

Analysis of the impact of incoming speeds on roundabout conflicts using microsimulation modelling

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ARTICLE INFO

DOI: 10.31075/PIS.72.03.01

Scientific paper

Received: 04.06.2026.

Accepted: 14.07.2026.

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Keywords

Microsimulations

SSAM

Roundabout

Incoming speeds

Conflicts

Conflict severity indicators

ABSTRACT

This study investigated the influence of incoming vehicle speeds on the frequency, typology, and severity of vehicle-to-vehicle conflicts at a single-lane roundabout, employing microsimulation modeling and the Surrogate Safety Assessment Model (SSAM). The roundabout model was held constant in terms of geometric design, and no variations in traffic demand were introduced. Incoming speeds between 30 and 70 km/h, representative of typical operational speeds in urban networks, were systematically evaluated. The findings show that higher incoming speeds increase intersection throughput and enhance operational performance, whereas safety performance remains more favorable at lower speeds. Although no clear functional relationship was observed between incoming speed and the total number of conflicts, a consistent increase in conflict severity metrics (TTC, PET, MaxS) was recorded with rising speeds, indicating elevated interaction risk. These results underscore that the conflict count alone is insufficient for assessing roundabout safety. A comprehensive evaluation requires the integration of multiple complementary indicators that jointly capture both the frequency and severity of surrogate safety events.

1. Introduction

Over the past decades, there has been a global increase in the urban population, which brings challenges in terms of optimizing mobility and the need to reduce the number of traffic fatalities. Many studies confirm that improper or inappropriate speed is one of the most common causes of traffic accidents. The analysis of incoming vehicle speeds and their impact on the occurrence and severity of traffic conflicts at roundabouts is a current issue in traffic planning and the analysis of urban traffic network safety. Roundabouts are traditionally considered intersections that reduce the number of conflicts and their severity, but their operational safety is conditioned by the specifics of the location, position in the network and driver behavior. The limitations of traditional safety indicator analyses based on historical accident data are the subject of a large number of studies, as well as the advantages of conflict modeling using Surrogate Safety Measures.

Time-based indicators are mainly used to describe the proximity of a collision, and there is a consensus among researchers that it is necessary to analyze speed-related indicators to gain a better insight into the severity of the conflict. Microsimulation modeling allows for the exploration of various what-if scenarios while taking into account the stochastic nature of traffic flow. By generating individual vehicle trajectories and driver responses, microsimulation provides a controlled environment for systematically varying incoming speeds and observing their effects on the frequency and severity of conflicts. The influence of incoming speeds, entry speeds, roundabout speeds, and exit speeds on the number and characteristics of conflicts has not been sufficiently investigated. This study analyzes the influence of incoming speeds on the characteristics of vehicle-vehicle conflicts at roundabouts using microsimulation traffic modeling in VISSIM and the Surrogate Safety Assessment Model.

The analysis was performed on a theoretical model of a medium-sized roundabout, and the analyzed range of incoming speeds is from 30 km/h to 70 km/h, which are recorded in urban traffic conditions. For each traffic scenario, the total number of conflicts, the number of conflicts by type, and conflict severity indicators related to time (Time to Collision – TTC, Post Encroachment Time – PET) and speed (conflict speeds and speed changes) were analyzed. The findings contribute to a deeper understanding of speed-related risk mechanisms in roundabouts and support evidence-based recommendations for speed management, and traffic calming strategies.

2. Research overview

The European Road Safety Policy Framework 2021–2030 identifies four key action areas: safe infrastructure, safe vehicles, safe user behaviour, and effective emergency response. Analyses show that one-third of crashes are linked to speed [1], and that drivers who exceed speed limits face a 12.8-times higher crash risk than compliant drivers [2]. While user responsibility is emphasised, the framework also highlights the importance of infrastructure designed to reduce conflicts and mitigate crash consequences, exemplified by the Dutch “Sustainable Safety” program [3]. The Surrogate Safety Assessment Model (SSAM), developed by the U.S. Federal Highway Administration, is designed to advance simulation-based road safety evaluation. It provides a standardized analytical framework capable of automatically detecting and assessing traffic conflicts using spatiotemporal outputs from microsimulation models. Within SSAM, conflicts are defined as instances in which two vehicles are on a collision trajectory and one must execute an evasive maneuver—such as braking or steering—to prevent a crash [4].

Al-Issawy and Boroujerdian, 2026 [5] analyzed drone-based video recordings from 14 urban roundabouts in three Iraqi cities. Vehicle trajectories were extracted to identify interactions using the Time to Collision indicator ($TTC \leq 5$ s), and conflict frequency was modeled with negative binomial regression using exposure as an offset. After normalizing for exposure, higher average speeds were negatively associated with conflict rates, while greater speeds corresponded to higher TTC values conditional on conflicts (approximately +1.6% to +2.5% per 1 km/h, depending on conflict type). Islam et al., 2023 [6] applied connected-vehicle GPS data to estimate Time to Collision (TTC) and used k-means clustering and binomial proportion tests to evaluate conflict likelihood. Their results show that absolute acceleration above 0.8 m/s^2 increases conflict probability by 8 percentage points, yaw rates above 8 deg/s double conflict probability, and travel speeds exceeding 140% of the recommended limit raise conflict probability by 7 percentage points.

In the study by Hasain and Ahmed, 2022 [7] Post Encroachment Time (PET) was used to identify critical conflicts at unsignalized intersections, demonstrating that vehicles approaching with higher speeds are responsible for a greater share of critical conflicts. Extreme Value analysis of temporal and speed-related indicators showed that the two dimensions are statistically independent: vehicles approaching each other closely in time do not necessarily travel at high speeds [8]. As a result, temporal indicators alone cannot predict severity. Borsos (2021) concludes that only by combining temporal and speed measures can severity be meaningfully inferred. Using their joint event probabilities, the study constructed risk levels that map events of equal probability. Research conducted by Kamrani et al., 2018 [9] driving volatility derived from high-frequency connected-vehicle data was examined as a surrogate safety indicator. Across several intersections, multiple volatility measures—especially those capturing extreme speed and acceleration deviations—were strongly associated with higher crash frequencies. Intersections with more data points beyond threshold bands and greater time-varying speed volatility showed consistently higher crash counts, indicating that volatility can help identify high-risk locations for proactive safety interventions.

The study [10] evaluates conflict severity in mixed traffic with human-driven vehicles and Connected Autonomous Vehicles (CAVs) by analysing microsimulated trajectories across automation levels. Using Time to Collision, speed-based surrogate measures, and a combined severity score, it finds that moderate L3–L4 penetration (35–55%) changes conflict patterns, while higher penetration (>55%) reduces conflict consequences. Once CAV levels reach ~50%, high-severity conflicts drop substantially, and full L4 operation cuts them by 75.5%, highlighting the safety benefits during the transition to automated traffic. In the research of Klobučar et al., 2026 [11], a model based on linear regression was developed to predict the number of daily conflicts in a traffic corridor that includes two intersections: a traffic light intersection and a roundabout. The model was developed for a traffic load of 20,000 vehicles per day, using a combination of microsimulations and SSAM model. Predictors that have a statistically significant impact on the total number of conflicts are the length of the red time at the traffic light intersection, the outer radius of the roundabout, and the distance of the intersection in the corridor. The analysis was conducted for the corridor, but also includes an isolated roundabout. The study [12] analyzed the safety and operational indicators of a single roundabout and a roundabout in a corridor between two traffic signalized intersections in real urban traffic conditions in Osijek, Croatia. 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 modelling with a default and calibrated model. The results show that the analysis of intersection in the corridor in relation to a separate roundabout has a greater impact on safety indicators than the calibration of the model. Pedestrians further contribute to this difference. Pedestrian activity increases turbulence in the traffic stream, particularly in the corridor, where multimodal interactions accumulate and amplify conflict frequency. Findings from the study [13] indicate that roundabout geometric design significantly influences vehicle speed and overall traffic safety.

Moderately widening entry and exit areas may reduce abrupt stop-and-go patterns, yet such adjustments must be balanced against the risk of increased operating speeds. A narrower roundabout lane can help discourage speeding and preserve the one-way character of these roundabouts, while larger exit radii and through lanes can streamline traffic flow but also allow for unwanted speed transfer. Daily traffic volume emerges as the dominant factor that amplifies or moderates these effects, suggesting that roundabout dimensions and deflection angles should be scaled to local traffic predictions to minimize conflict frequency. Nadimi et al., 2016 [14] point out that Surrogate safety measures can support collision-avoidance systems, but TTC and PET often give inconsistent signals. A mixed index (MI) combining clearance, speed and relative speed—calibrated through a fuzzy inference system—was tested on real car-following data. MI outperformed TTC and PET, detecting rear-end collision risk more accurately and in a more timely manner.

A review of research shows that some studies confirm that higher incoming vehicle speed increases the number and severity of conflicts [6,7], but these results cannot be said to be consistent. The results of Al-Issawy and Boroujerdian, 2026 [5] show that higher speed results in an increase in TTC, while the results of Borsos, 2021 [8] show that time indicators of conflict (TTC) and incoming vehicle speed are statistically independent variables and that it is necessary to introduce speed-related conflict parameters into the analysis. Other studies have shown the need to analyze a larger number of conflict indicators that are not only related to time indicators (TTC, PET), but also to speed and speed oscillation [9,14].

3. Methodology

In this research, the impact of incoming speeds on the total number of conflicts, type of conflicts, time-oriented indicators of conflicts (TTC, PET) and features of conflicts related to speed (speed in conflict and changes in speed) were analyzed. The analysis was made using two models: microsimulation traffic model VISSIM and Surrogate Safety Assessment Model (SSAM).

3.1. VISSIM and SSAM

Over the past ten years, the application of modeling in the analysis of safety features of traffic infrastructure has intensified, and comparison with field measurements has shown that the modeling results are comparable to field measurements [7,8,11,12]. VISSIM is one of the most widely used microsimulation software for road traffic modeling, which analyzes in detail the interactions between vehicles, pedestrians, cyclists and other traffic entities with the aim of optimizing traffic infrastructure, traffic regulation and analyzing various traffic scenarios. It is based on psychophysical models of driver and pedestrian behavior, including Wiedemann car-following models and advanced mathematical algorithms for lateral vehicle positioning, which allows for realistic reproduction of traffic flow dynamics in different conditions. The model is quasi-stochastic, which means that for the same input data it will give the same results, which makes the experimental data repeatable. However when the model is run multiple times using the same input data but different values of the random number generator (random seed), the modeling results become stochastic and model the true nature of the traffic flow. Vehicle speeds are both input and output indicators of the model. For each link, the incoming vehicle speed can be specified according to vehicle categories, but the specified speed represents the median of the normal speed distribution, which brings the dynamic modeling results closer to real traffic conditions. The speeds of each individual vehicle can be obtained as a result of the simulation at the locations where the Data Collection Points are set. In addition to operational, dynamic features and numerous other indicators, one of the output results of the modeling is vehicle trajectories that can be obtained as *.trj files and represent the input file for the Surrogate Safety Assessment Model.

The Surrogate Safety Assessment Model (SSAM), developed by the U.S. Federal Highway Administration (FHWA), was created to advance safety-assessment methodologies that rely on simulation-based data. Its development stemmed from the need for a standardized tool capable of automatically identifying and analyzing traffic conflicts using spatiotemporal parameters generated by microscopic traffic-simulation models. FHWA conflict feature indicators [4] employed in this Study:

- number and type of conflict points — the quantified occurrence and classification of locations at which vehicle trajectories intersect or interact,
- Time to Collision (TTC) — defined as the minimum remaining time to a potential collision between two vehicles assuming both maintain their current speeds and trajectories. Values below 1.5 s denote high-risk interactions, values between 1.5 s and 3 s indicate moderate risk, and values exceeding 3 s correspond to low-risk conditions,

- Post Encroachment Time (PET) — applied in situations involving path-crossing; it represents the temporal gap between the moment the first vehicle vacates the conflict point and the moment the second vehicle arrives at that same location. PET values below 5 s are associated with elevated risk,
- conflict speeds — vehicle speeds observed at the onset or during the progression of a conflict event,
- speed changes during conflicts — variations in vehicle speed that characterize the dynamics of a conflict and reflect drivers' evasive or corrective actions.

3.2. Theoretical model of a roundabout

A review of existing research shows that traffic load, traffic distribution, traffic flow structure, intersection geometry, and pedestrian traffic flows have an impact on the number and characteristics of intersection conflicts. The analysis in this study is based on a theoretical roundabout model (Figure 2), which was developed based on field measurements of a large number of roundabouts [13] and has standard geometric characteristics, as shown in Figure 1.

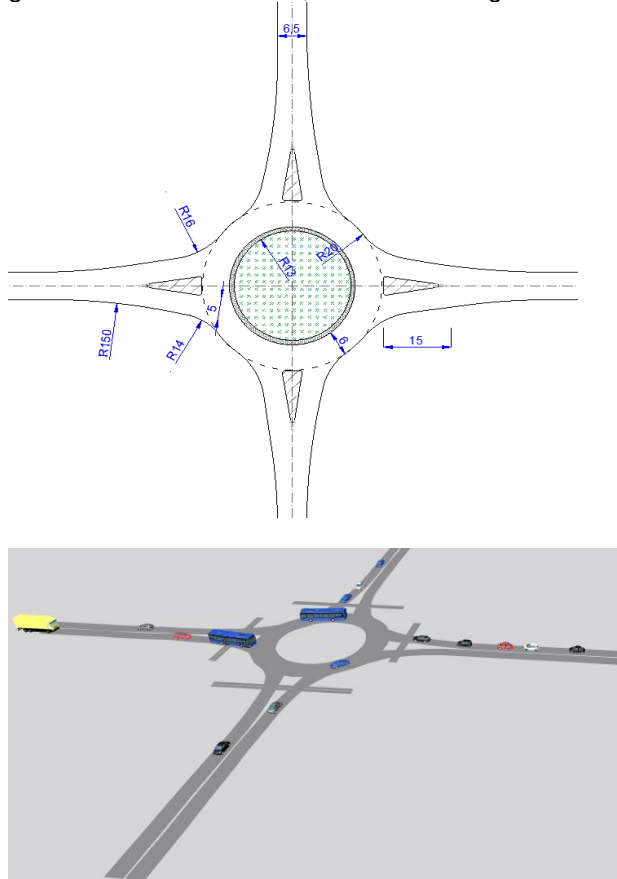


Figure 1. Geometric features of the roundabout and model
Source: (Authors)

The peak hour traffic load of 1600 vehicles/hour was analyzed, the traffic load distribution was adopted for the main east-west direction of 60%, and 20% left turns were given. The traffic flow structure entered into the model is 90% passenger cars, 5% freight vehicles and 5% buses.

All the above features are constant in all traffic scenarios, and only the incoming speeds were varied from 30 km/h to 70 km/h, in steps of 10 km/h, in order to be able to analyze only the influence of incoming speeds on the observed features and so that stronger correlations would not obscure weaker ones [15]. The model was constructed to facilitate the analysis of pedestrian effects on operational and safety parameters. Nevertheless, pedestrian traffic was not included in the scope of this study. Individual vehicle speeds were measured on the main road at the entrance and exit of the roundabout and in the roundabout for the east-west and west-east directions. Figure 2 shows the locations of individual vehicle speed measurements in the simulation and is marked with brown lines. For each speed scenario, 10 VISSIM simulation runs were performed, each with a duration of 3600 s. Random seed was set to 42, with a random seed increment of 10. The reported results represent the arithmetic mean of the 10 simulation runs.

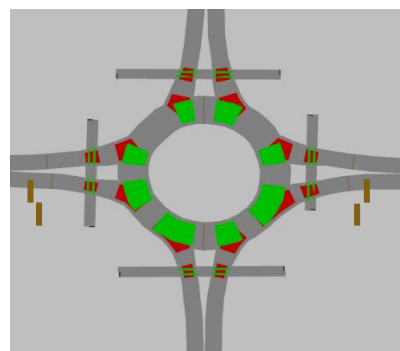


Figure 2. Data Collection Points in VISSIM model
Source: (Authors)

4. Results

4.1. Results of operational indicators

The selected operational indicators for different arrival speeds expressed in km/h are the average vehicle queue length (Q_{LEN}) in meters, the maximum vehicle queue length (Q_{LENMax}) in meters, the Level of Service (LOS) expressed categorically in letters and numbers, the average vehicle delay (VehDelay) expressed in seconds per vehicle, the delays caused by stopping (STOPDelay) in sec/vehicle and the average number of stops per vehicle. The operational indicators for the entire intersection for different incoming speeds are shown in Table 1.

Table 1. Roundabout operational indicators for different incoming speeds

Speed	Q_{LEN}	Q_{LENMax}	LOS	VehDelay	STOPDelay	STOPS
30	8,97	67,55	B / 2	12,53	3,18	0,93
40	5,69	65,58	B / 2	10,02	2,07	0,63
50	5,18	62,66	A / 1	9,80	1,51	0,57
60	3,62	60,05	A / 1	9,14	1,04	0,44
70	2,42	59,73	A / 1	7,6	0,89	0,33

Source: (Authors)

Table 2 shows the results of speeds at the marked measurement points in relation to the incoming speeds (km/h). The average time speed (SpeedAvgArith All) in km/h, the average spatial speed (SpeedAvgHarm All) in km/h and the vehicle acceleration (Acceleration All) in m/s^2 were analyzed.

Table 2. Dynamic indicators of a roundabout for different incoming speeds

Speed	Meas.point	SpeedAvg Arith (All)	SpeedAvg Harm(All)	Accelerat. (All)
30	1: East Entrance	17,53	8,29	-0,41
	2: East Exit	32,49	32,38	0,04
	3: West Entrance	16,20	8,00	-0,24
	4: West Exit	32,62	32,53	0,04
	5: W-E Roundab	30,93	29,83	0,06
	6: E-W Roundab	31,27	30,08	0,11
40	1: East Entrance	22,06	10,30	-0,43
	2: East Exit	41,85	41,70	0,21
	3: West Entrance	18,65	7,36	-0,31
	4: West Exit	42,04	41,92	0,16
	5: W-E Roundab	37,80	36,09	0,72
	6: E-W Roundab	38,20	36,39	0,67
50	1: East Entrance	26,66	11,85	-0,32
	2: East Exit	49,65	49,26	0,60
	3: West Entrance	21,44	9,48	-0,25
	4: West Exit	50,07	49,62	0,45
	5: W-E Roundab	41,44	39,14	1,11
	6: E-W Roundab	43,13	40,59	0,93
60	1: East Entrance	27,87	12,63	-0,39
	2: East Exit	54,27	53,25	1,00
	3: West Entrance	26,13	12,79	-0,22
	4: West Exit	55,36	54,30	0,86
	5: W-E Roundab	44,25	41,65	1,21
	6: E-W Roundab	45,03	42,67	1,12
70	1: East Entrance	37,37	16,81	-0,39
	2: East Exit	58,36	56,34	1,10
	3: West Entrance	34,74	16,56	-0,28
	4: West Exit	59,07	57,10	1,05
	5: W-E Roundab	47,82	42,29	1,00
	6: E-W Roundab	49,43	43,51	0,98

Source: (Authors)

The diagram of mean time speeds in the east-west and west-east directions for different incoming speeds at the observed intersection is shown in Figure 3.



Figure 3. Speed diagram for different incoming speeds and two driving directions Source: (Authors)

4.2. Indicators of conflict characteristics

The analyzed features of conflicts in relation to incoming speeds (Table 3) are the total number of conflicts, the number of conflicts by type - rear-end collision, lane changing, crossing, time-oriented indicators Time to Collision (TTC) in seconds and Post Encroachment Time (PET) in seconds, the mean maximum speed in the conflict (MaxS) (m/s) and the mean value of speed oscillations (DeltaS) (m/s).

Table 3. Analyzed conflict characteristics in relation to incoming speeds

Speed	Conflicts			
	Total conflicts	rear-end	lane changing	crossing
30	91	64	27	0
40	149	108	36	5
50	127	102	23	2
60	131	91	35	5
70	140	95	35	10
	Severity of the conflicts			
	TTC	PET	MaxS	DeltaS
30	1,29	1,25	8,4	3,82
40	1,21	1,17	10,62	4,36
50	1,18	1,18	11,62	3,86
60	1,19	1,18	11,84	5,62
70	1,17	1,15	12,36	6,22

Source: (Authors)

Figure 4 shows the total number of conflicts and the number of conflicts per conflict type for different incoming speeds.

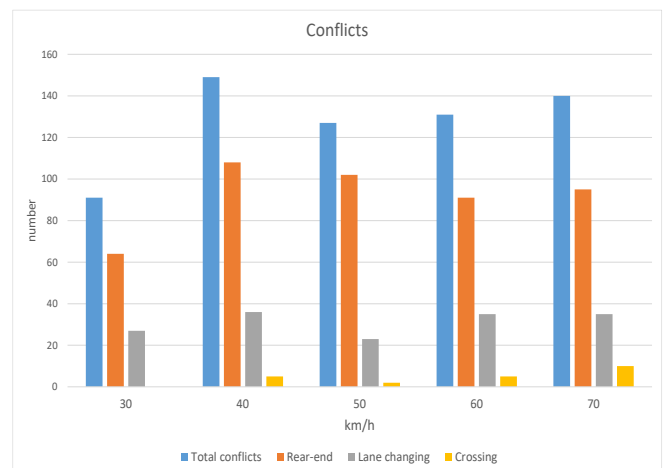


Figure 4. Number of conflicts depending on incoming speed

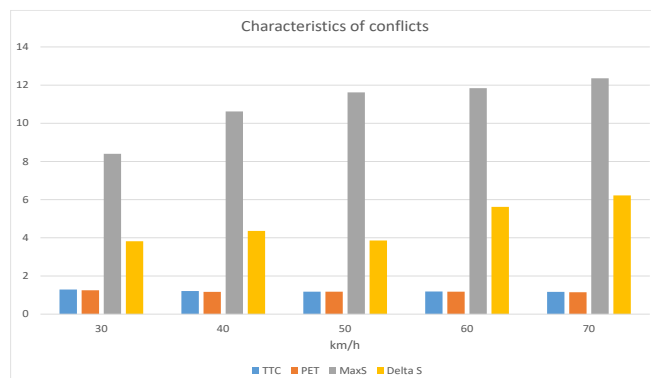
Source: (Authors)

Table 4 shows the basic statistical characteristics of the conflict severity indicators related to time and speed. Figure 5 shows the characteristics of conflicts related to time (TTC, PET) and speed (MaxS and DeltaS) in relation to the incoming vehicle speeds.

Table 4. Basic statistical characteristics of selected conflict indicators for roundabouts

	30	40	50	60	70
TTC					
Min	0,1	0	0	0	0
Max	1,50	1,50	1,50	1,50	1,50
Mean	1,29	1,21	1,18	1,19	1,17
Variance	0,07	0,09	0,07	0,07	0,09
PET					
Min	0,50	0	0	0	0
Max	2,80	1,80	2,00	2,00	2,00
Mean	1,25	1,17	1,18	1,18	1,15
Variance	0,11	0,08	0,09	0,1	0,12
MaxS					
Min	4,83	5,15	5,64	5,99	6,36
Max	10,06	12,76	15,10	17,54	21,09
Mean	8,40	10,62	11,62	11,84	12,36
Variance	1,12	2,20	4,52	5,68	9,22
DeltaS					
Min	0,13	0,01	0,11	0,03	0,03
Max	10,88	20,22	19,54	22,35	38,66
Mean	3,82	4,36	3,86	5,66	6,22
Variance	8,49	18,99	17,58	32,00	49,20

Source: (Authors)

**Figure 5.** Conflict severity characteristics in relation to incoming speeds Source: (Authors)

5. Discussion

The microsimulation results (Table 1) indicate that higher incoming speeds increase intersection throughput, with all operational performance measures consistently improving as speed rises. At 30 and 40 km/h, vehicle delays are greater, vehicle queues are longer, and the level of service corresponds to category B. Although safety indicators are more favorable at lower speeds, this does not substantially affect operational performance when considering that such speeds typically characterize lower-order facilities within the secondary road network. At approach speeds of 50 km/h and above, the level of service improves to category A, accompanied by reduced delays, shorter queues, and fewer vehicle stops. These speeds correspond to higher-order facilities within the primary network, where greater intersection throughput is required.

The obtained operational results are fully aligned with expectations. Dynamic indicators (Table 2) show that speeds at all Data Collection Points increase proportionally with higher incoming speeds. This trend is clearly visible in the speed profiles for the East–West and West–East movements, which represent the major traffic flows at the roundabout (Figure 3). These results are consistent with theoretical expectations. Since no deceleration zones were modeled, the observed speeds are solely the result of traffic conditions and roundabout geometry. It should also be noted that the model incorporates a substantial traffic load of 1600 veh/h.

Analysis of the relationship between incoming speeds and the number of conflicts (Table 3, Figure 4) does not reveal a clear functional dependence. Rear-end conflicts dominate, which is typical for roundabout operations. The total number of conflicts is highest at 40 km/h. For speeds between 50 and 70 km/h, the number of conflicts does not increase markedly; however, the conflict composition changes, with higher speeds producing more crossing conflicts, which are considered the most hazardous. These findings are consistent with previous studies reporting no clear relationship between approach speed and conflict frequency [5,8].

Regarding temporal indicators of conflict severity (TTC and PET; Table 4), both measures consistently decrease with increasing speed, indicating more severe interactions. Given the high traffic load and the adopted severity threshold of 1.5 s, mean TTC values for all speeds fall below this limit, confirming the presence of high-risk interactions; PET values show similar patterns. The reduction in TTC between 30 km/h and 70 km/h is 38%, and the reduction in PET is 33%, representing a non-negligible difference in safety performance. These findings align with studies demonstrating that higher approach speeds lead to more dangerous conflicts [6,7].

This trend is particularly evident in the MaxS indicator (speed at conflict), which increases consistently with rising incoming speed. The increase in mean conflict speed between 30 km/h and 70 km/h is 47%, providing an even clearer indication of escalating conflict severity. Mean values of speed change during conflicts do not exhibit a clear dependence on incoming speed, unlike conflict speed itself; however, the variability of speed changes increases markedly with higher speeds (Table 4), indicating more frequent sudden braking. Statistically, greater variance reflects larger deviations from the mean, suggesting a higher number of substantial speed changes attributable to micro-level traffic interactions. This indicator warrants further investigation due to its potential relevance for understanding conflict dynamics.

6. Conclusion

This study examined the influence of incoming vehicle speeds on the number, types, and characteristics of vehicle-to-vehicle conflicts at a roundabout. The analysis was conducted on a theoretical roundabout model with fixed geometric features and without variations in traffic demand, using microsimulation and the Surrogate Safety Assessment Model. Incoming speeds ranging from 30 to 70 km/h were evaluated, representing operational speeds typical of different functional levels within an urban road network. The results indicate that, within the scope of this study, no clear relationship can be established between incoming speed and the total number of conflicts. In contrast, a consistent increase in conflict severity was observed as incoming speeds rose. Time-based indicators showed decreasing values with higher speeds, reflecting more severe interactions. Mean conflict speeds also increased systematically with incoming speed, demonstrating a strong dependence and confirming that higher speeds intensify conflict severity. These findings clearly highlight the need to consider a broader set of surrogate safety indicators; relying solely on time-based metrics or on conflict counts and types does not provide a sufficiently realistic assessment of intersection safety. The findings of this study should be interpreted as preliminary. The analyses were based on aggregated data, which allow only general insights; without examining individual conflict records, statistical significance cannot be assessed, nor can datasets be compared in detail. These aspects are planned for future work, along with the inclusion of pedestrian flows in the model, which will contribute to a more realistic representation of urban traffic conditions.

Acknowledgements

This research is conducted within the framework of the European Union—NextGenerationEU ("Safety aspects of urban transport infrastructure SigINFRA", a scientific project at the Josip Juraj Strossmayer University of Osijek (581-UNIOS-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] European Commission. EU Road Safety Policy Framework 2021–2030: Next Steps towards "Vision Zero"; Publications Office of the European Union: Luxembourg, 2019. Available online: https://www.europarl.europa.eu/doceo/document/TA-9-2021-0407_EN.html (accessed on 15 July 2026).
- [2] Dingus, T.A.; Guo, F.; Lee, S.; Antin, J.F.; Perez, M.; Buchanan-King, M.; Hankey, J. Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proceedings of the National Academy of Sciences of the United States of America* 2016, 113, 2636–2641. <https://doi.org/10.1073/pnas.1513271113>.
- [3] SWOV Institute for Road Safety Research. Sustainable Safety—3rd Edition: The Advanced Vision for 2018–2030. Available online: https://swov.nl/system/files/publication-downloads/dv3_en_kort_rapport.pdf (accessed on 15 July 2026).
- [4] Federal Highway Administration. Surrogate Safety Assessment Model and Validation: Final Report; Georgetown Pike: McLean, VA, USA, 2008. Available online: <https://www.fhwa.dot.gov/publications/research/safety/08051/> (accessed on 15 July 2026).
- [5] Al-Issawy, M.; Boroujerdian, A.M. Faster but safer? Exploring the impact of vehicle speed on surrogate safety measures at roundabouts. *Innovative Infrastructure Solutions* 2026, 11, 4. <https://doi.org/10.1007/s41062-026-02561-w>.
- [6] Islam, Z.; Abdel-Aty, M.; Anwari, N.; Islam, R. Understanding the impact of vehicle dynamics, geometric and non-geometric roadway attributes on surrogate safety measures using connected vehicle data. *Accident Analysis & Prevention* 2023, 189, 107125. <https://doi.org/10.1016/j.aap.2023.107125>.
- [7] Hasain, N.M.; Ahmed, M.A. Safety evaluation of unsignalized intersections with heterogeneous traffic using post-encroachment time and conflicting vehicle speed. *European Transport—Trasporti Europei* 2022, 88. <https://doi.org/10.48295/ET.2022.88.3>.
- [8] Borsos, A. Application of bivariate extreme value models to describe the joint behavior of temporal- and speed-related surrogate measures of safety. *Accident Analysis & Prevention* 2021, 159, 106274. <https://doi.org/10.1016/j.aap.2021.106274>.
- [9] Kamrani, M.; Arvin, R.; Khattak, A.J. Extracting useful information from basic safety message data: An empirical study of driving volatility measures and crash frequency at intersections. *Transportation Research Record* 2018, 2672, 290–301. <https://doi.org/10.48550/arXiv.1803.02433>.
- [10] Miqdady, T.; de Oña, R.; de Oña, J. In search of severity dimensions of traffic conflicts for different simulated mixed fleets involving connected and autonomous vehicles. *Journal of Advanced Transportation* 2023, 4116108, 21 pages. <https://doi.org/10.1155/2023/4116108>.
- [11] 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* 2026, 18, 1321. <https://doi.org/10.3390/su18031321>.
- [12] Ištoka Otković, I.; Klobučar, M.; Deluka-Tibljaš, A.; Šurdonja, S. Evaluating the effects of signalized intersections on roundabout safety and capacity: A case study from Osijek. In *Proceedings of the 6th Serbian Road Congress*; Glavić, D., Mladenović, G., Eds.; Serbian Road Association "Via-Vita": Belgrade, Serbia, 2026; pp. 197–204. ISBN 978-86-88541-22-0.
- [13] Klobučar, M.; Šurdonja, S.; Deluka-Tibljaš, A. Impact of geometric parameters and operational speed on traffic safety at roundabouts: A conflict analysis using microsimulation models. *Journal of Road Safety* 2025, 36(3), 47–60. <https://doi.org/10.33492/jrs-d-25-3-2681114>.
- [14] Nadimi, N.; Behbahani, H.; Shahbazi, H.R. Calibration and validation of a new time-based surrogate safety measure using a fuzzy inference system. *Journal of Traffic and Transportation Engineering (English Edition)* 2016, 3(1), 51–58. <https://doi.org/10.1016/j.jtte.2015.09.004>.
- [15] Ištoka Otković, I.; Deluka-Tibljaš, A.; Šurdonja, S.; Campisi, T. Analysis of influencing parameters on children's crossing speeds at non-signalized crosswalks using neural network models. *Transportation Research Procedia* 2025, 90, 543–550. <https://doi.org/10.1016/j.trpro.2025.06.109>.