EVALUATING THE EFFECTS OF SIGNALIZED INTERSECTIONS ON THE ROUNDABOUT SAFETY AND CAPACITY: A CASE STUDY FROM OSIJEK

Irena Ištoka Otković[1], Mirna Klobučar[2], Aleksandra Deluka-Tibljaš[2], Sanja Šurdonja[2]
[1] Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture, Osijek
[2] University of Rijeka, Faculty of Civil Engineering

Abstract: *Urban traffic management is a critical component of sustainable city planning, directly influencing mobility, safety, and environmental impact. In many urban environments, roundabouts and signalised intersections are fundamental elements of traffic control, each with distinct operational characteristics and implications for traffic flow. The interplay between these two types of intersections is particularly significant in densely populated areas where the proximity of different types of intersections can have compounding effects on traffic behaviour. Signalised intersections and roundabouts are prominent features of Osijek's traffic network, each playing a vital role in managing the flow of vehicles and pedestrians. This study analyzed the safety and operational indicators of a single roundabout and a roundabout in a corridor between two traffic signalized intersections. The safety features were analyzed using the Microsimulation Traffic Model (VISSIM) and Surrogate Safety Assessment Model (SSAM). The analysis of operational indicators included field measurements and microsimulation traffic modeling with a default and calibrated model.*

Keywords: *roundabout, signalized intersections, corridor, safety analysis, capacity, case study*

PROCJENA UTJECAJA SEMAFORIZIRANIH RASKRIŽJA NA SIGURNOST I KAPACITET KRUŽNOG RASKRIŽJA: STUDIJA SLUČAJA IZ OSIJEKA

Irena Ištoka Otković[1], Mirna Klobučar[2], Aleksandra Deluka-Tibljaš[2], Sanja Šurdonja[2]
[1] Sveučilište Josipa Jurja Strossmayera u Osijeku, Građevinski i arhitektonski fakultet Osijek
[2] Sveučilište u Rijeci, Građevinski fakultet

Rezime: *Upravljanje urbanim prometom ključna je komponenta održivog urbanog planiranja, koja izravno utječe na mobilnost, sigurnost i utjecaj na okoliš. U mnogim urbanim okruženjima, kružna i semaforizirana raskrižja temeljni su elementi kontrole prometa, svaki s različitim operativnim karakteristikama i implikacijama za protok prometa. Međudjelovanje ove dvije vrste raskrižja posebno je značajno u gusto naseljenim područjima gdje blizina različitih vrsta raskrižja može imati složene učinke na ponašanje u prometu. Semaforizirana i kružna raskrižja dominantni su tipovi raskrižja prometne mreže grada Osijeka i imaju vitalnu ulogu u upravljanju protokom vozila i pješaka. U okviru ove studije analizirani su sigurnosni i operativni pokazatelji pojedinačnog kružnog raskrižja i kružnog raskrižja u koridoru, između dva semaforizirana raskrižja. Za analizu sigurnosnih značajki korišteni su modeli za mikrosimulacijsko prometno modeliranje (VISSIM) i Surrogate Safety Assessment Model (SSAM). Analiza operativnih pokazatelja obuhvatila je terenska mjerenja i mikrosimulacijsko prometno modeliranje sa default i kalibriranim modelom.*

Ključne reči: *kružno raskrižje, semaforizirana raskrižja, koridor, sigurnosne analize, kapacitet, studija slučaja*

1. INTRODUCTION

Urban traffic management is a critical component of sustainable city planning, directly influencing mobility, safety, and environmental impact. With nearly 75% of Europeans residing in urban areas, dealing with daily traffic congestion has become a widespread issue [1]. In many urban environments, roundabouts and signalised intersections are fundamental elements of traffic control, each with distinct operational characteristics and implications for traffic flow. The interplay between these two types of intersections is particularly significant in densely populated areas where the proximity of different types of intersections can have compounding effects on traffic behaviour [2].

This study focuses on the impact of signalised intersection on adjacent roundabout, using example from the City of Osijek, located in eastern Croatia, as a case study. Signalised intersections and roundabouts are prominent features of Osijek's traffic network, each playing a vital role in managing the flow of vehicles and pedestrians. However, the proximity of these two types of intersections within the city raises questions about their combined impact on traffic efficiency, safety, and environmental conditions. By analysing traffic volume and structure, vehicle operational speeds, pedestrian movement, delays, and conflicts, the research seeks to provide a comprehensive understanding of how these intersections interact and influence one another.

While effective in managing traffic at busy junctions, signalised intersections often lead to delays and increased vehicle emissions due to stop-and-go conditions. Conversely, roundabouts are designed to promote continuous flow, reducing the likelihood of severe accidents [3,4] and minimising vehicle delay [5,6], which can contribute to lower emissions and improved fuel efficiency [7]. Despite the advantages of roundabouts, their interaction with signalised intersections can create complex traffic dynamics. The effectiveness of a roundabout can be compromised by nearby signalised intersections, as the timing and coordination of traffic signals may disrupt the natural flow of vehicles approaching the roundabout [8-11].
The Croatian Guidelines for designing roundabouts [10] outline eight sets of criteria that need to be considered during planning phase when a roundabout is considered: functional, urbanistic, traffic flow, technical design, traffic safety, capacity and level of service, environmental, and economic criteria. Among these, the Level of Service (LOS) criterion is particularly important as it helps reduce delays and minimise adverse environmental effects. In addition to the intersection itself, it is essential to evaluate the functional aspect and consider the location and purpose of the intersection within the broader road network and its impact on nearby intersections. Although the literature [9,10,12,13] states that placing a roundabout between two adjacent signal-controlled intersections should be avoided; there are no specific guidelines for the acceptable distance between the signalised intersection and the roundabout. The design process of intersections generally follows the principles of isolated intersection design while the influence of the neighbouring intersection is ignored. Checking intersections in two phases would allow for a comprehensive overview of traffic conditions: the first step providing a model for an isolated intersection – a deterministic model and the second step, often overlooked, involving analyses of the model as a system – a stochastic model on which the traffic microsimulation methods are based [14,15]. The second step becomes even more important if two different types of intersections are nearby.

By examining a case study in the City of Osijek, this research analyzes the interaction between a roundabout and signalized intersections along an urban corridor. The analysis draws on experimentally collected traffic data that served as the basis for developing the microsimulation model. Model calibration was performed using field-observed data. The findings are intended to support local traffic management decisions and to contribute to the broader body of knowledge in urban traffic engineering.

2. METHODOLOGY

In the research presented in this paper the operational characteristics of the roundabout were analyzed using microscopic traffic simulation modeling in PTV - VISSIM. Four scenarios were considered: in the first scenario, the roundabout was analyzed as an isolated intersection, while in the second scenario the same roundabout was examined within a corridor between two signalized intersections, both with and without pedestrian flows. VISSIM provides vehicle trajectories as one of its possible outputs, and these trajectories were analyzed using the Surrogate Safety Assessment Model (SSAM) to compare the safety indicators of the observed scenarios. The methodological framework is presented in Figure 1.

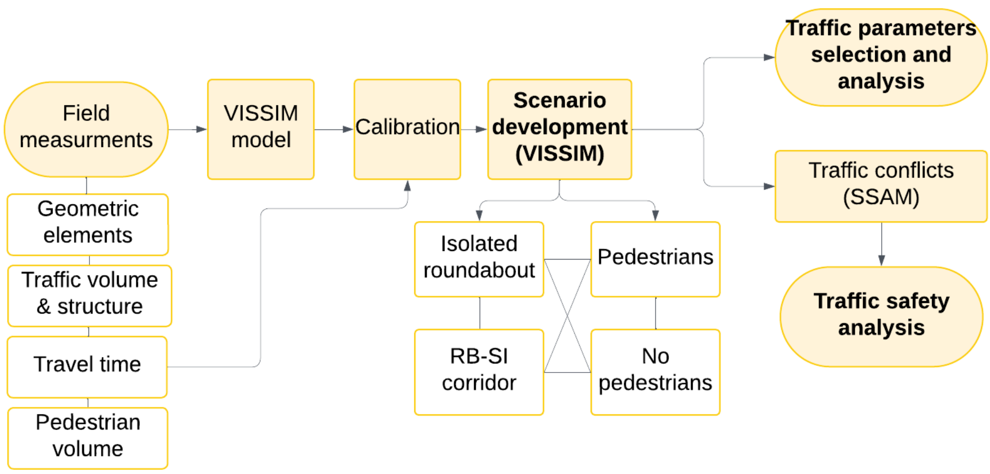

Figure 1. *Methodological steps diagram*

2.1. Location

The case study examines a roundabout in a signalised corridor along Vinkovačka Street in Osijek, Croatia. The roundabout is located between two signalised intersections, with the northern intersection 122 meters away and the southern one 178 meters away (Figure 2.-a Traffic corridor). Situated on a major road Vinkovačka, the roundabout is close to a residential area, a school, and a shopping centre. It is a four-legged intersection connecting Vinkovačka Street, Drinska Street, and Bosutska Street. Signalized Intersection A is also a four-legged intersection at the junction of Vinkovačka Street, Neretvanska Street, and Koranska Street, while Signalized Intersection B is a three-legged intersection at the junction of Vinkovačka Street and Gacka Street.

(a) (b)

Figure 2. *Traffic corridor with marked approaches for vehicles (a) and pedestrians (b)*

The specific geometric elements of the observed roundabout are described in Table 1: the outer radius of the roundabout (Rv), width of the circulatory roadway (u), entry and exit widths (e_{ent}, e_{ext}), entry and exit radius (R_{ent}, R_{ext}), traffic lane width on the approach (v), length of the dividing surface (m), entrance angle (Φ), deflection (d), length of the island including the part crossing the pedestrian crossing (m'), radius of the central island including the traversable apron (Rc), and width of the traversable apron (u'). Deviations from the Guidelines [10] are highlighted.

Table 1. *Geometric elements of the roundabout*

<table>
<tr><th>Approach</th><th>Rv</th><th>u</th><th>e_{ent}</th><th>R_{ent}</th><th>e_{ex}</th><th>R_{ex}</th><th>v</th><th>m</th><th>ϕ</th><th>d</th><th>m’</th><th>Rc</th><th>u’</th></tr>
<tr><td>Guide. Recom.</td><td>13,5-22,5</td><td>4,5-6,0</td><td>4-7</td><td>8-20</td><td>4-7</td><td>10-25</td><td>3-3,5</td><td>15-50</td><td>20-40</td><td>/</td><td>max 25</td><td>7,5-18</td><td>min 1</td></tr>
<tr><td>R1</td><td rowspan="4">15</td><td rowspan="4">6</td><td>6,3</td><td>11</td><td>4,3</td><td>25</td><td>3</td><td>34</td><td>40</td><td>6,3</td><td>15,6</td><td rowspan="4">9</td><td rowspan="4">2</td></tr>
<tr><td>R2</td><td>4,9</td><td>12</td><td>6</td><td>17</td><td>3,25</td><td>25</td><td>36</td><td>1,2</td><td>11,7</td></tr>
<tr><td>R3</td><td>5,5</td><td>6</td><td>4,6</td><td>15</td><td>2,6</td><td>0</td><td>29</td><td>8,5</td><td>0</td></tr>
<tr><td>R4</td><td>5,7</td><td>14</td><td>5,4</td><td>6</td><td>3,25</td><td>53</td><td>40</td><td>5,2</td><td>20</td></tr>
<tr><td colspan="14">Guide. Recom – Guidelines Recommendations
bold – deviation from Recommendations</td></tr>
</table>

In order to ensure the quality and integrity of the database, field measurements were conducted using Datacollect SRD radar traffic counters without interrupting the traffic flow (Figure 2-a, yellow triangles). A total of 8 traffic counters were placed at a height of 2,20 meters on the street light poles or traffic sign poles on each approach and data was continuously recorded for 24 hours. The analysis revealed that 16419 vehicles passed through the roundabout in a day. A further step was the determination of peak traffic hours, which was used as input data for traffic load and traffic structure for the analysis of operational indicators using microsimulations.

The vehicle traffic load is shown in Table 2, and the pedestrian traffic load at all pedestrian crossings in the observed area (Figure 2.-b) is shown in Table 3.

Table 2. *Vehicle traffic volume data collected in the field*

Approach	Vehicle Composition			Vehicle Number	Peak hour (veh/h)		Traffic Flow Ratio
	car	*truck*	*HGV*	*veh/day*	*7-8 h*	*15-16 h*	*major:minor flow*
A2	93,1%	5,1%	1,8%	7002	498	301	88:12
A3	97,8%	2,2%	0,0%	892	65	70	
R1	93,3%	6,0%	0,7%	3263	164	228	72:28
R2	79,6%	19,6%	0,8%	6064	255	400	
R3	100,0%	0,0%	0,0%	1222	94	60	
R4	94,6%	4,7%	0,7%	5870	468	359	
B1	97,8%	1,8%	0,4%	3571	246	160	79:21
B2	95,6%	3,4%	0,6%	6607	434	469	
HGV – heavy goods vehicle (>13 m)							

Table 3. *Pedestrian traffic load data collected in the field - morning peak hour*

P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
24	39	33	10	63	76	6	4	15	8	10	24	70	75	44	48	44	64	32	14

2.2. Microsimulation model VISSIM

For the analysis of the four observed scenarios (isolated roundabout; roundabout within a corridor; with pedestrians; without pedestrians), both the default VISSIM model and the calibrated model (explained in detail in [16]) were used. The model was calibrated using travel time measurements collected in the field, and the default and calibrated values of the selected model parameters are presented in Table 4.

Table 4. *Input parameters for the VISSIM model*

Parameter	Default	Calibrated
Random seed increment	1	9
Average standstill distance (m)	2	2,4
Additive part of desired safety distance (m)	2	1,8
Multiplicative part of desired safety distance (m)	3	3,5

To analyze the selected operational indicators for the observed roundabout, ten simulations were performed for different vehicle-arrival scenarios corresponding to the counted traffic demand, due to the stochastic nature of traffic flow. The presented indicator values represent the mean values across the analyzed scenarios.

Figure 3 shows the corridor model created in VISSIM.

Figure 3. *VISSIM model of roundabout in the signalised corridor*

2.3. Surrogate Safety Assessment Model (SSAM)

Recognising safety as a central concern, SSAM was employed to examine conflict types and their severity, enabling a detailed assessment of how various factors—such as pedestrian crossings, the proximity of signalised intersections, and driver behaviour—may increase crash risk. The software was used to estimate both the number and characteristics of vehicle conflicts. For each vehicle-to-vehicle interaction, SSAM computes surrogate safety measures and determines whether the interaction meets the criteria to be classified as a conflict. In this analysis, the research team applied time to collision (TTC) as the threshold for identifying conflicts and relative speed (DeltaS) as a proxy for crash severity. According to the Federal Highway Administration [17], their definitions are as follows:
1. "TTC" is the minimum time value observed during the interaction of two vehicles on a collision course. If, at any time step, the TTC drops below a given threshold (1,5 s in this work, as suggested for urban areas), the interaction has tagged a conflict.
2. DeltaS" is the difference in vehicle speeds observed at the instant of the minimum TTC.

3. RESULTS

The results of the safety and operational indicators of a single roundabout and a roundabout in a corridor between two traffic signalized intersections are presented.

3.1. Microsimulation results in VISSIM

To assess operational performance, the analysis considered several key indicators: average and maximum queue lengths (QLEN and QLENmax), level of service (LOS), vehicle delay (VehDelay), number of stops (Stop), and environmental metrics, including CO emissions and fuel consumption. Table 5 summarizes the results for all evaluated scenarios. With the exception of the initial corridor scenario, which relied on the default model, all subsequent scenarios were generated using the calibrated model.

Table 5. *Traffic parameters - VISSIM*

Model	QLEN	$QLen_{max}$	LOS	VehDelay	StopDelay	Stops	Emission CO	Fuel
	m	m	/	s/veh	s/veh	num/veh	g	gall
Default model - corridor	2,56	78,80	C	22,24	10,75	1,32	2329,95	33,33
Calibrated model-corridor	2,54	78,80	C	22,43	10,84	1,33	2347,46	33,58
Without pedestrians - corridor	2,45	79,12	B	19,07	9,74	1,04	2015,21	28,83
Isolated roundabout	2,29	81,17	A	9,61	2,86	0,82	1341,88	19,20
Isolated without pedestrians	1,76	63,23	A	6,55	2,08	0,50	1062,46	15,20

3.2. SSAM results

Table 6 summarises the total number of conflicts and their distribution by conflict type. Figure 4 provides a visual representation of conflicts by type and severity, based on TTC values obtained from SSAM, for the calibrated corridor model.

Table 6. *Number of potential conflicts and distribution by conflict type*

Model	Total	Crossing	Rear End	Lane Change
Default model - corridor	138	5	123	10
Calibrated model-corridor	142	6	126	10
Without pedestrians - corridor	88	2	80	6
Isolated roundabout	62	1	58	4
Isolated without pedestrians	40	2	37	1

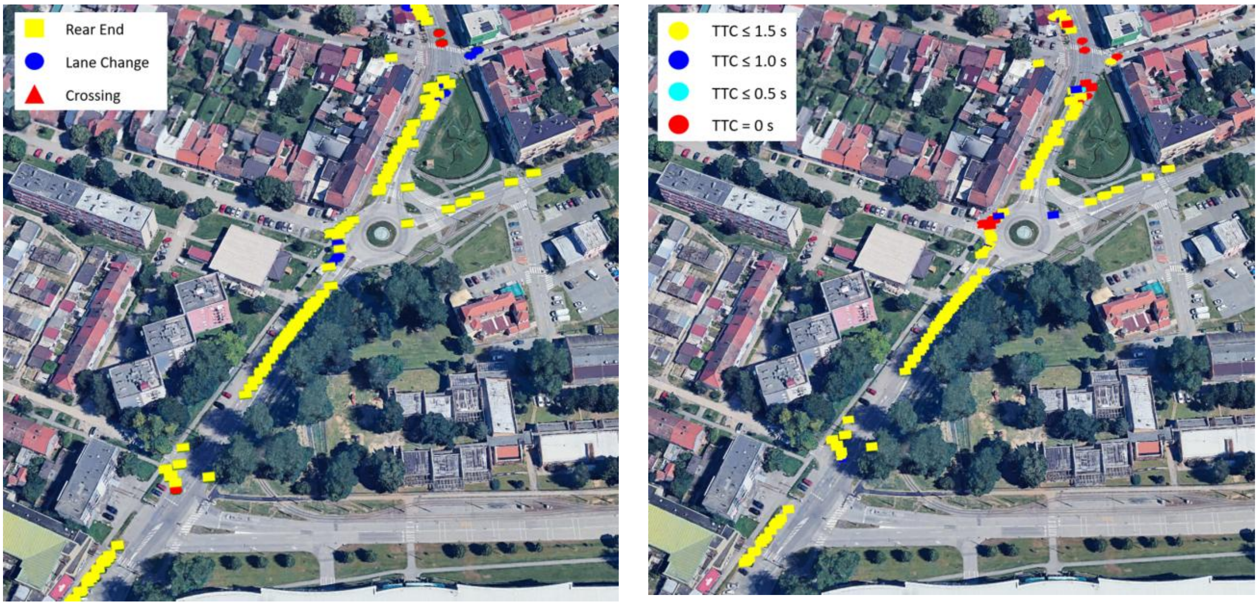

Figure 4. *Conflict type (left); Conflict severity (right) – SSAM model for calibrated corridor model*

5. DISCUSSION AND CONCLUSION

The results (Table 5) show that the isolated-intersection scenarios produce substantially more favourable operational and environmental indicators than the corridor-based scenarios, yet these improvements primarily reflect the removal of the broader traffic environment rather than a true increase in intersection efficiency. When the roundabout is evaluated within the corridor, its performance is shaped by upstream arrivals, downstream constraints, pedestrian interactions, and cumulative delays that are not present in the isolated setting. As a result, queue lengths, delays, number of stops, and emissions are consistently higher in the corridor analysis, and the level of service remains at LOS C, which demonstrates that the roundabout, when evaluated within the corridor context, operates with reduced capacity relative to the isolated roundabout scenario. These findings demonstrate that traffic-signalized intersections in the observed corridor exert a measurable influence on intersection performance and cannot be disregarded. The comparison between the calibrated and uncalibrated models shows that the default input parameters produce a more optimistic prediction of delay, CO emissions, and fuel consumption, which is consistent with the findings of previous research [18,19] conducted for Osijek.

In contrast, the isolated roundabout scenarios—especially those without pedestrians—show markedly lower delays, fewer stops, and significantly reduced emissions and fuel consumption, reaching LOS A. However, these values represent an idealized condition in which the intersection is detached from real operational pressures. The removal of pedestrians further amplifies this effect: delays drop to their lowest levels, stop-related metrics are minimized, and environmental indicators improve by more than half compared with the corridor scenario. This confirms that pedestrian activity introduces additional friction that meaningfully affects both efficiency and environmental outcomes, particularly in corridor settings where interactions accumulate across multiple intersections.

The conflict-analysis results (Table 6) reinforce the same core finding as the operational indicators: the roundabout performs substantially better when modeled in isolation, but this improvement reflects the absence of real traffic interactions rather than genuinely safer conditions. Corridor scenarios consistently show a higher number of vehicle–vehicle conflicts—particularly rear-end and lane-change conflicts—because they capture the influence of upstream arrivals, fluctuating demand, pedestrian activity, and interactions with adjacent nodes. Both for the calibrated and for the default model, the total number of conflicts remains markedly higher in the corridor, confirming that realistic traffic conditions generate more complex and risk-prone dynamics than an isolated model suggests. The results show that the analysis of intersections in the corridor has a greater impact on safety indicators than the calibration of the model. Pedestrians further contribute to this difference. Pedestrian activity further increases turbulence in the traffic stream, particularly in the corridor, where multimodal interactions accumulate and amplify conflict frequency. It is important to note that SSAM models only vehicle–vehicle conflicts; it does not account for multimodal vehicle–pedestrian conflicts, which would make the overall safety picture even more complex. Overall, the comparison confirms that reliable safety assessment requires analyzing the roundabout within its corridor context rather than as an isolated facility.

Taken together, the comparison highlights that isolated-intersection analysis systematically produces overly optimistic estimates of both performance and safety, whereas corridor-based evaluation captures the actual operational and safety burden imposed by real traffic dynamics. These findings underscore the importance of analyzing intersections within their full network context, as the influence of upstream and downstream conditions, multimodal interactions, and coordinated traffic flows cannot be neglected when assessing realistic performance or planning effective interventions.

Acknowledgements

This research was funded by the European Union—NextGenerationEU ("Safety aspects of urban transport infrastructure SigINFRA", a scientific project at the Josip Juraj Strossmayer University of Osijek (581-UN-IOS-71) and "Optimizing Transport Infrastructure in the Function of Sustainable Mobility in the Cities", a scientific project at the University of Rijeka (uniri-iz-25-32)).

References

[1] UN. (2014). *World urbanization prospects*. UN. https://doi.org/10.18356/527e5125-en
[2] Taglieri, D., Liu, H., & Gayah, V. V. (2024). Network-Wide Implementation of Roundabouts Versus Signalized Intersections on Urban Streets: Analytical and Simulation Comparison. Transportation Research Record, 2678(5), 719–735. https://doi.org/10.1177/03611981231192093/ASSET/IMAGES/LARGE/10.1177_03611981231192093-FIG7.JPEG
[3] Brilon, W. (2016, January 10). Safety of Roundabouts: International Overview. Transportation Research Board 95th Annual Meeting.

[4] Elvik, R. (2003). Effects on Road Safety of Converting Intersections to Roundabouts: Review of Evidence from Non-U.S. Studies. *Transportation Research Record*, *1847*, 1–10. https://doi.org/10.3141/1847-01
[5] Retting, R. A., Mandavilli, S., Russell, E. R., & McCartt, A. T. (2006). Roundabouts, traffic flow and public opinion, *Traffic Engineering and Control*, *47*(7), 268–272.
[6] Otkovic, I. I., & Dadić, I. (2009). Comparison of Delays at Signal-controlled Intersection and Roundabout, *Promet - Traffic&Transportation*, *21*(3), 157–165. https://doi.org/10.7307/PTT.V21I3.221
[7] Jackson, M., & Rakha, H. A. (2012, January 23). Are Roundabouts Environmentally Friendly? An Evaluation for Uniform Approach Demands. *Transportation Research Board*.
[8] CERTU. (1997). *Guide les mini-giratoires: Textes et recommendations.* https://beaulieu-sur-oudon.fr/wp/wp-content/uploads/2015/01/Les-mini-giratoires.pdf
[9] Federal Highway Administation. (2000). *Roundabouts: An Informational Guide*. https://www.fhwa.dot.gov/publications/research/safety/00067/00067.pdf
[10] Hrvatske ceste. (2014). *Smjernice za projektiranje kružnih raskrižja na državnim cestama*. https://hrvatske-ceste.hr/uploads/documents/attachment_file/file/106/SMJERNICE_KRUZNA_RASKRIZJA-HRVATSKE_CESTE.pdf
[11] Kennedy, J. V, Peirce, J., & Summersgill, I. (2007). *International Comparison of Roundabout Design Guidelines*. https://www.trl.co.uk/uploads/trl/documents/PPR206_secure.PDF
[12] Ning, W. (1998, January). Estimation of queue lengths and their percentiles at signalized intersections, *3rd International Symposium on Highway Capacity*.
[13] U.S. Department of Transportation. (2000). Roundabouts: An Informational Guide.
[14] Lenters, M. (2014, August 14). Roundabouts Near Traffic Signals. *TexITE Meeting*, https://www.texite.org/wp-content/uploads/meeting-presentations/F145B2.pdf
[15] Šurdonja, S., Nežić, D., Deluka-Tibljaš, A. (2015). Mikrosimulacijski model proračuna kapaciteta kružnog raskrižja, *Pomorski zbornik*, *49–50*(1), 143–165. https://hrcak.srce.hr/138199
[16] Klobučar, M., Šurdonja, S., Deluka-Tibljaš, A., Ištoka Otković, I. Application of the SSAM in the Safety Analysis of Combined Roundabout and Signalized Intersections Under Different Traffic Conditions, *Sustainability*, 18 (2026), 1321, 28. doi: 10.3390/su18031321
[17] Federal Highway Administration. (2008). *Surrogate Safety Assessment Model and Validation: Final Report*. https://www.fhwa.dot.gov/publications/research/safety/08051/
[18] Ištoka Otković, I., Tollazzi, T., Šraml, M. Calibration of microsimulation traffic model using neural network approach, *Expert systems with applications*, 40 (2013), 15; 5965-5974. doi: 10.1016/j.eswa.2013.05.003
[19] Ištoka Otković, I., Deluka-Tibljaš, A., Šurdonja, S. Validation of the calibration methodology of the micro-simulation traffic model, *Transportation research procedia*, 45, 2020. str. 684-691. doi: 10.1016/j.trpro.2020.02.110