic safety. From the possible "look-a-like" roundabout designs, a designer can select any traffic organization solution with minimal reconstruction costs, taking into account that traffic flows will be separated solely by road markings. The choice of a traffic organization method primarily depends on traffic volumes at individual entries and for specific movements. Depending on land availability and the analyzed traffic volumes, a designer can select an appropriate "look-a-like" roundabout design to achieve improvements not only in traffic safety but also in capacity.

The case study analysis of traffic safety improvements on three existing three-lane roundabouts, where only the traffic organization on the roundabout roadway was changed, demonstrated that "look-a-like" roundabouts can significantly enhance traffic safety.

Source materials

[1] de Baan D., Turborotondes, ExtraCT 3 maart 2009, s. 34–37, https://www.dirkdebaan.nl/publicaties.html, dostęp 20.09.2022.

[2] de Baan D., Typen turborotondes, https://www.dirkdebaan.nl/types.html, dostęp 2.07.2022.

[3] de Baan D., Boender J., Fortuijn L.G.H., Vrij baan voor veilige turborotonde, Verkeerskunde, 3, s. 30 – 35, 2008.

[4] Balado J., Díaz-Vilariño L., Arias P., Novo A., A safety analysis of roundabouts and turbo roundabouts based on Petri nets, Traffic Injury Prevention, Volume 20(4), s. 400-405, 2019. https://doi.org/10.1080/15389588.2019.1594208.

[5] Borowiec M., Plac Grunwaldzki z rondem półturbinowym, https://radioszczecin.pl/1,392232,plac-grunwaldzki-z-rondem-polturbinowym-zdjecia, artykuł z dnia 2019-07-27, dostęp. 5.05.2022.

[6] Brilon W., Roundabouts: A state of the art in Germany, International Roundabout Conference, April 7th – 10th, 2014 Seattle, Washington, s. 1–15;

http://teachamerica.com/RAB14/RAB14papers/RAB14ppr045_Brilon.pdf, dostęp 14.12.2020.

[7] Brilon, W., Roundabouts: A state of the art in Germany, 3rd International Conference on Roundabouts, 18–20 May 2011 Carmel, Indiana, s. 1–15, 2011. http://www.rub.de/verkehrswesen/download/literatur/Brilon_roundabouts_2011_05_29_cit.pdf, dostęp 14.11.2020.

[8] Chan S., Livingston R., Design vehicle's influence to the geometric design of turbo-roundabouts, International Roundabout Conference, April 7th – 10th, 2014 Seattle, Washington, s. 1–17, 2014. http://teachamerica.com/RAB14/RAB14papers/RAB14ppr147_Chan.pdf, dostęp 14.12.2020.

[9] Clausen A. Turbo-Kreisverkehr in Baden-Baden – Teil 1: Planung und Bau, Straße und Autobahn, 4, s. 209 – 2014, 2008.

[10] Czetowicz M., Zmiany na Rondzie Uniwersyteckim. Niektórzy kierowcy mają problem, https://radioszczecin.pl/1,392101,zmiany-na-rondzie-uniwersyteckim-niektorzy-kiero, artykuł z dnia 2019-07-24, dostęp. 5.05.2022.

[11] Forrest P.L., Kendal G. R., Design and implementation of the R102 – Zululand University Turbo Roundabout in Kwazulu-natal, South Africa, https://sarf.org.za/wp-content/uploads/2016/08/Peter-Forrest_LATE_not_on_DVD.pdf, dostęp 20.07.2022.

[12] Fortuijn L.G.H., Turbo-Kreisverkehre Entwicklungen und Erfakrungen, Semiar Aktuelle Themen der Strassenplanung, 25.01.2007 Bergisch Glasbach. s. 1–61, https://docplayer.org/46250169-Turbo-kreisverkehre-entwicklungen-und-erfahrungen-turbo-roundabouts-development-and-experiences-25-january-2007.html, dostęp 20.03.2022.

[13] Fortuijn L.G.H., Turbo Roundabouts: Design Principles and Safety Performance, Transportation Research Record: Journal of the Transportation Research Board, [w]: Traffic safety: roundabouts, trucks, older drivers, and traffic law enforcement, 2096, s. 16-24, 2009. https://doi.org/10.3141/2096-03.

[14] Fortuijn L.G.H., Turborotonde en turboplein: ontwerp, capaciteit en veiligheid, Trail Thesis series T 2013/1, Trail Research School, Dissertation of Delft University of Technology 8.01.2013. http://www.turbotrafficsolutions.nl/dissertatie/index.html, dostęp 15.07.2022.

[15] Gallelli V., Vaiana R., Safety improvements by converting a standard roundabout with unbalanced flow distribution into an egg turbo roundabout: simulation approach to a case study, Sustainability, 11 (2), 466, 2019; https://doi.org/10.3390/su11020466.

[16] Gallelli V., Vaiana R., Iuele T., Comparison between simulated and experimental crossing speed profiles on roundabout with different geometric features, ScienceDirect, Procedia - Social and Behavioral Sciences, 111, 117 – 126, 2014, https://journals.co.za/doi/abs/10.10520/EJC163354.

[17] Gallelli V., Perri G., Vaiana R., Operational and safety management at intersections: can the turbo-roundabout be an effective alternative to conventional solutions?, Sustainability, 2021, 13, 5103. https://doi.org/10.3390/su13095103.

[18] Google Earth, strona dostępna online: http://www.earth.google.com, dostęp 19.09.2022.

[19] Groot J., Turborotondes: veiliger en meer capaciteit, Verkeer in Beeld, 2008, 10, 34 – 37.

[20] Hanasiuk K,, Motylewicz M., Badania ruchu pojazdów i zachowań kierowców na rondach turbinowych bez wyniesionych separatorów pasów ruchu, Transport miejski i regionalny, 2022, 3, s. 4-14.

[21] Isz, Półturbina na rondzie Hakena, https://24kurier.pl/aktualnosci/wiadomosci/polturbina-na-rondzie-hakena/, artykuł z dnia 2020-05-15, dostęp. 5.05.2022.
[22] Jaszczyński M., Plac Grunwaldzki po nowemu. Na próbę jako rondo "półturbinowe". Jak jeździć?, https://szczecin.naszemiasto.pl/plac-grunwaldzki-po-nowemu-na-probe-jako-rondo-polturbinowe/ar/c4-7274777, artykuł z dnia 2019-07-27, dostęp 5.05.2022.
[23] Kendal G. R., Reutener I., Design and implementation of a turbo roundabout, Proceedings of the 33rd Southern African Transport Conference (SATC 2014), 7 – 10 July 2014 Pretoria, South Africa, https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.890.9208&rep=rep1&type=pdf, dostęp 22.08.2022.
[24] Kodeks drogowy – Ustawa z dnia 20 czerwca 1997 Prawo o ruchu drogowym. Dziennik Ustaw 1991 poz. 373 z późn. zm.
[25] Kwakwa O. K., Adams Ch. A., Assessment of turbo and multilane roundabout alternatives to improve capacity and delay at a single lane roundabout using microsimulation model Vissim: A case study in Ghana, American Journal of Civil Engineering and Architecture, 2016, Vol. 4, No. 4, 106-116, DOI: 10.12691/ajcea-4-4-1.
[26] Macioszek E., Stan bezpieczeństwa ruchu drogowego na rondach turbinowych w Polsce, Prace Naukowe Politechniki Warszawskiej, z. 96, Warszawa, 2013, s. 295–307.
[27] Macioszek E., The road safety at turbo roundabouts in Poland. Archives of Transport, 2015, 33 (1), 57–67. DOI 10.5604/08669546.1160927
[28] Nieradka K., Krytykowane przez kierowców słupki zostaną na rondach, https://radioszczecin.pl/1,396838,krytykowane-przez-kierowcow-slupki-zostana-na-ro, artykuł z dnia 2019-11-13, dostęp. 5.05.2022.
[29] Olszewska A., Projekt koncepcyjny przebudowy skrzyżowania ulic 11 Listopada, Gdańskiej i Matejki w Świnoujściu, inżynierska praca dyplomowa, Zachodniopomorski Uniwersytet Technologiczny w Szczecinie, 2022.
[30] Petru J., Krivda V., An analysis of turbo roundabouts from the perspective of sustainability of road transportation, Sustainability, 2021, 13, 2119. https://doi.org/10.3390/su13042119.
[31] Pierwsze rondo półturbinowe w Szczecinie już działa, https://wszczecinie.pl/aktualnosci,pierwsze_rondo_polturbinowe_w_szczecinie_juz_dziala_foto,id-32388.html, artykuł z dnia 24.07.2019, dostęp. 5.05.2022.
[32] Porter, R., Gooch, J., Peach, K., Chestnutt, C., Moore, B., Broeren, P., Tigelaar, J., Advancing Turbo Roundabouts in the United States: Synthesis Report FHWA-SA-19-027, Federal Highway Administration Office of Safety, Washington, DC, 2019.
[33] Roundabouts: An Informational Guide NCHRP Program Report 672, Second Edition, Transportation Research Board Washington, D.C. 2010.
[34] *Roundabouts – Application and design, A practical manual*, Royal Haskoning DHV. Ministry of Transport, Public Works and Water Management, Partners for Roads, Hague 2009.
[35] Severino A., Pappalardo G., Trubia S., Safety evaluation of turbo roundabout considering autonomous vehicles operation, *Archives of Civil Engineering*, 2021, Vol. 67, nr 1, s. 439–460, DOI 10.24425/ace.2021.136482.
[36] *System ewidencji wypadków i kolizji SEWIK*, http://sewik.pl/search, dostęp. 5.10.2022.
[37] Sołowczuk A., Wałdoch L., Tarko M., Cykliński D.: Studium kształtowania geometrii czterowlotowych rond turbinowych cz. 1 (propedeutyka i podstawowe typy), *Drogi – Budownictwo Infrastrukturalne*, 2013, nr 9, s. 34 – 45.