CETRA^{2024} 15-17 May 2024, Cavtat, Croatia
8th International Conferenceon Road and Rail Infrastructure

INFLUENCE OF TRUCK APRON DESIGN ON TWO-GEOMETRY ROUNDABOUTS' SPEED MANAGEMENT POTENTIAL

Saša Ahac, Maja Ahac
University of Zagreb, Faculty of Civil Engineering, Zagreb, Croatia

Abstract

An alternative type of modern roundabout with variable circulatory roadway width, the so-called two-geometry roundabout, has an elliptical outer carriageway edge and a circular inner carriageway edge. This variable width results in a roundabout that is less bulky than standard modern roundabouts and therefore more easily placed in locations with space constraints. Previous research has shown that these roundabouts must be equipped with truck aprons to guarantee vehicle trajectory deflection linked width the required personal vehicle speed reduction. The investigation presented in this paper aimed to determine the influence of truck apron design on two-geometry roundabouts' personal vehicle speed reduction capabilities and relative speed. The investigation was based on computer simulations of vehicle movement and the resulting swept paths of a tractor with a semitrailer generated by the Autodesk Vehicle Tracking 2020 software. 32 four-legged single-lane roundabout schemes were designed in the Autodesk AutoCAD 2021 software by varying lengths of (1) the major axis from 18 to 25 m, with a 1-meter increment, and (2) the minor axis from 0.75 to 0.90 times the major axis length, with an increment of 0.05. Additional eight four-legged single-lane roundabout schemes were designed to represent a standard modern roundabout by varying the outer radius from 18 to 25 m, with a 1-meter increment. The truck aprons were designed to accommodate the 5-meter-wide circulatory lane. The expected driving speed through the roundabouts was estimated by constructing the fastest paths, measuring the path radii, and calculating driving speed according to the FHWA model. The investigation resulted in relative speeds between conflicting traffic streams and consecutive geometric elements, whose consistency can help to improve traffic safety at intersections.

Keywords: computer simulation, swept path, long vehicle, path deflection, fastest path

1 Introduction

Modern roundabouts are intersections where the yield-at-entry rule is applied, and the traffic is continuous and circulating at low speed in one direction around a raised central island towards the exits at the intersection legs. Compared to conventional intersections, adequately designed modern roundabouts provide numerous benefits like improved intersection safety and capacity, better vehicle speed management, reduced maintenance costs, and reduced pollution generated by road traffic [1-5]. Today, due to the constant development of modern roundabouts, there are numerous alternatives to standard single-lane or double-lane roundabouts either in use or in the development phase worldwide, such as hamburger, turbo, peanut, flower, elliptical, and target roundabouts [6-8]. One such alternative modern roundabout is the so-called two-geometry roundabout. This alternative modern roundabout is equipped with variable circulatory roadway widths (that vary from "x" to "y"), defined by the elliptical outer carriageway edge (defined by the major axis “a” and the minor axis “b”) and a circular inner carriageway edge (defined by the central island radius “R_c”), as shown in Figure 1. Variable circulatory roadway width results in a roundabout that is less bulky than standard modern roundabouts and therefore more easily placed in locations with space constraints [2, 8].

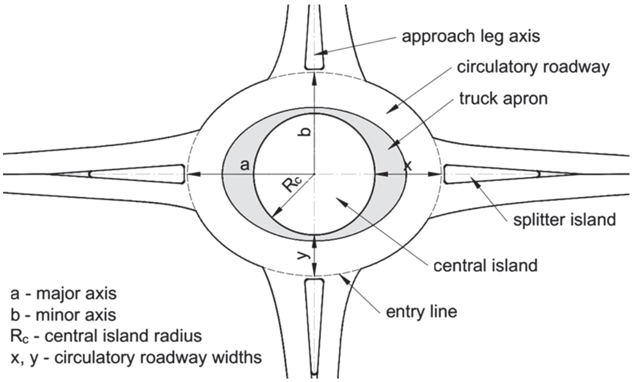

Figure 1 Two-geometry roundabout design elements

Previous research has shown that two-geometry roundabouts must be equipped with truck aprons to guarantee vehicle trajectory deflection linked width the required personal vehicle speed reduction [9]. The investigation presented in this paper aims to determine the influence of the truck apron design on two-geometry roundabouts’ personal vehicle speed reduction capabilities and relative speed. According to [10], relative speeds between conflicting traffic streams and between consecutive geometric elements should be minimized such that the maximum speed differential between movements should be no more than approximately 15 to 25 km/h.
As there is not yet enough experimental data collected on constructed two-geometry roundabouts because their number is still low [8], the presented investigation is based on computer simulations: the selected design vehicle movement is simulated, and the resulting vehicle swept paths are used as the basis for the design of roundabout schemes. On the resulting roundabout schemes, the passenger vehicle relative speed analysis is conducted by constructing the fastest paths, measuring the path radii, and then calculating the vehicle speed using the FHWA model [9]. The results of this investigation have shown that the introduction of the truck apron in a two-geometry roundabout design can provide sufficient traffic safety when the truck apron design is based on the 5-meter-wide circulatory lane.
The paper is organized as follows. Input parameters and methods used in the investigation are presented in Section 2. The results of the investigation are given in Section 3. These results are discussed and interpreted from the perspective of the investigated roundabout design elements’ applicability and safety in Section 4. In the same section possible future research directions are highlighted and conclusions are drawn.

2 Methodology

The investigation presented in this paper was conducted on 40 single-lane roundabout schemes designed in the Autodesk AutoCAD 2021 software by utilizing computer simulations of the design vehicle movement and the resulting swept paths generated by the Autodesk Vehicle Tracking 2020 software. The design vehicle used in this investigation was a tractor with a semi-trailer based upon a Scania R500 LA6x2/4MNA (Södertälje, Sweden) tractor with a generic 13.6 m long and 2.55 m wide trailer (Figure 2), which is defined as a standard European long vehicle in the Vehicle Tracking 2020 database. This long, articulated vehicle was selected because these types of vehicles face issues while maneuvering the roundabout due to their large turning envelope requirements [11, 12].

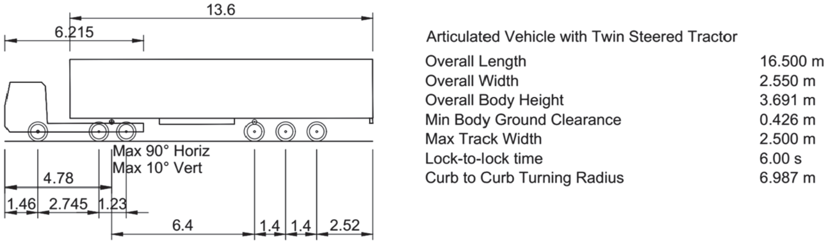

Figure 2 Design vehicle

A total of 32 initial schemes were constructed by varying the major axis of the elliptical outer edge of a two-geometry roundabout (a) from 18 to 25 m, with a 1 m increment, and varying the minor axis of the elliptical outer edge of a two-geometry roundabout (b, where b = 0.75a, 0.80a, 0.85a, and 0.90a.) Eight additional initial schemes were created to represent a standard modern roundabout with an outer radius (R, where R = a) between 18 and 25 m, designed with a 1 m increment. An increment of 1 m was chosen to capture the dispersity of the results and to create a sample that is representative, manageable, and easy to present at the same time. Roundabout approach leg axes in all schemes intersect in the center of the roundabout's outer edge. Approach legs are radial to the outer edge, and their axes intersect in the center of the roundabout. A triangular splitter island, 15 m long, 3 m wide, and placed 0.5 m from the roundabout outer edge, was selected for this investigation (Figure 3 a).

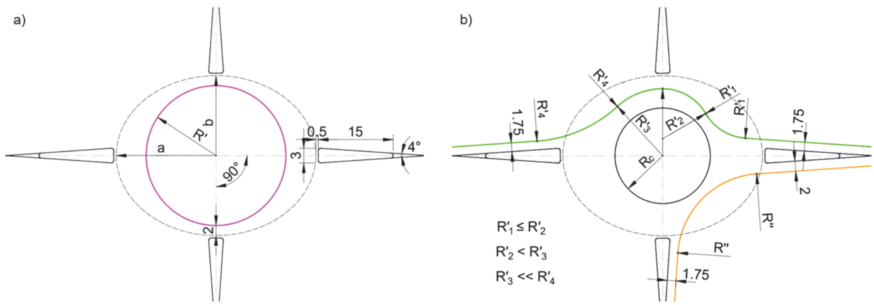

Figure 3 Roundabout initial schemes and the front axle center point paths

The input parameter necessary for defining the swept path at roundabouts is the design vehicle steering path, i.e., the front axle center point path. For this investigation, the front axle center point paths for the circular movement around the central island (Figure 3 a, shown in magenta) were constructed with a circular arc with a radius that is offset by 2 m from the roundabout's minor axis ($R' = b - 2$). Paths for the right-turn movement (Figure 3 b, shown in orange) were constructed with an entry line that was offset by 1.75 m from the splitter island on the roundabout entry, an exit line that was offset by 2.0 m from the splitter island on the roundabout exit, and a circular arc (R'') tangential to these lines. Paths for through movement (Figure 3 b, shown in green) were constructed following the principles of hairpin bend geometry [13], i.e., with an entry line, four consecutive circular arcs (R'_1, R'_2, R'_3, and R'_4), and an exit line. Entry and exit lines were offset by 1.75 m from the splitter island on the roundabout entry and exit (Figure 3 b).

Minimal safety lateral widths of 0.25 m were ensured along the elevated splitter islands, central island, and outer carriageway edge in every roundabout scheme, according to the instructions given in [14]. The resulting swept paths were used to determine the central island radii (R_c) and carriageway edge design. All designed roundabout schemes were equipped with a truck apron. The truck apron width was based on the selected width of the circulatory lane, which was set to 5 m. This width is in line with the recommendations given in [8], which state that the circulatory lane widths on two-geometry roundabouts can be between 4 to 6 m. Furthermore, the 5-m-wide circulatory lane was selected because previous research, given in [9], has shown that the circulatory lane widths of 5.5 m resulted in excessive relative speed for the analyzed paths at the exit.

On the resulting roundabout schemes, estimations of the expected driving speed based on the fastest path analyses were conducted. The fastest paths were drawn for all approaches and all movements: through movement (Figure 4, shown in red), right-turn (Figure 4, shown in purple), and left-turn movements (Figure 4, shown in blue). The fastest paths were constructed in Autodesk AutoCAD 2021 software using cubic splines, piecewise polynomials of the third degree with function values, and second derivatives that agree at the points (nodes) where they join. Nodes were defined in such a way that they result in a spline curve tangent with the following minimum clearances: 1 m from the painted edge line of the splitter island and 1.5 m from the right carriageway edge and the central island (Figure 4).

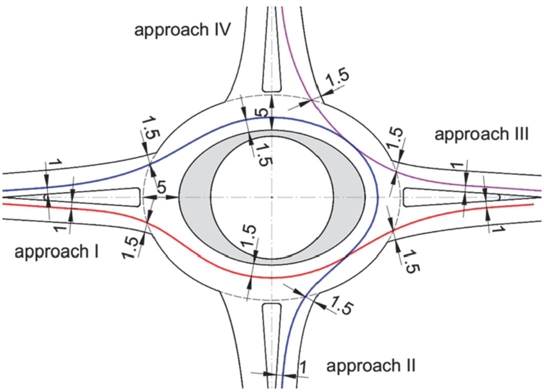

Figure 4 Fastest paths and the minimum clearances

Following the construction of the fastest paths, the path radii were defined for each approach (Figure 5): (1) the entry path radii ($R'_{(1)}$, $R'_{(4)}$, $R''_{(1)}$, and $R''_{(4)}$), which are the minimum radii on the fastest through paths (shown in red) and left-turn paths (shown in blue) before the entrance line; (2) the circulating path radii ($R'_{(2)}$, $R'_{(5)}$, $R'_{(6)}$, $R''_{(2)}$, $R''_{(5)}$, and $R''_{(6)}$), which are the minimum radii on the fastest through paths and left-turn paths around the central island; (3) the exit path radii ($R'_{(3)}$, $R'_{(7)}$, $R''_{(3)}$, and $R''_{(7)}$), which are the minimum radii on the fastest through paths and left-turn paths into the exit; and (4) the right-turn path radii ($R'_{(8)}$ and $R''_{(8)}$), which are the minimum radii on the fastest paths of a right-turning vehicle (shown in purple) [10]. Estimations of vehicle speed were conducted for every path radius based on the following speed–radius relationship, given in [10]:

$$V_i = \sqrt{127 \cdot R_i \cdot \left(f \pm e\right)} \qquad (1)$$

where V_i [km/h] is the predicted design speed, R_i [m] is the radius of the curve, f [-] is the side friction factor, and e [-] is superelevation (assumed to be +0.025 for entry and exit curves and -0.025 for curves around the central island). Finally, the relative speed between conflicting traffic streams and consecutive fastest path elements was determined.

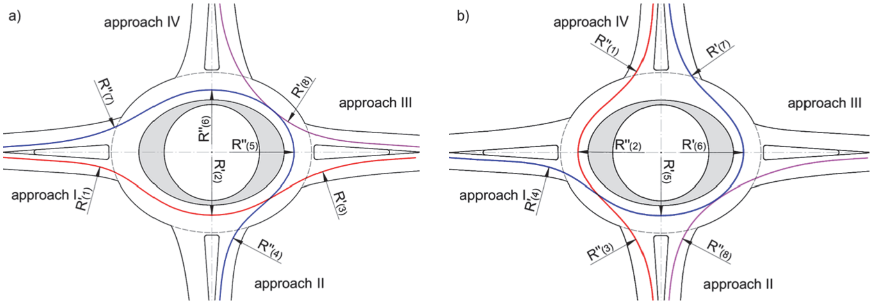

Figure 5 Fastest paths and the minimum clearances

3 Results

Resulting entry design speeds (V'_1, V''_1, V'_8, and V''_8) and relative speed between conflicting traffic streams ((V'_1-V''_5), (V'_4-V''_2), (V''_1-V'_5), and (V''_4-V'_2)) are given in Figure 6. It can be noted that the entry design speeds are smaller than the recommended maximum value for single-lane roundabouts of 40 km/h, that is given in [10]. This maximum value is exceeded by 1 km/h only at a standard roundabout scheme with an outer radius of 25 m for right-turn entry speed (V'_8 and V''_8). Relative speeds between conflicting traffic streams on two-geometry roundabouts are larger for approach I (((V'_1-V''_5) and (V'_4-V''_2)) compared to approach II ((V''_1-V'_5) and (V''_4-V'_2)).

Major axis	Minor axis	V'1	V'8	V'1-V"5	V'4-V"2	V"1	V"8	V"1-V'5	V"4-V'2
18	0.75a	29	29	11	11	27	26	0	0
	0.80a	29	29	10	10	27	29	0	0
	0.85a	29	30	9	9	29	29	3	3
	0.90a	30	30	9	9	31	30	6	6
	1.00a	35	33	11	11	35	33	11	11
19	0.75a	29	30	10	10	25	26	-2	-2
	0.80a	29	30	10	10	26	28	0	0
	0.85a	30	31	9	9	28	29	2	0
	0.90a	30	32	8	8	30	31	5	5
	1.00a	35	34	11	11	35	34	11	11
20	0.75a	27	30	8	8	25	27	-3	-3
	0.80a	28	31	9	9	26	28	-1	-1
	0.85a	29	31	8	8	29	32	3	3
	0.90a	31	32	8	8	31	31	5	5
	1.00a	35	36	11	11	35	36	11	11
21	0.75a	28	30	9	9	26	28	-3	-3
	0.80a	30	31	10	10	29	31	1	1
	0.85a	31	32	9	9	29	32	2	2
	0.90a	32	33	9	9	31	33	5	5
	1.00a	37	38	12	12	37	38	12	12
22	0.75a	27	28	7	7	26	28	-3	-3
	0.80a	29	30	8	8	32	35	4	4
	0.85a	31	32	8	8	30	32	3	3
	0.90a	33	35	10	10	32	36	5	5
	1.00a	34	36	9	9	34	36	9	9
23	0.75a	26	29	6	6	26	28	-4	-4
	0.80a	28	31	6	6	28	30	-1	-1
	0.85a	32	33	9	9	30	32	2	2
	0.90a	34	36	10	10	33	36	5	5
	1.00a	35	37	9	9	35	37	9	9
24	0.75a	28	29	7	7	29	30	-1	-1
	0.80a	31	31	8	8	30	31	0	0
	0.85a	33	33	10	10	32	34	3	3
	0.90a	35	36	10	10	33	35	5	5
	1.00a	38	40	12	12	38	40	12	12
25	0.75a	28	30	6	6	28	27	-3	-3
	0.80a	29	32	6	6	30	30	0	0
	0.85a	33	34	10	10	32	33	3	3
	0.90a	35	38	10	10	34	37	5	5
	1.00a	37	41	10	10	37	41	10	10

Figure 6 Entry design speeds and relative speeds between conflicting traffic streams

The resulting relative and average expected driving speed along the analyzed fastest paths are given in Figure 7. According to [10], for vehicles to safely negotiate the roundabout, the maximum relative speed between consecutive fastest path elements should not exceed 15 to 25 km/h. As it can be noted, on all two-geometry roundabout schemes, relative speeds between consecutive fastest path elements are below the recommended maximum value of

15 km/h. On standard roundabout schemes, the largest noted relative speed between consecutive fastest path elements is 16 km/h. It can also be noted that the calculated expected driving speeds through the roundabout for the major and minor axis directions ($V_{(I-III)}$, $V_{(I-IV)}$, $V_{(II-IV)}$, and $V_{(II-I)}$) are lower than 35 km/h, which is in line with recommendations given in [15].

Major axis	Minor axis	V'1-V'2	V'3-V'2	V(I-III)	V'4-V'5	V'5-V'6	V'6-V'7	V(I-IV)	V''1-V''2	V''3-V''2	V(II-IV)	V''4-V''5	V''5-V''6	V''6-V''7	V(II-I)
18	0.75a	2	11	33	2	9	10	27	9	10	26	9	-9	11	29
	0.80a	2	10	32	2	8	10	27	8	10	26	8	-8	10	29
	0.85a	3	9	31	3	6	11	28	9	11	28	9	-6	9	29
	0.90a	5	10	31	5	4	12	29	10	12	30	10	-4	10	29
	1.00a	11	14	34	11	0	14	32	11	14	34	11	0	14	32
19	0.75a	2	11	33	2	8	9	27	6	9	25	6	-8	11	28
	0.80a	3	10	31	3	7	9	26	7	9	25	7	-7	10	28
	0.85a	4	9	31	4	5	9	28	7	9	27	5	-5	9	28
	0.90a	5	10	31	5	3	11	29	8	11	29	8	-3	10	29
	1.00a	11	14	33	11	0	14	31	11	14	33	11	0	14	31
20	0.75a	-1	8	31	-1	9	8	26	6	8	25	6	-9	8	28
	0.80a	1	8	31	1	8	10	27	7	10	26	7	-8	8	28
	0.85a	3	8	31	3	5	9	27	8	9	28	8	-5	8	29
	0.90a	5	9	32	5	3	10	29	8	10	30	8	-3	9	30
	1.00a	11	14	33	11	0	14	31	11	14	33	11	0	14	31
21	0.75a	-1	6	31	-1	10	9	27	7	9	25	7	-10	6	28
	0.80a	2	6	31	2	8	9	27	9	9	27	9	-8	6	29
	0.85a	4	7	31	4	5	9	29	7	9	28	7	-5	7	29
	0.90a	6	9	32	6	3	10	29	8	10	30	8	-3	9	30
	1.00a	12	16	35	12	0	16	33	12	16	35	12	0	16	33
22	0.75a	-2	4	30	-2	9	7	26	6	7	25	6	-9	4	28
	0.80a	1	5	31	1	7	8	27	11	8	28	11	-7	5	29
	0.85a	4	7	31	4	4	8	29	7	8	29	7	-4	7	29
	0.90a	6	8	32	6	4	10	30	9	10	30	9	-4	8	30
	1.00a	9	15	34	9	0	15	32	9	15	34	9	0	15	32
23	0.75a	-4	2	30	-4	10	8	26	6	8	25	6	-10	2	27
	0.80a	-1	4	31	-1	7	7	27	6	7	27	6	-7	4	29
	0.85a	4	6	32	4	5	8	29	7	8	29	7	-5	6	29
	0.90a	6	7	33	6	4	10	31	9	10	31	9	-4	7	31
	1.00a	9	13	34	9	0	13	32	9	13	34	9	0	13	32
24	0.75a	-2	2	30	-2	9	7	27	8	7	27	8	-9	2	28
	0.80a	1	3	32	1	7	7	29	7	7	28	7	-7	3	29
	0.85a	4	4	32	4	6	9	30	9	9	29	9	-6	4	30
	0.90a	7	7	33	7	3	8	31	8	8	31	8	-3	7	31
	1.00a	12	15	35	12	0	15	33	12	15	35	12	0	15	33
25	0.75a	-3	0	30	-3	9	6	28	6	6	26	6	-9	0	28
	0.80a	-1	2	31	-1	7	8	29	7	8	28	7	-7	2	29
	0.85a	4	4	32	4	6	9	30	9	9	29	9	-6	4	30
	0.90a	6	7	34	6	4	10	31	9	10	32	9	-4	7	31
	1.00a	10	14	35	10	0	14	33	10	14	35	10	0	14	33

Figure 7 Relative and average expected driving speed along the fastest paths

4 Discussion and conclusions

The investigation presented in this paper aimed to provide insight into the impact of two-geometry roundabouts on traffic safety, i.e., to determine whether the two-geometry roundabouts can provide the appropriate vehicle speed reduction and consistency between consecutive geometric elements. Namely, according to [10], the consistency between the speeds of various movements within the intersection can help to minimize the crash rate between conflicting traffic streams.

Previous research has shown that two-geometry roundabouts must be equipped with truck aprons to guarantee vehicle trajectory deflection linked width the required personal vehicle speed reduction [9]. Therefore, investigated roundabout schemes (designed according to the long design vehicle swept paths) were equipped with truck aprons. Apron widths were based on the selected circulatory lane width of 5 m. On the designed roundabout schemes, the passenger vehicle relative speed analysis was conducted by constructing the fastest paths, measuring the path radii, and then calculating the vehicle speed using the FHWA model described in [10].

The results of this investigation have shown that the introduction of the truck apron in a two-geometry roundabout design can provide appropriate vehicle speed reduction and consistency between consecutive geometric elements, and, therefore, sufficient traffic safety. Future research will be based on the circulatory lane widths' optimization. Namely, variable circulatory lane widths will be investigated to determine limit width values that will provide sufficient deviation of the vehicle trajectories and lowering of vehicle speed for two-geometry roundabouts.

References

[1] Hydén, C., Várhelyi, A.: The effects on safety, time consumption and environment of large scale use of roundabouts in an urban area: A case study, Accident Analysis & Prevention, 32 (2000) 1, pp. 11–23

[2] Gazzarri, A., Pratelli, A., Souleyrette, R.R., Russell, E.R.: Unconventional roundabout geometries for large vehicles or space constraints, 4th International Conference on Roundabouts, Seattle, pp. 1-17, Washington, April 16–18, 2014.

[3] Fernandes, P., Teixeira, J., Guarnaccia, C., Bandeira, J.M., Macedo, E., Coelho, M.C.: The Potential of Metering Roundabouts: Influence in Transportation Externalities, Transportation Research Record Journal of the Transportation Research Board, 2672 (2018) 1, pp. 21–34, DOI: 10.1177/0361198118774667

[4] Distefano, N., Leonardi, S.: Experimental Investigation of the Effect of Roundabouts on Noise Emission Level from Motor Vehicles, Noise Control Engineering Journal, 67 (2019), pp. 282–294

[5] Jandacka, D., Decky, M., Hodasova, K., Pisca, P., Briliak, D.: Influence of the Urban Intersection Reconstruction on the Reduction of Road Traffic Noise Pollution, Applied Science, 12 (2022) 8878

[6] Tollazzi, T.: Alternative Types of Roundabouts: An Informational Guide, Springer Tracts on Transportation and Traffic, 6 (2015), ed. Roess, R.P.; Springer: New York, NY, USA

[7] Alozi, A.R., Hussein, M.: Multi-criteria comparative assessment of unconventional roundabout designs, Int. J. Transp. Sci. Technol., 11 (2022), pp. 158–173

[8] Pratelli, A., Souleyrette, R.R., Brocchinia, L.: Two-Geometry Roundabouts: Design Principles. Transp. Res. Procedia, 64 (2022), pp. 299–307

[9] Ahac, S., Ahac, M., Majstorović, I., Bašić, S.: Speed Reduction Capabilities of Two-Geometry Roundabouts, Appl. Sci., 13 (2023) 11816

[10] Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., Moule, M., Persaud, B., Lyon, C.;, Hallmark, S.: NCHRP Report 672: ROUNDABOUTS: An Informational Guide, 2nd ed., Transportation Research Board: Washington, DC, USA, 2010.

[11] Carrasco, M.S.: Turning vehicle simulation: Interactive computer-aided design and drafting application, Transp. Res. Rec., 1500 (1995), pp. 1–11

[12] Ahac, S. Design of Suburban Roundabouts Based on Rules of Vehicle Movement Geometry, Ph.D. Thesis, University of Zagreb, Zagreb, Croatia, April 2014.

[13] Ahac, S., Ahac, M., Džambas, T., Dragčević, V.: The Design Vehicle Steering Path Construction Based on the Hairpin Bend Geometry—Application in Roundabout Design, Applied Sciences, 12 (2022) 21, 11019

[14] Stančerić, I., Dobrica, T., Ahac, S., Dragčević, V., Tenžera, D.: Offtracking control requirements for quality roundabout design, 3rd International Conference on Road and Rail Infrastructure - CETRA 2014, Split, Croatia, 28 - 30 April 2014, pp. 263–268

[15] CROW: Eenheid in Rotondes, CROW Publication no.126, CROW: Ede, The Netherlands, 1998.