https://doi.org/10.3311/PPtr.44205
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Periodica Polytechnica Transportation Engineering

Analysis of Vehicle Movements and Speed Profiles in Mini-roundabouts

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Received: 02 April 2026, Accepted: 25 September 2026, Published online: 13 November 2026

Abstract

The application of mini-roundabouts simultaneously serves to enhance traffic safety and improve traffic flow. Their operational characteristics are significantly influenced by driver behavior and travel speeds. The aim of the research was to examine the extent to which vehicles utilize the central island at a selected mini-roundabout, and how this relates to speed conditions. Vehicle movements were analyzed based on video recordings using DataFromSky software, while speed data were determined through side-view radar measurements. To characterize central island usage, two concentric zones were defined, enabling the distinction between partial and full overrunning. The results indicate that a substantial proportion of passenger cars do not fully follow the designated circular path, but instead partially or completely overrun the central island. In the case of motorcycles, overrunning is also common, while for buses it can primarily be explained by geometric constraints. Radar measurements showed that average speeds typically ranged between 27–38 km/h, while maximum speeds exceeded 80 km/h during several periods. The findings suggest that a visually marked central island without physical elevation is not always sufficient to enforce either low speeds or proper circular path adherence. The study highlights that, in addition to geometric design, a comprehensive traffic safety assessment of mini-roundabouts also requires the joint analysis of actual vehicle trajectories and speed profiles.

Keywords

mini-roundabout, traffic safety, speed analysis, radar measurement, video analysis, driver behavior

1 Introduction

In the case of mini-roundabouts, it is often observed that vehicles do not follow the designated circular path, but instead partially or fully overrun the central island. This is particularly evident for passenger cars and motorcycles, where the vehicle size would not justify the use of the island. The phenomenon is presumably driven by convenience, the intention to shorten the travel path, and the avoidance of speed reduction, which calls into question the actual traffic-calming effectiveness of mini-roundabouts.

The interpretation of this issue is further complicated by the fact that the legal status of driving over the central island in Hungary is not clearly defined. Current regulations (Government of Hungary, 1975) do not explicitly prohibit the use of the central island; however, its application is debated from a professional standpoint, especially in the case of smaller vehicles. As a result, varying driver behaviors can be observed in practice.

The analysis of central island usage cannot be separated from the examination of vehicle speeds. It can be assumed that vehicles traveling at higher speeds are more likely to overrun the island, thereby reducing the effective curvature of the circular path and altering the operational characteristics of the intersection.

The aim of the research is to provide a detailed analysis of central island usage. The study was conducted at a mini-roundabout in Székesfehérvár, where video-based behavioral analysis and radar-based speed measurements were applied, enabling the joint evaluation of vehicle movements and speed conditions.

2 Driver behavior at mini-roundabouts

A detailed examination of driver behavior is essential for understanding the operation and traffic safety effects of mini-roundabouts. Previous studies clearly indicate that the

Cite this article as: Marászi, R. D., Henézi, D. (2026) "Analysis of Vehicle Movements and Speed Profiles in Mini-roundabouts", Periodica Polytechnica Transportation Engineering, https://doi.org/10.3311/PPtr.44205

effectiveness of this type of intersection depends not only on the geometric design, but also to a significant extent on drivers' decisions, perception processes, and speed choice.

2.1 Speed choice

Drivers' speed choice fundamentally determines the traffic safety performance of mini-roundabouts. According to the literature, one of the key advantages of mini-roundabouts is the reduction of approach and circulating speeds, which directly contributes to mitigating crash severity. A study conducted in Australia showed that after the implementation of mini-roundabouts, the proportion of vehicles exceeding the speed limit decreased, and compliance with yield rules improved (Delbosc et al., 2017).

The speed-reducing effect is the result of several interacting factors. On the one hand, the small-radius circular path imposes a geometric constraint that necessitates lower speeds. On the other hand, drivers must adapt to a dynamic traffic situation within the intersection, which increases attentional demand and leads to more cautious driving behavior. A fundamental characteristic of roundabout operation is that all entering drivers must yield to circulating traffic, which also contributes to speed reduction (Delbosc et al., 2017).

However, the extent of traffic-calming effects depends on the quality of design. According to UK guidelines, mini-roundabouts are only effective in reducing speeds when appropriate geometric and visual design is provided, whereas central islands marked solely by pavement markings without physical elevation may have a limited effect. As a result, some drivers are able to pass through the intersection at higher speeds (Department for Transport, 2006).

Speed choice is not homogeneous within the traffic stream but shows considerable variability. Traffic volume, vehicle type, and driver decisions all influence speed. Studies have shown that different vehicle types exhibit distinct speed profiles at mini-roundabouts, further increasing the heterogeneity of speed distributions (Distefano et al., 2024). In addition, while the speed-reducing effect of mini-roundabouts can directly contribute to reducing both the number and severity of crashes, this effect is not always unequivocal. Some studies indicate that converting signalized intersections into mini-roundabouts can reduce crash frequency, whereas in other cases – particularly at already low-speed, priority-controlled intersections – the number of crashes may even increase (Qawasmeh et al., 2023). This highlights that although speed reduction and safety effects are closely related, they are strongly dependent on the initial conditions and the specific design. Therefore, evaluating mini-roundabouts requires not only analyzing average speeds, but also examining the full speed distribution and extreme values.

Studies involving micromobility devices (bicycles, e-scooters) have shown that vehicle stability and design significantly influence speed profiles and path selection. For example, e-scooters tend to exhibit greater speed variability, particularly in entry and exit sections, while bicycles generally demonstrate more uniform motion (Distefano et al., 2024).

Mini-roundabouts do not always provide optimal conditions for all road users. Several studies point out that, from the perspective of pedestrians and cyclists, less favorable conditions may arise in certain cases, especially where adequate traffic calming or visibility is lacking (Šurdonja et al., 2012).

2.2 Future challenge

The development of autonomous vehicles may present new challenges for road infrastructure. The operation of autonomous driving systems depends not only on the performance of onboard sensors and algorithms but also on how clearly the traffic environment can be interpreted by these systems. According to Borsos and Koren (2021), current autonomous vehicle development primarily focuses on environments where road edges, traffic lanes, and traffic regulations are clearly defined. However, they also point out that relatively little research has examined the extent to which existing road infrastructure is suitable for the safe operation of autonomous vehicles.

Lengyel et al. (2021) point out that the design of road markings and infrastructure significantly influences the behavior of highly automated vehicles. In their view, the widespread adoption of autonomous driving will require not only advances in vehicle technology but also further development of road infrastructure and regulatory frameworks.

This issue may be particularly relevant in the case of mini-roundabouts. The central island of the roundabout examined in the present study has neither a physically raised island nor pavement markings delineating its perimeter. Instead, it is distinguished from the circulating roadway solely by a different pavement color and surface texture. While this is generally sufficient for human drivers to recognize the function of the roundabout, it remains uncertain how the perception systems of autonomous vehicles would interpret the same design.

According to Song et al. (2025), one of the key advantages of autonomous vehicles is their ability to make intelligent decisions in a wide range of traffic situations.

However, this capability depends on the accurate perception of the surrounding environment. Elgharbi et al. (2024) likewise emphasize that the motion planning and decision-making processes of autonomous vehicles are fundamentally based on the continuous perception and prediction of their surroundings.

Based on these considerations, an important question arises as to whether the central island of mini-roundabouts without physical elevation provides sufficiently clear information for autonomous vehicles. The findings of the present study indicate that a substantial proportion of human drivers partially or completely traverse the central island. Future research should therefore investigate the trajectories selected by autonomous vehicles in similar situations and assess whether modifications to the design of this type of mini-roundabout may be necessary to better support automated driving.

3 Description of the studied roundabout

The intersection of Horog Street and Halász Street is located in the western part of Székesfehérvár (Hungary), within the Palotaváros residential district. The junction is characterized by low traffic volumes and a residential environment, where a mini-roundabout was installed in 2023 to improve traffic safety. The area is part of a traffic-calmed zone with a 30 km/h speed limit.

The roundabout is situated in a relatively densely built-up, block-type residential environment. Its immediate surroundings include parking areas, green spaces, and residential buildings, reflecting the characteristic urban structure of Palotaváros. The nearby Palotaváros lakes are also located in this area and are regularly used for recreational and leisure activities.

According to the WEB-BAL database (Magyar Közút Nonprofit Zrt., online), no recorded personal injury road traffic accidents occurred at the studied intersection between 1 February 2023 and 31 December 2025 following its conversion into a mini-roundabout.

The central island of the roundabout was designed without physical elevation and is delineated solely by visual markings.

The examined roundabout is shown in Fig. 1.



Fig. 1 The studied roundabout (own photo)

4 Video-based survey

The application of video-based measurement was of fundamental importance in this study, as it enabled a detailed spatial analysis of vehicle movements, with particular emphasis on central island usage. While radar measurements are primarily suitable for accurately determining speed, video-based processing allows for the examination of the trajectories followed by vehicles within the roundabout and the extent to which they deviate from the designated circular path.

The objective of the analysis was to identify the proportion and manner in which vehicles utilize the central island, with particular attention to differences between vehicle categories.

Data collection was carried out on March 15, 2026 (Sunday), between 11:55 and 14:01, with a total duration of 2 h, 5 min, and 56 s. Weather conditions were clear and sunny, with no precipitation.

The recordings were made using a fixed-position camera providing a top-down view of the entire intersection, ensuring continuous and distortion-free tracking of vehicle movements. Data processing was performed using DataFromSky software (RCE systems s.r.o., online), which automatically detects and tracks vehicles and determines their movements in both time and space.

The aggregated trajectories identified by DataFromSky software (RCE systems s.r.o., online) are shown in Fig. 2.

The DataFromSky software (RCE systems s.r.o., online) was provided by the Department of Transport Infrastructure and Water Resources Engineering at Széchenyi István University.



Fig. 2 Aggregated trajectories of vehicle movements in the studied roundabout

4.1 Applied software and zone definition

The processing of video recordings was carried out using the DataFromSky software (RCE systems s.r.o., online), which applies artificial intelligence–based image processing techniques to automatically detect and track traffic participants. The system is capable of identifying and distinguishing between different object types – such as passenger cars, heavy vehicles, cyclists, and pedestrians – and describing their movements in both temporal and spatial dimensions.

The analysis was performed in the DataFromSky Viewer environment (RCE systems s.r.o., online), which enables the definition of various traffic analytics elements, including area-based investigations. For the analysis of central island usage, two so-called traffic regions were defined.

The first, outer region represented the area covering the perimeter of the central island, while the second, inner region covered an area located approximately 0.7 m further inward.

Vehicle movements were evaluated relative to these regions. If a vehicle's trajectory intersected a given region, the use of that zone was recorded. A hierarchical classification approach was applied, meaning that intersection with the inner region automatically implied intersection with the outer region as well.

4.2 Results of the video-based analysis

During the video-based processing, a total of 791 objects were identified across different traffic participant categories (Table 1). The sample included 610 passenger cars, 20 motorcycles, and 3 buses, as well as other road users (pedestrians, cyclists, and other categories).

From the perspective of central island usage, motorized vehicles were subjected to detailed analysis.

For motorcycles, compliant movement and the use of the central island occurred at nearly identical rates. Given that the size of these vehicles does not justify the use of the island, crossing it in this case can clearly be interpreted as a driver's decision. In the case of light commercial vehicles, the use of the central island also appeared at a high rate, with particularly frequent use of the inner zone, which may indicate the combined effect of larger vehicle size and a tighter turning radius.

For passenger cars, the use of the central island is a common phenomenon. Nearly half of the vehicles do not follow the designated circular path but instead drive across the island. Within this, a significant variation can be observed in the extent of use, as not only is contact with the outer zone typical, but the use of the inner zone also appears in a considerable proportion. This suggests that some drivers deliberately shorten the trajectory, rather than deviating from compliant movement solely due to geometric constraints.

In the case of buses, the different categories appear in equal proportions; however, due to the low sample size (n = 3), the results are not suitable for drawing general conclusions.

The distribution by vehicle type according to the categories of central island use is illustrated in Fig. 3.

Table 1 Distribution of detected moving objects

Vehicle type	Detected objects
Number of tracked objects	791
Car	610
Bus	3
Motorcycle	20
Bicycle	46
Pedestrian	106
Light truck	1
Van	4
Carriage	1

5 Radar measurement

The application of radar measurement was crucial in this study, as video-based analysis primarily allows for the observation of vehicle movement and the use of the central island, while speed determination using such a method is of limited accuracy. In contrast, radar provides highly accurate, direct speed measurements, thereby offering a reliable basis for evaluating vehicle dynamics. The study was conducted at the same roundabout as the video-based analysis.

One of the central research questions was the relationship between the use of the central island and vehicle speed. Investigating this required an independent and precise speed measurement method, enabling the analysis of speed distributions and extreme values.

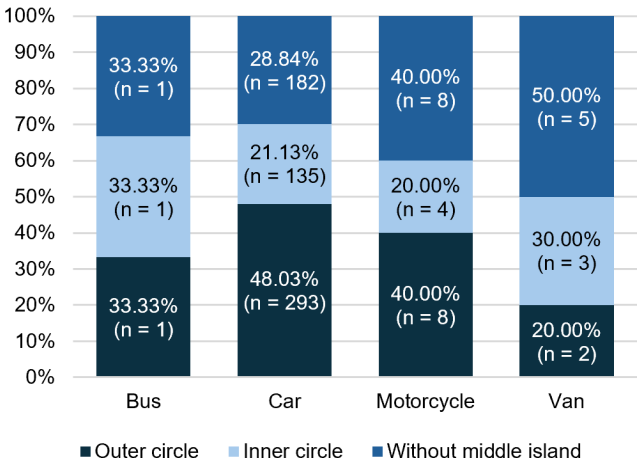


Fig. 3 Distribution of central island usage by vehicle type

Using radar data, it became possible to determine the average and maximum speeds for different time periods, as well as how speed conditions change with variations in traffic load. This made it possible to interpret to what extent the observed vehicle behavior – particularly driving across the central island – is related to speed choice.

The measurement was carried out between March 20, 2026, 18:52:35 and March 24, 2026, 20:21:10. During this period, the weather was typically cool and early spring-like, with mostly cloudy skies.

5.1 Measurement equipment, method, and data processing

For speed measurement, an SDRtraffic-type side-looking microwave radar device was used. The system operates with a radar sensor in the 24 GHz frequency range, which is suitable for determining vehicle speed and other characteristics.

The device is capable of measuring vehicle count, direction of travel, and speed, and it also provides information on vehicle length. The recorded data are timestamped, meaning that each vehicle is associated with a separate event (date, time, speed, direction, length).

The radar resolution is 1 km/h for speed and 0.1 m for vehicle length, enabling detailed traffic characterization. The installation and parameterization of the system were carried out on-site using a smartphone application, which allowed precise configuration of measurement directions, sensitivity, and other settings.

The radar device was provided by the Department of Transport Infrastructure and Water Engineering at Széchenyi István University.

The radar installation relative to the roadway is shown in Fig. 4.

During radar positioning, the two branches of Horog Street were interpreted as a straight line, and the device was configured accordingly, as if the roundabout were not present and traffic on a straight road section were being measured. The measurement directions were therefore aligned with the axis of Horog Street, meaning that vehicle movements were interpreted toward Kelemen Béla Street and Selyem Street.

This setup enabled consistent measurement of traffic speed in the main direction; however, it introduced distortions in certain traffic movements. Vehicles approaching from the northeastern leg (Halász Street) and then proceeding toward the southeastern direction (Horog Street) were detected twice due to the measurement geometry, resulting in duplicated data in the database.

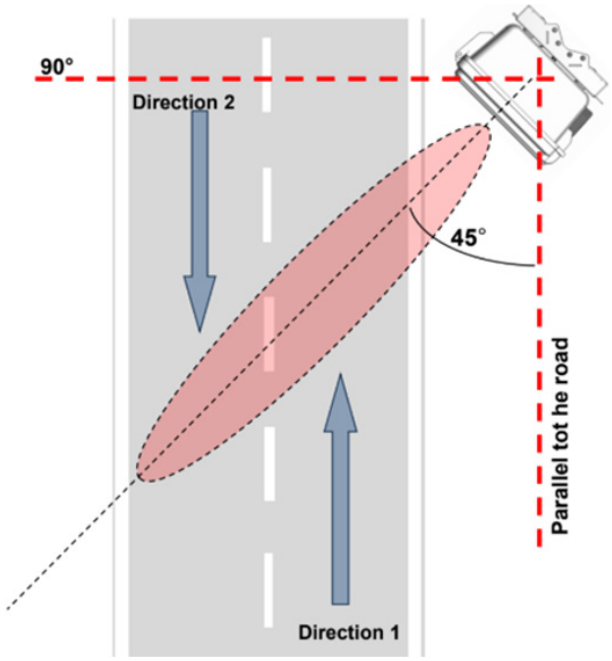


Fig. 4 Radar installation setup

To eliminate duplicates, filtering criteria were defined based on the measurement data. From pairs of records, one entry was removed if the time difference between detections was less than 3 s and, simultaneously, the difference in measured vehicle length did not exceed 0.2 m. These criteria were established based on on-site observations during system installation, when the duplication phenomenon was identified. Experience showed that different vehicles passing in quick succession typically exhibited differing length and/or speed parameters, making these conditions suitable for distinguishing duplicate data.

As a result of the filtering process, a total of 3,101 records were removed, and 25,320 vehicles were included in the subsequent analysis. All vehicle categories could appear in the dataset; however, the radar did not detect pedestrians.

5.2 Measurement results

The temporal distribution of traffic is illustrated in Fig. 5 along with the corresponding hourly data. The results clearly show a daily cyclic pattern, with significant differences between weekdays and weekends.

On weekdays (Monday, Tuesday), a pronounced morning peak occurs between 7:00 and 8:00, when traffic reaches 862 vehicles/h (Monday) and 881 vehicles/h (Tuesday). Following the morning peak, traffic decreases, then increases again in the afternoon. The afternoon peak typically occurs between 15:00 and 17:00, for example reaching 661 vehicles/h (16:00–17:00) on Monday and 667 vehicles/h on Tuesday.

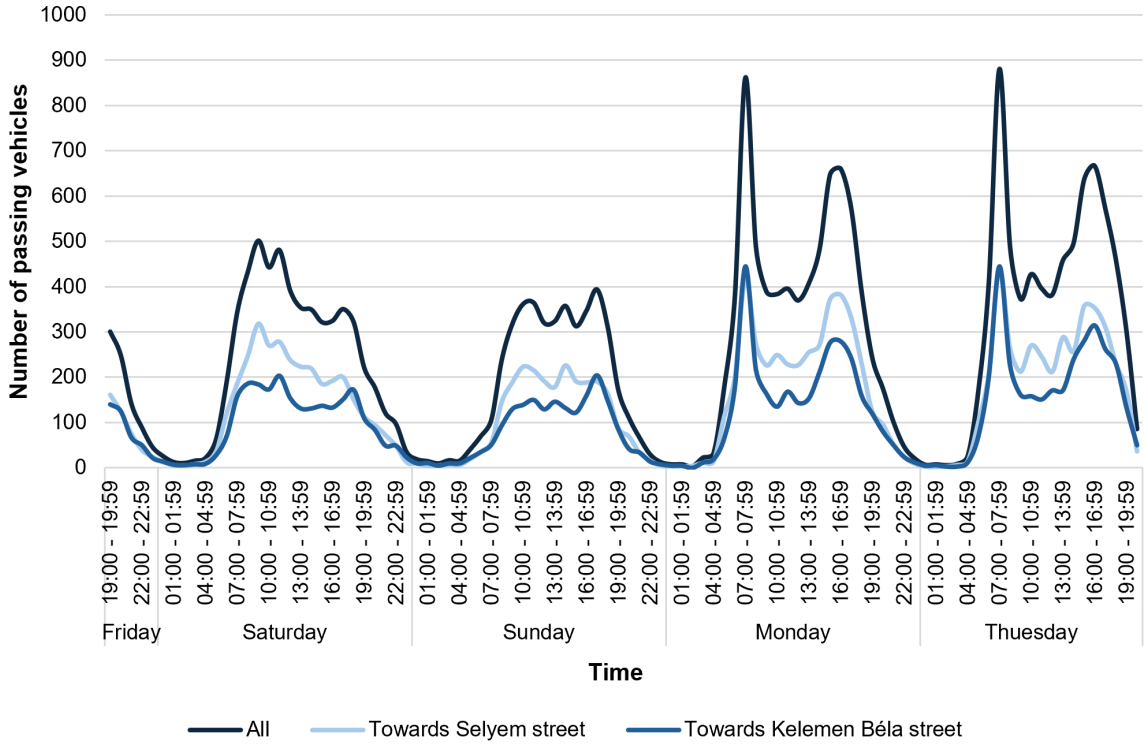


Fig. 5 Traffic volume over time

In contrast, traffic load is more evenly distributed on weekends. On Saturday, the highest traffic occurs in the late morning (502 vehicles/h between 9:00 and 10:00), while on Sunday peak values generally remain within the range of 300–400 vehicles/h (e.g., 394 vehicles/h between 17:00 and 18:00). Weekend mornings show a less pronounced peak, with traffic more evenly spread throughout the daytime period.

Based on directional distribution, traffic toward Selyem Street is generally higher, particularly during peak periods. For example, on Monday between 7:00 and 8:00, 418 vehicles traveled in this direction, while 444 vehicles moved toward Kelemen Béla Street, indicating a nearly balanced load during this period, although asymmetry appears at other times.

During nighttime hours, low traffic volumes are observed on all examined days (typically 10–30 vehicles/h), with volumes beginning to increase in the early morning.

Overall, it can be concluded that traffic at the examined mini-roundabout is strongly time-dependent, with distinct peak periods on weekdays, while a more balanced pattern is observed on weekends.

Based on the detailed daily radar data, the variation in speeds can be clearly tracked both over time and across different days (Fig. 6).

Average speeds show different patterns on weekdays and weekends. On weekdays (Monday, Tuesday), during the morning peak period (7:00–9:00), average speeds typically range between 27–31 km/h (e.g., 30.8 km/h on Monday and 29.9 km/h on Tuesday between 7:00 and 8:00), while higher values are observed during nighttime hours (e.g., 43.7 km/h on Tuesday between 1:00 and 2:00). On weekends, speeds are generally higher, especially during low-traffic periods (e.g., 44.2 km/h on Sunday between 2:00 and 3:00).

Maximum speeds show considerable variability on all examined days and in several cases exceed 70–80 km/h. Notable examples include 83 km/h on Friday between 21:00 and 22:00, 80 km/h on Saturday between 23:00 and 24:00, and 79 km/h on Monday between 17:00 and 18:00. The highest values typically occur during evening and nighttime periods when traffic volumes are lower.

Due to the high variability of maximum speeds, a fourth-degree polynomial trend line was also applied in Fig. 6. The purpose of this trend line was to reduce the effect of outliers and better illustrate the general temporal pattern of speeds. The trend reveals a clear U-shaped daily pattern: maximum speeds are higher during early morning and late evening hours, while lower values are observed during daytime, especially in the late morning and early afternoon. This is consistent with traffic conditions, as lower traffic volumes allow higher speeds, whereas higher daytime traffic results in reduced speeds.

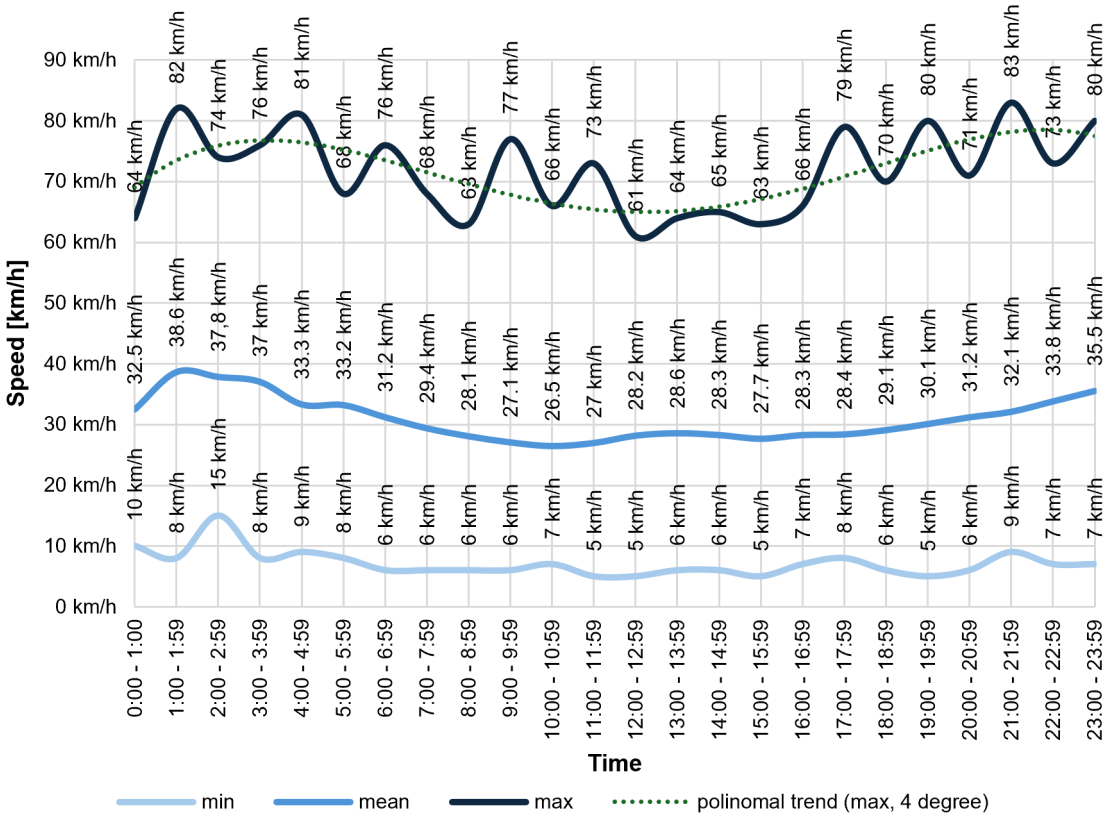


Fig. 6 Temporal distribution of speeds

The trend confirms that the highest – and from a roundabout safety perspective most critical – speeds primarily occur during low-traffic periods.

Minimum speeds generally range between 5–10 km/h, indicating that some vehicles significantly slow down when approaching the intersection, possibly also reflecting the presence of micromobility devices with lower speeds. In some periods, however, higher minimum values are observed (e.g., 19–23 km/h in the early hours of Sunday), which can be explained by lower traffic density and smoother traffic flow.

Comparison of daily averages shows that speeds are generally higher on weekends (e.g., Sunday daily average ≈ 32.1 km/h), while lower values dominate on weekdays (e.g., Monday ≈ 32.0 km/h, Tuesday ≈ 31.1 km/h), consistent with higher traffic loads.

The calculated percentile speeds provide a clear characterization of the speed distribution and driver behavior. The proximity of the mean speed (V_{mean} = 29 km/h) and the median speed (V_{50} = 28 km/h) indicate a relatively balanced distribution without significant skewness. This suggests that most vehicles travel at or below the 30 km/h speed limit, indicating that the roundabout partially fulfills its traffic-calming function.

However, upper percentiles present a different picture. The value V_{85} = 38 km/h indicates that a substantial proportion of vehicles pass through the intersection at higher-than-desirable speeds. This suggests that the geometric and traffic design of the roundabout does not always enforce adequate speed reduction. Notably, this value exceeds the local 30 km/h speed limit, which is unfavorable from a traffic safety perspective.

Detailed data also show that out of 25,320 vehicles, 10,177 vehicles exceeded 30 km/h, representing approximately 40.2% of total traffic. This is a significant proportion and further supports the conclusion that the intersection does not always effectively limit speeds. Exceeding the 30 km/h threshold to this extent is particularly critical in residential areas from a safety standpoint.

The lower percentile (V_{15} = 20 km/h) indicates that a smaller portion of vehicles approaches and navigates the roundabout at significantly lower speeds. This value corresponds to the design entry speed specified in the Hungarian guideline "Design of Roundabouts" (MAÚT Magyar Út- és Vasútügyi Társaság, 2026) (20 km/h), suggesting that some drivers adhere to the intended design principles. The difference between V15 and V85 (18 km/h) indicates relatively high variability, reflecting heterogeneous speed choices among drivers.

Based on the combined interpretation of percentile values and average speed, it can be concluded that the speed distribution in the examined mini-roundabout is not homogeneous. While some drivers adapt to the environment and travel at lower speeds, a significant proportion choose higher speeds. This variation is likely related to central island usage, as higher speeds increase the likelihood of trajectory shortening and driving over the island. The results suggest a relationship between speed and vehicle movement, which is of key importance in the safety evaluation of mini-roundabouts.

6 Conclusion

Based on the results of the study, it can be concluded that the traffic-calming effect of mini-roundabouts is only partially realized in the investigated case. The video-based analysis revealed that the use of the central island is a frequent phenomenon and is not exclusively associated with larger vehicles. A significant proportion of passenger cars, as well as a considerable share of motorcycles, partially or fully traverse the central island, even though in these cases this behavior is generally not driven by geometric constraints. This suggests that some drivers deliberately shorten their trajectories, which represents a partial circumvention of the intended operational principle of the roundabout.

Based on the combined interpretation of video- and radar-based results, it can be assumed that a relationship exists between vehicle trajectories and travel speeds; however, direct verification would require vehicle-level data matching. The average speed was 29 km/h, and the median speed was 28 km/h, indicating that a substantial portion of traffic operates close to the 30 km/h zone speed limit. At the same time, percentile indicators clearly showed that the speed distribution cannot be considered favorable. The value of V_{85} = 38 km/h indicates that the dominant upper speed level exceeds the desirable threshold, while V_{15} = 20 km/h coincides with the entry design speed specified in the Hungarian road design guideline "Design of Roundabouts" (MAÚT Magyar Út- és Vasútügyi Társaság, 2026). This implies that although some vehicles approach the intersection in accordance with design principles, a significant share travels at higher speeds.

A particularly important finding is that out of the 25,320 vehicles analyzed, 10,177 vehicles – representing 40.2% of total traffic – traveled at speeds above 30 km/h. This proportion alone suggests that the design of the mini-roundabout is not always capable of enforcing the speed levels expected in residential environments. Maximum speeds exceeded 80 km/h in several cases, which is especially unfavorable from a road safety perspective, even if these values primarily occurred during low-traffic periods.

Based on the joint evaluation of video- and radar-based results, it is likely that a relationship exists between more frequent central island overrun and higher travel speeds. Crossing the central island can therefore be interpreted not only as geometric adaptation but also as a manifestation of insufficient speed reduction. This is particularly significant in the case of passenger cars and motorcycles, where central island usage is often the result of driver choice.

The results also indicate that a visually delineated central island without physical elevation is not necessarily sufficient to ensure the desired driver behavior and speed levels. Therefore, in the design of mini-roundabouts, it is not enough to assess geometric compliance alone; it is also necessary to analyze actual vehicle movements and speed profiles in an integrated manner. Based on the findings, the application of design and traffic engineering solutions that more effectively enforce lower speeds and more consistent path adherence may be justified.

A limitation – and at the same time direction for further research – is that the analysis was conducted at a single location, and the video and radar data were not processed within the same time window nor matched at the vehicle level. Accordingly, the results are primarily suitable for identifying potential relationships rather than directly proving causality. Future research should therefore focus on linking trajectory and speed data at the individual vehicle level.

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