



OPTIMIZATION OF ROUNDABOUT GEOMETRY BASED ON MEASURED AND SIMULATED OPERATING SPEEDS

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Abstract

Roundabouts have become a frequent solution in recent years for both the reconstruction of existing at-grade intersections and the design of new ones, owing to their generally positive influence on traffic flow efficiency and safety under varying traffic conditions. In certain cases, particularly within urban traffic networks, their implementation at specific locations does not fully achieve the anticipated traffic-calming effects typically associated with this type of intersection. This paper presents a case study focused on optimizing the geometry of an existing four-leg unsignalized intersection, which has been reconstructed into a single-lane roundabout in an urban area. The goal is to examine different analysis methods for roundabouts that can contribute to optimizing roundabout design. Field measurements using automatic traffic counters to record traffic volumes and operating speeds were conducted before and after the reconstruction. The results indicated that operating speeds at the existing intersection and on the reconstructed roundabout were significantly higher than expected, up to 50 km/h in the urban area and 40 km/h in the roundabout zone. A calibrated microsimulation model of the existing roundabout was developed to analyze vehicle trajectories and operating speeds. To analyze the influence of individual geometric elements on a roundabout, a new roundabout design has been proposed, incorporating adjustments to certain geometric elements to meet the recommendations of Croatian design guidelines for roundabouts on state roads. The influence of the adjusted geometry on vehicle speeds was evaluated using the path-speed model proposed in the US guidelines, and also with microsimulation model. The study highlights the importance of combining field measurements, microsimulation, and geometric design principles in optimizing roundabout performance, as well as the potential of simulation tools in supporting safe and efficient geometric design adjustments.

Keywords: roundabout, microsimulation, analytical models, optimized design

1 Introduction

Roundabouts have been widely adopted as a traffic-calming and safety-improvement measure due to their ability to reduce conflict points and lower vehicle speeds compared to conventional intersections. Numerous before–after studies have confirmed significant reductions in crash frequency and severity following conversion to roundabouts [1, 2]. Speed reduction is consistently identified as one of the primary mechanisms for achieving safety improvements [3]. In Croatia, the design of roundabouts is based on the national design guidelines [4], which, similarly to US design guidelines [5], define procedures for checking operating speeds using analytical models.

Both documents describe a trajectory-based approach in which the vehicle's path serves as the key parameter for estimating operating speed. Although widely applied in practice, several studies indicate that analytically predicted speeds may differ from observed driver behavior, particularly in urban single-lane roundabouts. This discrepancy highlights the importance of empirical validation [6]. Traffic microsimulation has increasingly been used to evaluate roundabout performance and geometric sensitivity [7]. Reliable applications of microsimulation require rigorous calibration, most commonly using travel time and speed indicators as calibration criteria [8]. In traffic environments where crash data are incomplete or underreported, operating speed analysis is frequently used as a surrogate safety measure for assessing intersection safety performance [3].

2 Research methodology

The research methodology is based on a combination of field measurements, analytical calculation of operating speeds, and microsimulation traffic modelling. The analysis was conducted through a comparison of traffic conditions before and after the reconstruction of the intersection located in a wider zone of Rijeka, into a roundabout, with an additional evaluation of the impact of roundabout geometric parameter modifications on vehicle operating speeds. The research approach includes empirical verification of the analytical model results and validation of the obtained indicators using a microsimulation model developed in PTV Vissim.

2.1 Location and geometric characteristics of the intersection

The analyzed intersection is located in Rešetari, on a county road connecting the City of Kastav with Rijeka. Prior to its reconstruction into a roundabout (figure 1, left), the intersection operated as a conventional unsignalized at-grade intersection, with the major traffic flow running along the 1–3 approach, while approaches 2 and 4 functioned as minor legs. All approaches were two-way, two-lane roadways, except for approaches 1 and 3, which provided an exclusive left-turn lane designated solely for left-turning vehicles.



Figure 1 Analyzed intersection: conventional unsignalized intersection – before reconstruction (left) and roundabout – after reconstruction (right)

Following the reconstruction (figure 1, right), the conventional intersection was replaced by a single-lane roundabout with an outer radius of 16 m, which, according to the Croatian Guidelines [4] classifies it as a medium-sized urban roundabout. All applied geometric design elements comply with the Guidelines [4], except for the circulatory roadway width of 6.5 m (recommended up to 6 m) (figure 2, left).

In addition to the existing roundabout, a potential design alternative was also analyzed in this paper, in which a single geometric parameter was modified – the width of the circulatory roadway. The circulatory roadway at the existing roundabout exceeds the values recommended by current design guidelines; therefore, a reconstruction proposal with a reduced circulatory roadway width is presented as a potential improvement (reduction from 6.5 m to 5.0 m) (figure 2, right).

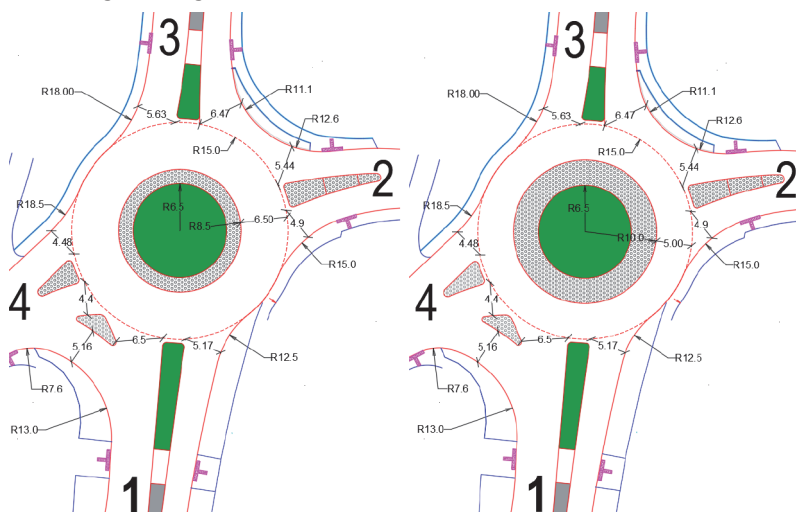


Figure 2 Geometric elements of the existing roundabout (left) and the proposed reconstruction layout (right)

Simultaneously, the width of the central island truck apron was increased from 2.0 m to 3.5 m. The truck apron was designed as a slightly raised surface with a different pavement treatment to discourage passenger vehicles from encroaching onto the central island, thereby reducing the effective path radius and operating speeds. At the same time, it allows necessary overrunning by long vehicles, ensuring operational functionality.

2.2 Field measurements – before and after reconstruction

In addition to geometric characteristics of the intersection, field measurements were conducted to collect data on traffic volumes and vehicle speeds using equipment from the Transportation Laboratory of the Faculty of Civil Engineering, University of Rijeka. Traffic counters Datacollect SRD were used to continuously record traffic flow (in both main directions) over a 24-hour period on a typical working day (Wednesday or Thursday). The counters were installed at two locations, on each main approach (1 and 3), enabling the identification of four characteristic speeds (figure 3):

- approach speed- cross-section A and D
- entry speed – cross-section B and C
- exit speed – cross-section B and C
- departure speed – cross-section A and D.

Based on the collected data, the mean speed (V_{avg}) was determined for the period from 10:00 to 11:00 a.m. During this time interval, a significant number of vehicles pass through the intersection, yet they achieve noticeably higher speeds than those recorded during the peak hour.

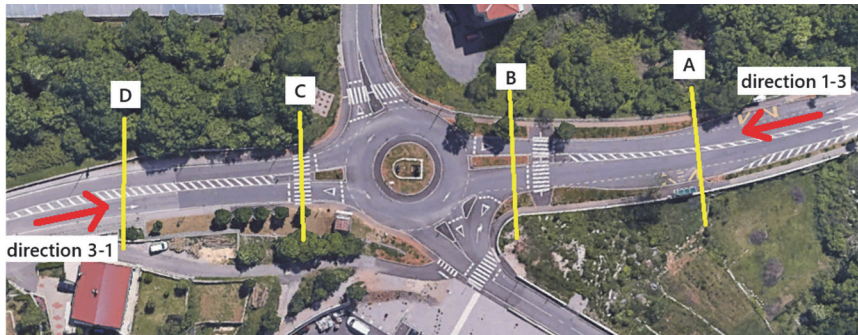


Figure 3 Positions of cross-sections

2.3 Analytical estimation of operating speed – application of the US model

Although the Croatian Guidelines [4] provide a procedure for checking operating speed, this adopted approach yields a single representative operating speed for the roundabout as a whole and does not enable the separate evaluation of speeds at specific zones (entry, circulatory roadway, and exit). However, the field measurements conducted in this study revealed noticeable differences between entry and exit speeds at the roundabout, suggesting that a single “average” value may not adequately reflect the actual speed profile across the roundabout. To enable a more detailed assessment of operating speed variations along the vehicle trajectory, the US model proposed in [5] was applied. This approach enables the construction of specific vehicle paths and the calculation of operating speeds corresponding to defined geometric conditions at the entry and exit sections.

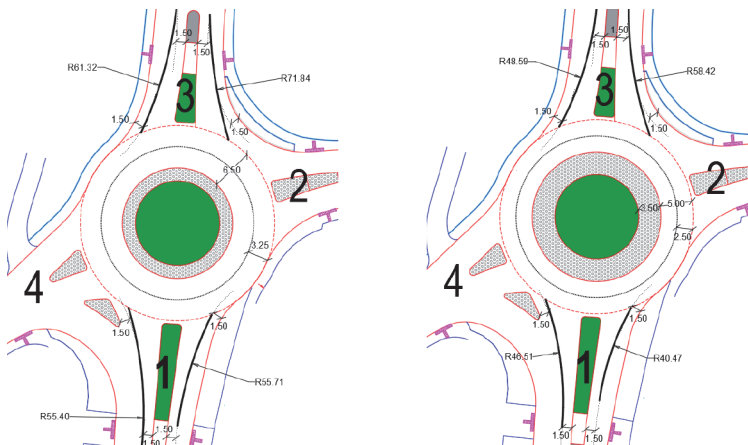


Figure 4 Entry and exit vehicle paths for the existing roundabout (left) and the proposed reconstruction (right), according to the US operating speed model.

The US model was applied to estimate operating speeds at the existing roundabout (figure 4, left) but also to assess the impact of a controlled geometric modification (figure 4, right).

2.4 Development and calibration of the microsimulation model

Based on field measurements conducted at the analyzed medium-sized urban roundabout, a VISSIM traffic microsimulation model of the existing roundabout was developed. The model incorporated geometric and traffic parameters obtained from the field measurements, including daily traffic volumes, traffic flow composition, vehicle entry, exit, approach, and departure speeds. Microsimulations were performed over a 60-minute period, with 10 simulation runs to ensure robust, reliable results.

2.4.1 Calibration of the model of the existing roundabout

To achieve the most accurate representation of real traffic conditions, the microsimulation model of the existing roundabout was calibrated using travel time as the calibration indicator. Travel time was selected because it integrates multiple aspects of driver behavior, including desired speeds, reaction times, vehicle interactions, and queue formation, providing a comprehensive representation of traffic flow dynamics [8, 9]. Additionally, travel time measurements are relatively simple to obtain and precise.

Simulated travel times obtained from the VISSIM model for the existing roundabout were compared with observed travel times recorded on a 200 m route through the roundabout in both main directions. Travel times were recorded using the GPS application GeoTracker, which provides high-resolution measurements of both route length and travel duration. Data were collected using a passenger vehicle operated by two different drivers. For each of the two analyzed routes (direction 1-3 and 3-1), travel times were assessed from 10 independent passes through the roundabout. The calibration criterion [8] was defined as:

$$\left| \frac{T_{MOD} - T_{MEAS}}{T_{MEAS}} \right| \leq 5\% \quad (1)$$

where T_{MOD} denotes the mean model-predicted travel time between reference points, and T_{MEAS} represents the mean measured travel time between the same points. The model is considered calibrated when the above condition is satisfied. For calibration, the following parameters were adjusted:

- random seed increment (default = 2, calibrated = 5)
- average standstill distance [m] (default = 2, calibrated = 1.5)
- additive part of the desired safety distance [m] (default = 2, calibrated = 2)
- multiplicative part of the desired safety distance [m] (default = 2, calibrated = 1.5).

The random seed increment determines the step size for the random number generator, producing different stochastic values in the model. The remaining three parameters relate to driver behavior as defined by the Wiedemann 74 car-following model, which is particularly suitable for urban traffic networks.

2.4.2 Microsimulation model of the reconstructed roundabout

After calibrating the base model representing the existing roundabout, an alternative microsimulation scenario was developed in VISSIM that modified the circulatory roadway width and width of traversable apron. By using the calibrated model as a validated baseline, all traffic input parameters and driver behavior settings were retained, while only the selected geometric element was altered.

3 Results

The impact of roundabout implementation on traffic speed reduction was analyzed through a comparative assessment of speeds measured at an intersection reconstructed from a conventional unsignalized intersection into a roundabout. Field measurements were conducted both before and after reconstruction, enabling a direct evaluation of changes in operating speed profiles.

The results (table 1) of field measurements indicate that the reconstruction into a roundabout led to a noticeable reduction in average approach speeds. In direction 1–3, the approach speed decreased from 65 km/h to 62 km/h (5% reduction), while in direction 3–1, the reduction was more pronounced, from 69 km/h to 51 km/h (26% reduction). Departure speeds were also reduced, particularly in direction 1–3, where a decrease from 65 km/h to 48 km/h (26%) was recorded. However, despite these reductions, average measured speeds at certain cross-sections (figure 3) remained relatively high compared to the expected 40 km/h operating speeds for urban roundabouts.

Table 1 Results of average speed from field measurements, from the microsimulation model, and from the US model

		Average speed (V_{avg}) [km/h]						
		Field measurements		Microsimulation model			US model	
Direction	Speed	Cross-section	Intersection (before Reconstruction)	Roundabout (after reconstruction)	Existing roundabout	Proposed reconstruction of the roundabout	Existing roundabout	Proposed reconstruction of the roundabout
1-3	Approach	A	65	62	61.42	58.60	n/a	n/a
	Entry	B	n/a	41	44.53	40.11	45.2	38.5
	Exit	C	n/a	49	39.77	38.99	51.3	46.3
	Departure	D	65	48	48.89	48.40	n/a	n/a
3-1	Approach	D	69	51	53.94	50.36	n/a	n/a
	Entry	C	n/a	52	38.62	34.31	47.4	42.2
	Exit	B	n/a	47	40.81	37.89	45.1	41.3
	Departure	A	68	60	53.02	51.45	n/a	n/a

Both the microsimulation model and US analytical model for the existing roundabout produced speed values relatively high for the roundabout zone (40 km/h), which is consistent with field measurements. In a scenario with reduced circulatory roadway width, both the microsimulation model and the US analytical model demonstrated a decrease in operating speeds across all analyzed cross-sections compared to the existing roundabout configuration. This confirms that targeted geometric modification—specifically the reduction of circulatory roadway width combined with an increased truck apron—can contribute to additional speed reduction through geometric self-enforcement. Overall, the results indicate that while reconstruction into a roundabout reduced operating speed, the initial geometric configuration did not achieve the full expected speed management effect. Further geometric optimization appears necessary to achieve operating speeds more consistent with urban safety objectives.

4 Conclusion

In Croatia, accident statistics for roundabouts are often incomplete, as a significant proportion of minor crashes with only material damage or no injuries go unreported. Due to the lack of reliable safety performance indicators, specifically accident data before and after reconstruction, speed analysis is often adopted as the primary surrogate safety measure. Under such circumstances, the comparison of operating speeds before and after reconstruction represents a robust and widely accepted indirect indicator of traffic safety performance. The applied methodological framework, combining field measurements, analytical speed estimation, and microsimulation modelling, enabled a comprehensive evaluation of the relationship between roundabout geometry and vehicle operating speeds. By integrating field data with analytical calculations and validated simulation scenarios, the study provides a robust, systematic assessment of geometric impacts on traffic safety. Such a multi-level approach increases the reliability of the findings and provides a solid basis for evaluating potential design modifications aimed at speed management at urban roundabouts particularly in environments where reliable crash data are unavailable.

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References

- [1] Persaud, B.N., Retting, R.A., Garder, P.E., Lord, D.: Safety effect of roundabout conversions in the united states: Empirical bayes observational before-after study, *Transportation Research Record*, 1751 (2001) 1, pp. 1-8
- [2] Retting, R.A., Persaud, B.N., Garder, P.E., Lord, D.: Crash and injury reduction following installation of roundabouts in the United States, *American journal of public health*, 91 (2001) 4, 628
- [3] Elvik, R., Høye, A., Vaa, T., Sørensen, M.: *The handbook of road safety measures*, Emerald Group Publishing Limited, 2009.
- [4] Hrvatske ceste d.o.o., Smjernice za projektiranje kružnih raskrižja na državnim cestama, Zagreb, Hrvatska, 2014.
- [5] Rodegerdts, L.A.: *Roundabouts: An informational guide*, Transportation Research Board, 2010.
- [6] Rodegerdts, L.A.: *Roundabouts in the United States*, NCHRP Report 572, Washington, DC: Transportation Research Board, 2007.
- [7] Barceló, J.: *Fundamentals of traffic simulation*, New York, Springer, 2010.
- [8] Ištoka Otković, I., Tollazzi, T., Šraml, M., Varevac, D.: Calibration of the microsimulation traffic model using different neural network applications, *Future transportation*, 2 (2023) 3, pp. 150-168
- [9] Park, B., Qi, H.: Development and Evaluation of a Procedure for the Calibration of Simulation Models, *Transportation Research Record*, 1934 (2005) 1, pp. 208-217

