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Evaluation of Shared Space Feasibility Based on Traffic-Engineering Data

ROMAN DOSTÁL, ANETA DOSTÁLOVÁ, DAVID HUDEC, JOSEF KOCOUREK

Czech Technical University in Prague, Faculty of Transportation Sciences, Konviktská 20, Prague 1, 110 00, Czech Republic

ABSTRACT: This article embarks on a detailed examination of the square Dolní Náměstí in the town of Odolená Voda, concentrating on the implications of implementing shared spaces from perspectives of safety and traffic management. In the study advanced surveillance technologies were employed to systematically document the movements of a variety of road users, serving to pinpoint potential conflict zones. This designation underscores the necessity to reassess urban design and traffic control strategies to meet modern safety standards. Efforts were directed towards aligning urban infrastructure with pedestrian movement patterns, aiming to diminish safety risks and augment accessibility. The study hypothesizes that certain strategic alterations in urban design, such as the realignment of pedestrian pathways and the imposition of vehicle speed controls, could considerably improve the quality of shared spaces. Central to this research is the ambition to forge a new methodological framework for assessing the capacity of shared spaces mathematically. This initiative seeks to fill a significant research gap by quantitatively evaluating the capacity of shared spaces to fulfil a varied set of urban mobility requirements. This framework aims to establish a foundation for the systematic appraisal and enhancement of shared spaces. Recommendations for urban planners and traffic engineers are presented, promoting a design strategy that merges pedestrian preferences with traffic management objectives to cultivate safer, more efficient, and universally accessible urban areas. These recommendations endeavor to steer the evolution of shared spaces towards a harmonious balance of user needs. This work aims to make a substantive contribution to urban planning, traffic management, and pedestrian safety domains, paving the way for future exploratory studies and practical deployments in shared space advancements. It emphasizes the critical need to integrate both vehicular and pedestrian considerations into urban design processes, striving to create urban spaces conducive to sustainable mobility and improved urban living standards.

KEYWORDS: Shared Space; Trajectories; Pedestrian Safety; Road Safety Audit; Conflict Points

1. INTRODUCTION

Shared space is defined as "space designed to improve the movement and comfort of all road users". In this space, no road user is preferred, and all users of the shared space must respect each other and not endanger each other (Reid, Kocak, Hunt, 2009).

Based on a study conducted by Greek scientists (Tzouras, Kepaptsoglou, Vlahogianni, 2023), it was discovered that the implementation of shared spaces in urban environments significantly increases pedestrian crossings and decreases traffic speeds. This correlation suggests that shared spaces contribute to more uniform driving behavior, potentially leading to safer and more pedestrian-friendly environments. The findings of this study underscore the potential of the shared space concept in positively influencing road users' behavior and transforming urban roads into safer and more welcoming spaces.

The results of German scientists (Batista, Friedrich, 2022) show that for cyclists and pedestrians to avoid traffic conflicts, they may choose to ride and walk on the edges of the movement zone or seek refuge in the safe zone. In this context, the "movement zone" refers to the area where cyclists and pedestrians move and may encounter vehicles, while the "safe zone" is a designated safe area where they can retreat to avoid traffic conflicts. Pedestrians are more likely to walk in the movement zone at shared space intersections than on street segments. However, this comparative analysis showed that pedestrian movements are still varied and difficult to predict based on design alone.

Research from Singapore and Korea (Che, Wong, Lum, Wang, 2021) explored the interaction between pedestrians and cyclists on shared sidewalks, revealing that perceived control and priority shape their behavior. Cyclists tend to respect pedestrians more and act more cautiously, while pedestrians often underestimate the risks posed by cyclists. The study, limited to a single location and a small sample, suggests the need for broader research. Recommendations include increasing safety awareness, supporting unidirectional movement, and enforcing rules for pedestrian priority to improve safety on shared sidewalks.

Dutch engineer and innovator Monderman (Hembrow, 2008) stated that the lack of space delineation and traffic facilities in shared spaces creates uncertainty for drivers and pedestrians, and this can lead to reduced driving speeds and increased safety awareness. In such an environment, road users become more aware of the movement patterns around them by perceiving interactions through eye contact and anticipatory behavior.

In a study conducted by researchers from Italy and Germany (Orsini, Batista, Friedrich, Gastaldi, Rossi, 2023), video data were collected and analyzed both before and after the implementation of a shared space to identify the trajectories of road users. This comprehensive analysis encompassed traffic volumes, trajectories, speeds, and traffic conflicts, with the aim of estimating accident rates pre and post intervention. The results demonstrated a notable decrease in the risk of accidents following the implementation of the shared space.

Swedish researchers (Warner, Andersson, Patten, 2022) investigated how pedestrians of varying ages experience shared spaces, particularly comparing a basic design to one with large planters. Using visual scanning and Q-methodology, they found age-specific responses to these designs,

with older participants favoring traffic-relevant elements and younger ones showing equal interest in all elements. The addition of planters reduced feelings of uncertainty among older individuals, indicating that such features can enhance the perceived safety of shared spaces. This underscores the importance of further research on how different designs affect user experience and safety across age groups.

Researchers from Thessaloniki (Nikiforiadis, Basbas, Mikiki, Oikonomou, Polymeroudi, 2021) investigated various methodologies for assessing the *Level of Service* (LOS) for pedestrians and cyclists, with the aim of identifying their strengths and weaknesses while providing a foundation for future improvements in the sustainability of urban transport systems. Through a literature review and practical application upon shared spaces, it was found that a combination of quantitative and qualitative methodologies offer more accurate LOS estimates, but the subjectivity of qualitative aspects presents challenges. The findings highlight a lack of readily usable tools for the practical assessment of LOS in shared spaces and emphasize the need for an individual approach considering local conditions. This study opens pathways for further research focused on refining methodologies for a more objective evaluation of pedestrians' and cyclists' perceptions in shared spaces.

Researchers from China (Liang, Meng, Zheng, 2021) analyzed conflict behavior in shared spaces, examining 12 hours of video from three sites and identifying 337 conflicts using the DOCTOR method. The DOCTOR method is a structured observational technique for analyzing traffic conflicts in shared spaces, systematically identifying and evaluating interactions among pedestrians, bicycles, and e-bikes to assess behavior, characteristics, and safety concerns. Findings show a correlation between traffic volume and the number of conflicts, with participants' reactions varying based on the type and severity of conflicts. The study suggests using a conflict coefficient for improved safety assessment and highlights methodological limitations, including observer estimation subjectivity and limited data scope.

Research (Liang, Meng, Zheng, 2021) underscores the transformative role of shared spaces in urban environments, showing they not only modify pedestrian and driver behaviors—leading to slower vehicle speeds and enhanced social interactions—but also stress the critical importance of design tailored to local nuances. Despite their benefits, critiques and analyses signal that the effectiveness of shared spaces can vary greatly, influenced by cultural norms and traffic conditions. This variability points to an urgent need for further exploration and innovation in the field of shared spaces, particularly in improving urban public realms through strategic implementation.

The Shared Space approach, gaining traction internationally, represents a progressive trend in urban street redevelopment. Yet, most studies to date have predominantly examined these spaces through the lenses of urban design or their impact on traffic incidents, significantly overlooking the aspect of spatial capacity. This gap highlights a crucial shortfall in current literature, as understanding the capacity of shared spaces is paramount for optimizing their use and ensuring they effectively cater to the varied demands of urban mobility.

Our research aims to bridge this gap with a focus on the capacity of shared spaces from a transportation perspective, a key element that has been underexplored. The study addresses the pressing issue of developing a suitable methodology and identifying key parameters for the implementation of shared spaces on the Czech Republic's main multipurpose streets. The absence of specific legislation, methodologies, or conditions guiding the selection of shared spaces over residential or pedestrian zones underlines the current reliance on urban planners' or architects' subjective decisions. By concentrating on the capacity of shared spaces, our research seeks to offer a more objective framework for their planning and implementation, ensuring they are not only designed for aesthetic and social benefits but are also are functionally equipped to handle the diverse needs of urban transport.

2. THE METHODOLOGY

The concept of shared spaces within urban environments has garnered significant attention as a strategy to facilitate the harmonious coexistence of various transportation modes alongside pedestrians. This approach aims to enhance both the functionality and aesthetic appeal of public spaces. By diminishing the segregation between vehicles and pedestrians, shared spaces are anticipated to improve traffic flow and elevate safety levels, thereby cultivating a more interactive and socially vibrant urban landscape. However, the implementation of such spaces requires careful evaluation to ensure they truly offer these advantages without compromising safety.

The only existing methodology that addresses the capacity of uncontrolled intersections, while considering the impact of pedestrians on vehicle traffic, is currently being developed by a German team led by Werner Brilon (Brilon, Bondzion, Wu, 1997). For this methodology to be applied, it is imperative that a substantial number of pedestrians and vehicles traverse the intersection, particularly in scenarios where pedestrian volumes are expected to surpass 100 pedestrians per hour. This threshold is vital for the effective utilization of the formulas and for determining capacity reliably. The pedestrian impact formula, optimized for situations with higher pedestrian volumes, highlights the necessity of significant movement among both groups to ensure accurate capacity assessment (1).

$$(1)\quad k_{v,ped} = \frac{1120 - 0{,}63 * I_o - 0{,}63 * \frac{I_{ped}}{k_{skup}} + 0{,}00071 * I_o * \frac{I_{ped}}{k_{skup}}}{1069{,}2 - 0{,}57 * I_o}$$

where

$k_{v,ped}$ coefficient of pedestrian influence (2) on entry into a roundabout intersection [-],

I_o volume of traffic on the roundabout [vehicles/h],

I_{ped} volume of preceding pedestrians [ped/h],

k_{group} grouping coefficient of pedestrians [-]. It is determined as follows:

$k_{group} = 1{,}00$ **for I_{ped} ≤ 200 ped/h**

$k_{group} = 0{,}004 * I_{ped} + 0{,}2$

for I_{ped} >200 ped/h (2)

Formula (1) is valid for I_{ped} > 100 ped/h. In the case of I_{ped} ≤ 100 ped/h the value of $k_{v,ped} = 1{,}00$.

In this initial stage, we employ a blend of traffic and pedestrian counts, along with an examination of the existing infrastructure, to determine the square's suitability for a shared space conversion. Our chosen methodology aims to capture a snapshot of the present traffic trajectories, discern the distribution of different transportation modes, and pinpoint potential areas for improvement in the context of shared space.

The forthcoming sections of this article will outline the specific methodologies employed in the preliminary evaluation phase for the potential conversion of Dolní Náměstí in Odolená Voda into a shared space. This foundational assessment will pave the way for a meticulous exploration of the site's capacity to sustain a shared space and will be instrumental in the development of a proposal that aligns with the community's aspirations for safety, efficiency, and societal benefit.

2.1 Traffic accidents

One of the initial steps involves the selection of suitable locations for the survey and the assessment of the potential implementation of shared spaces.

The choice of appropriate sites for the validation of the shared space calculation and implementation method in cities is based on the work of Ing. Anton Ostach, Ph.D. (Ostach, 2021), who examined the sites primarily from an urban planning perspective.

The methodology for mapping the sites concentrates on public spaces with mixed traffic, where there is no segregation of individual users and can only be created under conditions of very calm and slow traffic according to Czech legislation (Ministry of Transport of the Czech Republic and EDIP s.r.o., 2008).

An important parameter for the investigation of shared spaces is the *relative accident rate*, which indicates only accidents with personal consequences (Police of the Czech Republic, 2023). This parameter is critical as it allows us to observe the zones of conflict between passenger vehicles and pedestrians, which can be utilized to develop targeted safety strategies that aim to reduce the specific types of crashes that occur in these locations. In 2022, there were 43 fatalities on local roadways per 10 million population. The inclusion of traffic accidents within shared zones in this statistic is attributed to their designation as integral components of local roadways, reflecting their character and function within the broader urban infrastructure.

Generally, the number of accidents in shared spaces can be lower than in traditional streets with separated infrastructure for cars, buses, and pedestrians. This is because shared spaces are designed to slow down vehicle traffic and create a more forgiving environment for all road users. Lowering the speed limit on streets can decrease the number of accidents, reduce the severity of collisions, and increase the reaction time of road users. However, it is essential to note that the number of accidents in shared spaces can also be affected by other factors, such as the volume of traffic, the design of the shared space, and the behavior of individual road users.

Accident events were monitored in the period from January 1, 2012 to December 31, 2022. It is important to note that in 2020 and 2021, the data was affected by the COVID-19 pandemic, which had an impact on the movements of vehicles and the most vulnerable participants (pedestrians and cyclists).

2.2 Road safety inspection

The road safety inspection was carried out on September 27th, 2023 for the purpose of safety assessment regarding the condition of the Dolní náměstí (town square) in Odolená Voda. The town of Odolena Voda is located north of Prague at the intersection of roads II/522, III/24210, III/24211, III/24213. Near the city is EXIT 9 of the D8 highway. The square is located in the historic center of the village and is more of a crossroads and parking lot than a square. Importantly, it is the center of the village, where the municipal office, post office and business units are located. The inspection was carried out by a team of 4 transport engineers and focused on all transport modes. The technique of the performed inspection was based on the "Methodology of road safety inspection - implementation methodology", 3rd edition (Directive (EU) 2019/1936 of the European Parliament and of the Council, 2019).

To evaluate road traffic safety in the addressed locality, individual risks were evaluated based on their importance and severity. The inspection team evaluate the identified risks according to their severity at three levels: low, medium and high. Furthermore, the difficulty of implementing the proposed solution is determined, when it is a simple, administrative or complex solution.

2.3 Dolní Náměstí in the town of Odolena Voda

Dolní Náměstí in the town of Odolena Voda was chosen for the evaluation of road traffic safety and the analysis of the suitability of shared space. Due to the large number of services and the high volume of pedestrians in the square, there are a large number of pedestrian and bicycle corridors in its area. For that reason, the square was identified as a potentially suitable place for the future implementation of a shared space, since all forms of transport (pedestrians, cyclists, passenger vehicles) are present in a large percentage. A comprehensive traffic survey was conducted to determine the movement of all road users. The traffic survey was conducted on Wednesday, August 2, 2023, between 9:30 a.m. and 4:30 p.m. This day and time was chosen because of the greatest traffic and intensities of all types of transport. The survey was carried out with the help of 3 cameras located on public lighting poles so that they covered the entire area under investigation. A diagram of the current state of Dolní Náměstí, including important sources and destinations of the roads and the location of cameras for data collection, is shown in the figure (Figure 1).

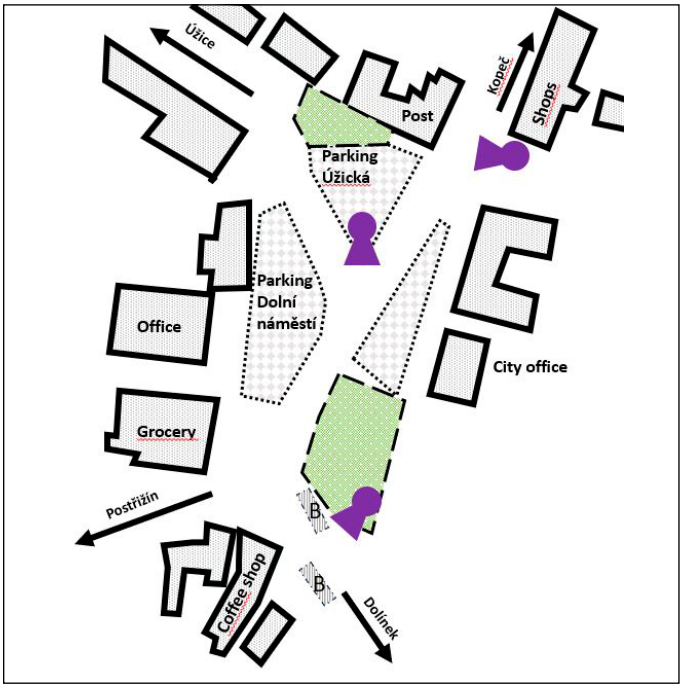

Figure 1: Location of the Camera in Dolní Náměstí, Odolená Voda.

The recorded video footage was then analysed using the academic licensed software "DataFromSky" from RCE SYSTEMS. This software enables the evaluation of intensities, trajectories of all participants moving in space and the identification of collision points between participants, for example the collision between a pedestrian and a car or a so-called HEAT MAP showing, for example, the main pedestrian corridors.

Although this method provides valuable information about the points of conflict in Dolní Náměstí, it also has its limitations. Video footage may not always accurately capture all conflicts, especially if some areas of the square are poorly visible. In addition, the DataFromSky software can sometimes incorrectly identify conflict points if the trajectories of road users are complex or unusual.

As part of the safety analysis, a camera recording was taken of the intersection of roads II/522 (ul. Postřižínská) and III/24211 (ul. Květnová) on Dolní Náměstí on August 2, 2022, from 10 a.m. to 5 p.m. From the camera recording, a directional summation was made for all types of vehicles in the busiest hour during the afternoon rush hour, and a conversion to 50th peak hour volume was made (K-Factor). The traffic

quality level is based on the intersection traffic survey and the subsequent capacity assessment. The traffic quality level is divided into six grades A-F, where grade A means that the driver is not restricted in any way by other participants, grade F represents traffic congestion (Directive (EU) 2019/1936 of the European Parliament and of the Council, 2019).

3. DATA AND RESULTS

In analyzing Dolní Náměstí in Odolená Voda, the focus is on infrastructure favoring vehicular traffic. The square, intended for community use, lacks adequate pedestrian pathways, revealing gaps in urban design. Three disjointed parking areas near essential services further highlight the need for better integration. Despite hosting key facilities, the square's car-centric layout, with multiple intersections and parking spaces, diminishes its communal appeal.

This study provides a detailed view of traffic trajectories and road safety in the square, using advanced camera surveillance. It reveals complex interactions among pedestrians, vehicles, and public transport. Safety inspections identified various risk factors, from poor signage to shared space challenges, each evaluated for impact and remediation complexity. Special attention is given to conflict points, crucial for understanding mixed traffic safety issues. Data analysis, employing Data from Sky software and Python, created heat maps and trajectory plots, essential for urban planning aimed at improving safety, efficiency, and community engagement in Dolní Náměstí.

3.1 Traffic Flow

The measured volume values were processed into a load diagram of intensities. Concurrently, based on the measured values, a calculation of traffic-engineering indicators was conducted, including Annual Average Daily Traffic (AADT), Daily Traffic Volume, and the 50th Peak Hour Volume. An overview of the examined intersections can be seen in the figure below (Figure 2).

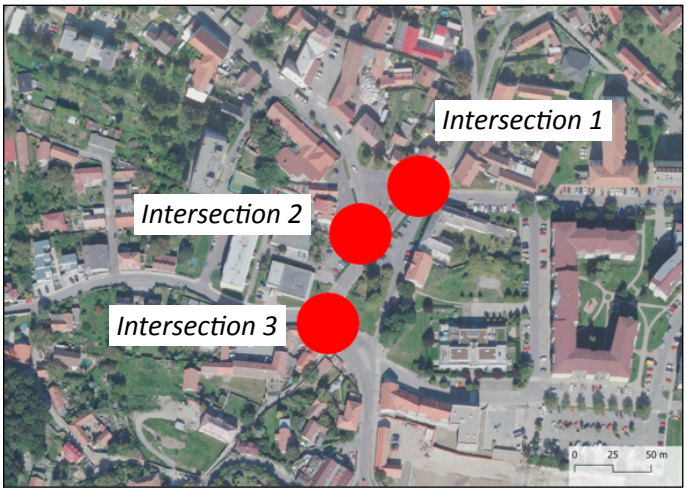

Figure 2: The location of the examined intersections on the square in Odolená Voda.

The first intersecting junction at Velkoveská and Pod Tvrzí (Intersection 2) the parking lot near the post office was analyzed in Figure 3 below. The measurements indicated that during peak traffic hours, the highest volume at the first junction was recorded from the direction of Velkoveská from Dolní Náměstí towards Velkoveská in the direction of Kopeč, totaling 109 vehicles per hour. The second highest traffic volume was observed in the opposite direction, amounting to 95 vehicles per hour. The diagram also shows a relatively large number of vehicles heading to and from the parking lot. It was observed that many people parked their vehicles in the parking lot, went shopping or ran errands at the post office, and then departed. Vehicles predominantly arrived at the parking lot from Dolní Náměstí, accounting for 24 vehicles per hour. In the opposite direction, 27 vehicles per hour were recorded.

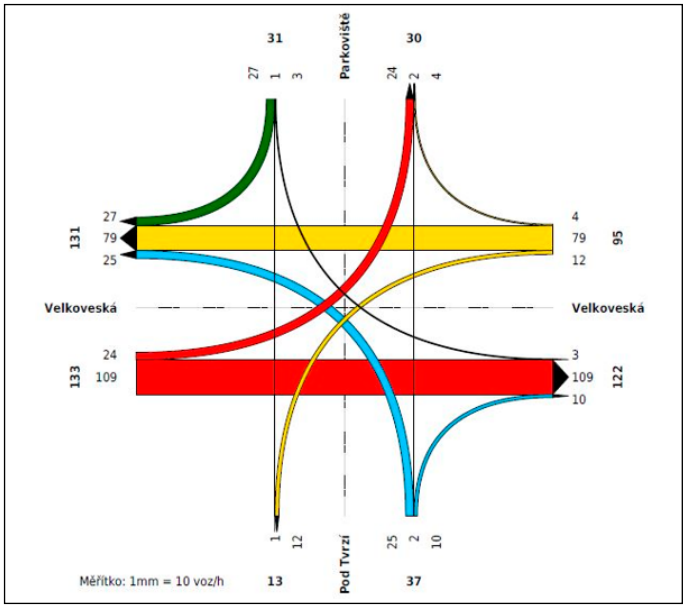

Figure 3: Load diagram of intersection 1 – Pod Tvrzí x Velkoveská x Parkoviště in the period 16:00 – 17:00 from 2 August 2023.

The second intersection analyzed was the crossing of Úžická, Velkoveská, Dolní Náměstí and Městský úřad (Figure 4). The survey conducted in this area revealed that during peak traffic hours, the highest volume at the second junction (Intersection 2) was measured from Dolní Náměstí towards Velkoveská, with a volume of 215 vehicles per hour. The second highest traffic volume was recorded in the opposite direction, this totaled 108 vehicles per hour. From Úžická Street, a total of 94 vehicles per hour were observed, which then dispersed onto the main thoroughfare.

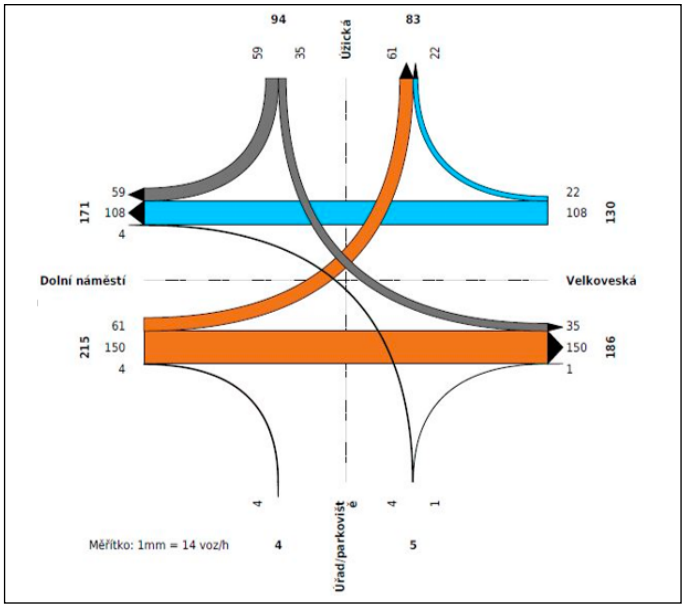

Figure 4: Load diagram of intersection 2 - Úžická x Velkoveská x Dolní Náměstí x Městský úřad in the period 16:00 – 17:00 from 2 August 2023.

Within the scope of the last junction surveyed (Intersection 3), Postřižinská x Květnová, the highest traffic volume

was measured in the direction from Květnová to Postřižinská North, totaling 200 vehicles per hour (Figure 5). For the opposite direction, the volume was 160 vehicles per hour. From Postřižinská West, 61 vehicles per hour were recorded heading towards Postřižinská North.

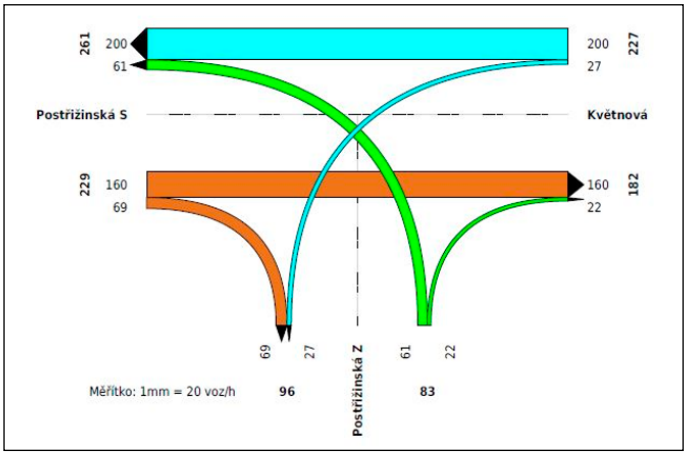

Figure 5: Load diagram of intersection 3 – Postřižinská x Květnová in the period 16:00 – 17:00 from 2 August 2023.

The traffic volume data from various intersections in Dolní Náměstí was thoroughly analyzed, yielding crucial insights. At the Velkoveská and Pod Tvrzí intersection near the post office, the peak traffic flow was 109 vehicles per hour from Velkoveská towards Kopeč. The Úžická and Velkoveská junction, adjacent to Dolní Náměstí and the Municipal Office, recorded the highest volume at 215 vehicles per hour towards Velkoveská. Additionally, the Postřižinská and Květnová junction showed significant traffic, with 200 vehicles per hour moving from Květnová to Postřižinská North.

The analysis also revealed that most routes achieved a Traffic Quality Level (ÚKD) 'A', signifying optimal traffic conditions. An exception was noted from Velkoveská North to Dolní Náměstí, which attained a Level of Service 'B', indicating marginally lower yet acceptable traffic flow efficiency.

The data conclusively indicates that the capacity at each analysed intersection aligns well with the current traffic volumes and patterns, maintaining an overall satisfactory Level of Service.

3.2 Traffic Accident Data

Data on the number of traffic accidents were obtained from the web application 'Accident Locations' – https://nehody.cdv.cz. Over the last ten years, 9 traffic accidents have been reported in the area under study. These included 7 accidents with material damage and 2 with minor injuries. Six of the accidents involved a collision with a moving non-rail vehicle. Two involved collisions with pedestrians, and one involved a collision with a parked or stationary vehicle. Both incidents resulting in minor injuries involved pedestrians, who presumably crossed the roadway in locations lacking official pedestrian crosswalks. These crossing points, while not formally designated, appear to align more closely with intuitive and direct pedestrian routes, as opposed to the existing, planned pedestrian infrastructure. This observation suggests a discrepancy between the naturally preferred pedestrian pathways and the currently implemented urban design.

Further analysis of these incidents reveals a pattern of accidents predominantly involving moving vehicles, highlighting potential safety concerns for non-rail vehicle traffic. The frequency of accidents with pedestrians also underscores the need for improved pedestrian safety measures in this area. The data suggests that while the number of accidents is relatively low, the nature of these incidents calls for targeted interventions to enhance road safety, particularly in terms of vehicle speed regulation and pedestrian crossing safety. Each of the accidents is depicted in the image below (Figure 6).

Figure 6: Accident Analysis Situation at Dolní Náměstí in Odolená Voda (Police of the Czech Republic, 2023).

3.3 Safety Inspection

A safety inspection at Dolní Náměstí in Odolená Voda identified critical traffic safety issues. The inspection revealed that straight road sections lacked features to engage driver attention in areas frequented by vulnerable road users, warranting complex solutions despite being low risk. High-risk areas included busy intersections and inadequately designed exits from parking areas, with the Úžická - Velkoveská intersection posing additional cyclist visibility risks.

Road conditions, characterized by worn surfaces and sharp curb edges, raised concerns for vehicle control, necessitating both complex and moderate remedial measures. Similarly, parking zones, especially bus lay-bys, were poorly designed, creating hazardous conditions that require comprehensive solutions. Inconsistencies in traffic signage at intersections and inadequate pedestrian crossing lighting were also identified, both needing complex interventions.

A notable issue was the lack of sidewalks and pedestrian-friendly infrastructure, leading to unregulated pedestrian movement and heightened risks. This was compounded by insufficient infrastructure for cyclists and narrow sidewalks in Dolní Náměstí, emphasizing the need for holistic solutions. Additional concerns included low flowerpots creating visibility issues for larger vehicles and overly long pedestrian crossings at Pod Tvrzí Street lacking clear guidance.

In total, 34 traffic and safety risks were identified during the inspection. The proposed measures to address these risks varied in complexity, with the objective of enhancing traffic safety to an acceptable level in Odolená Voda. Figure 7 illustrates the key locations of these traffic and safety deficits.

The safety inspection at Dolní Náměstí in Odolená Voda highlighted key deficiencies in intersection layouts, road surfaces, and pedestrian infrastructure. Recommended corrective measures include:

Overhauling traffic signage, replacing confusing signs, and updating horizontal markings for clarity and safety. Adjusting routes to accommodate visually impaired and mobility-restricted individuals, aligning with Regulation No. 398/2009 Coll., to enhance accessibility and safety.

Figure 7: Overview of all identified traffic safety risks at Dolní Náměstí in Odolená Voda.

3.4 Road Safety Audit

The road safety audit, conducted for the 'Odolená Voda – Reconstruction and Modification of Dolní Náměstí' project at the Detailed Design Documentation (DUR) level, identified 22 risks of varying severity. These were categorized as 7 low, 12 medium, and 3 high risks. The audit focused on evaluating the design aspects of the square, aiming to enhance safety and functionality rather than critique the complex work of the designer (Directive (EU) 2019/1936 of the European Parliament and of the Council, 2019).

Significant findings from the audit include substantial reductions in parking spaces proposed by the project, which could adversely affect the surrounding area of Dolní Náměstí. The new parking design presented several deficiencies and risks, notably the lack of clear signage and surface treatment for the descent into the parking area, potentially leading to dangerous situations (Figure 8).

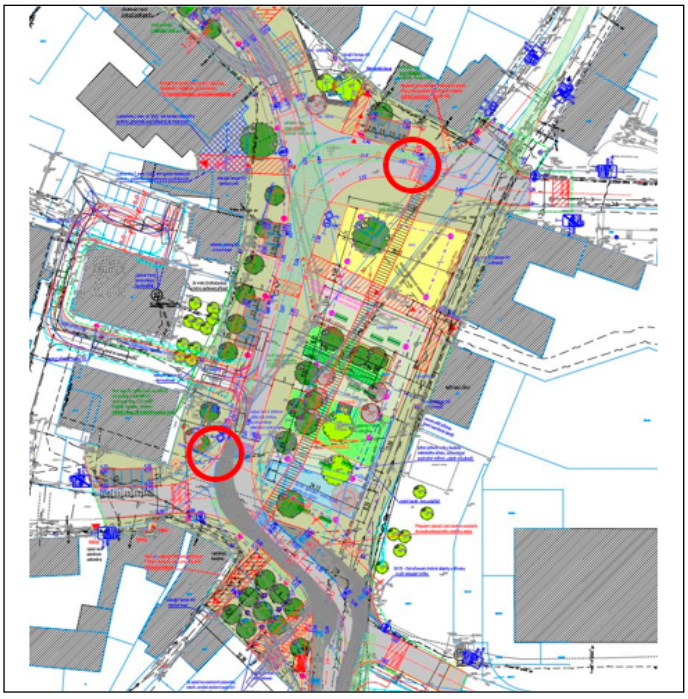

Figure 8: Evaluated Proposed Documentation of the Square in Odolená Voda by company KT ING s.r.o.

The road safety audit for Dolní Náměstí's extensive reconstruction plan revealed significant shortcomings. The project documentation lacks crucial information on directional alignment, vertical profiling (elevation), and roadway widths, impeding the assessment of vital aspects like road drainage and sidewalk accessibility.

A road safety audit is a proactive process in traffic planning and design aimed at accident prevention, involving independent evaluations of transport projects to identify and address security risks before they manifest, rather than merely ensuring technical compliance or suggesting new solutions.

The current design of Dolní Náměstí in Odolená Voda appears inadequate, as the redevelopment plan fails to address existing safety concerns and introduces new risks. This highlights the importance of considering shared spaces in the redesign, which could enhance pedestrian safety and overall urban appeal, fostering a safer, more pedestrian-friendly environment.

3.5 Defining conflict points

A comprehensive collection of data on road user trajectories within the Odolená Voda municipality square in the Central Bohemian region was undertaken. The entire square was covered using advanced camera surveillance equipped with motion detection capabilities. Data was acquired on August 2, 2023, from 9:30 am to 4:30 pm. Through this timeframe, a holistic capture of user movement patterns, interactions, and potential congestion points throughout the day was achieved.

By the primary camera targeting the Úžická and Velkoveská intersection, 2,957 trajectories (Vectors) were recorded. Included in these were 461 pedestrians, 51 bicycles, 59 buses, 2,022 cars, 38 motorcycles, 219 vans, 10 heavy trucks, and 219 light trucks. Significant pedestrian movement was observed around 11:00 am, which is believed to coincide with lunch breaks, as access to grocery stores on the opposite side of the square was noted. Additionally, trajectories from the Úžická parking area towards bus stops and grocery stores were identified. It was also observed that during peak times, certain zones experienced higher foot traffic, suggesting potential areas for infrastructure improvement (Figure 9).

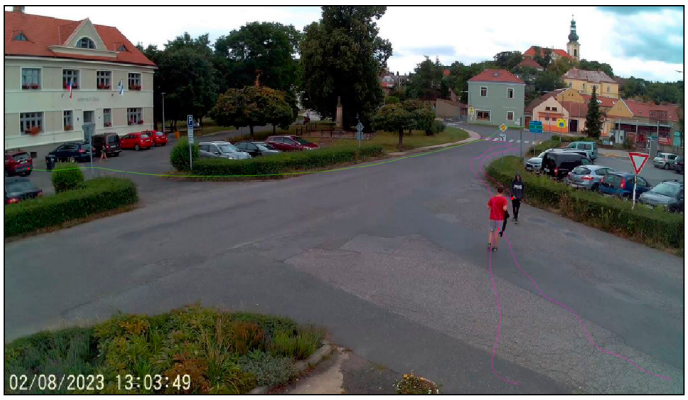

Figure 9: A sample from the camera recording of Camera 1, capturing pedestrians crossing from the Úžická parking lot towards the bus stop and the grocery store.

The secondary camera system documented 3,338 trajectories, comprising 1,005 pedestrians, 57 bicycles, 40 buses, 1,857 cars, 41 motorcycles, 234 vans, 11 heavy trucks, and 93 light trucks. Prominent pedestrian activity was observed in the morning, especially towards the Czech Post office, which opens at 10:00 am. Increased movement towards Velkoveská Street's retail establishments was also noted. While most pedestrians used designated crosswalks, deviations were particularly evident around the Velkoveská and Pod Tvrzí intersection. Private vehicles frequently accessed the square's parking area, indicating commercial activities influencing vehicular traffic. Public transport predominantly operated along Úžická Street towards Úžice, with identified bus routes

Figure 10: Footage from the second camera showing a large number of pedestrians heading towards the Czech Post during its opening hours.

Figure 11: Occupancy of the Úžická parking area during the morning hours - view from Camera 2.

Figure 12: Sample of pedestrian trajectories during the arrival times of city public transport buses - view from Camera 3.

Figure 13: Sample of pedestrians crossing outside of the designated crosswalk between bus stops - view from Camera 3.

also serving Kopč and Veliká Ves. The regularity of bus routes indicates a well-organized public transport system in the area (Figure 10, Figure 11).

Through the tertiary camera installation, 3,041 trajectories were documented. The dataset was found to comprise 898 pedestrians, 49 bicycles, 61 buses, 1,732 cars, 27 motorcycles, 194 vans, 8 heavy trucks, and 72 light trucks. Distinct patterns in pedestrian movement were revealed, believed to be primarily influenced by the scheduled intervals of city public transport buses. Peak pedestrian counts during the afternoon, especially at 13:00 and post-16:00, were observed. Identification of the primary trajectories between the "Odolená Voda, Dolní Náměstí" bus stop and residential areas near the St. Kliment Church was made. Observation of secondary trajectories between the Odolená Voda Municipal Office and the aforementioned bus stop was also made. Crossing of Květnová Street away from designated crosswalks by some pedestrians was observed, indicating potential areas for safety enhancements. Service of the mentioned bus stop by five public transport routes was identified. Operation hourly by two of these bus lines and sporadic operation by the others were noted. Strict adherence to their designated routes between Vodolská and Postřižínská streets by buses was observed. An anomaly between 13:30 and 14:30, where a bus remained stationary at the "Odolená Voda, Dolní Náměstí" stop, was noted, likely indicating a scheduled driver break, suggesting the importance of ensuring adequate facilities for public transport staff (Figure 12, Figure 13).

The analysis of pedestrian and vehicular trajectories within the precincts of Odolená Voda square unveils a temporal delineation of urban mobility, distinctly characterized by pedestrian flux and consistent vehicular flow, as depicted in the associated graphical representation. During the early morning hours, pedestrian trajectories were markedly sparse, indicating a subdued level of urban activity. These trajectories shifted noticeably around 10:00 AM, in tandem with the opening of the local post office and other commercial establishments within the square. This led to an augmented pedestrian influx as illustrated in the figure. Subsequent surges in pedestrian trajectories were observed at approximately 1:00 PM and 4:00 PM, ostensibly corresponding with the typical workday egress.

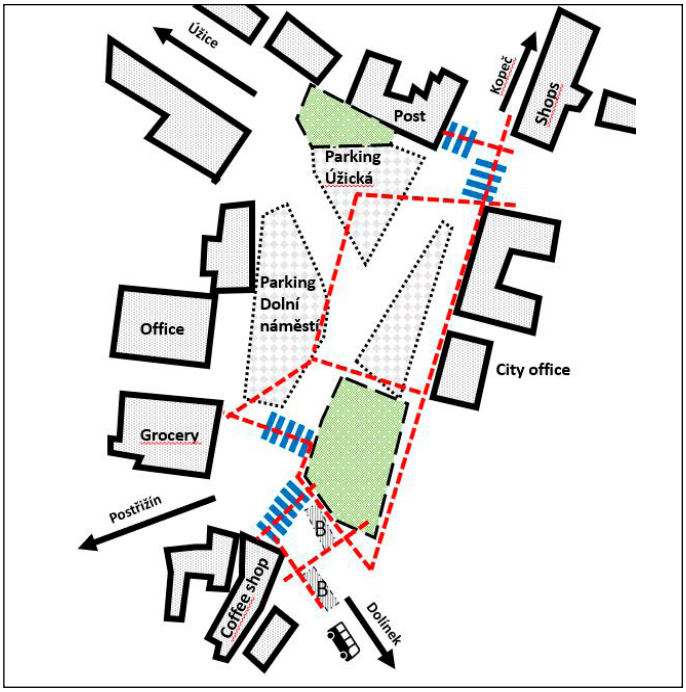

Figure 14: Scheme of recorded trajectories of pedestrians on the measured day of 2. 8. 2023 (depicted by red dotted lines).

An examination of pedestrian spatial utilization reveals a predominant adherence to designated pedestrian pathways and crosswalks. However, a discernible number of trajectories deviating from these predefined paths were recorded, as delineated in the figure below. Such trajectories underscore a predisposition among pedestrians towards a more liberal utilization of the square's spatial expanse, beyond the confines of designated crosswalks (Figure 14).

On the vehicular front, the trajectories of bus transit showcased a sustained consistency throughout the diurnal cycle with no discernible fluctuations. The temporal intervals between successive bus services manifested a uniform pattern, evidencing a well-regulated flow of public transportation within the designated transit corridors. The delineated data provides a multifaceted insight into the temporal and spatial trajectories governing pedestrian and vehicular mobility within the square, illustrating the interplay of service operation hours, workday schedules, and pedestrian spatial preferences in shaping urban mobility patterns.

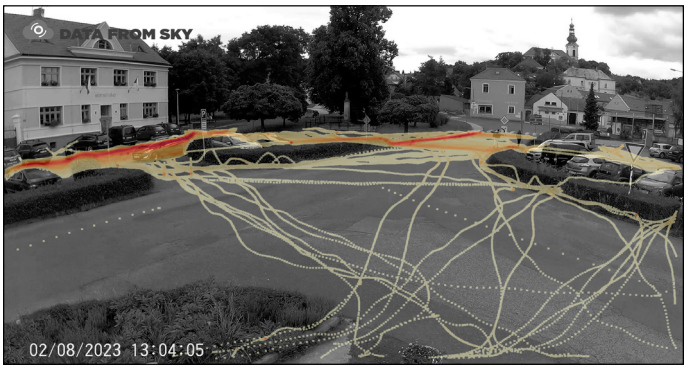

Figure 15: Overlayed trajectories using the Data From Sky software and Python, specifically for pedestrians during the traffic survey – Camera 1.

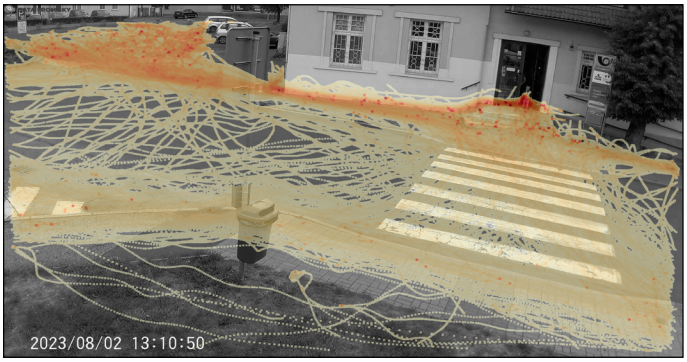

Figure 16: Overlayed trajectories using the Data From Sky software and Python, specifically for pedestrians during the traffic survey – Camera 2.

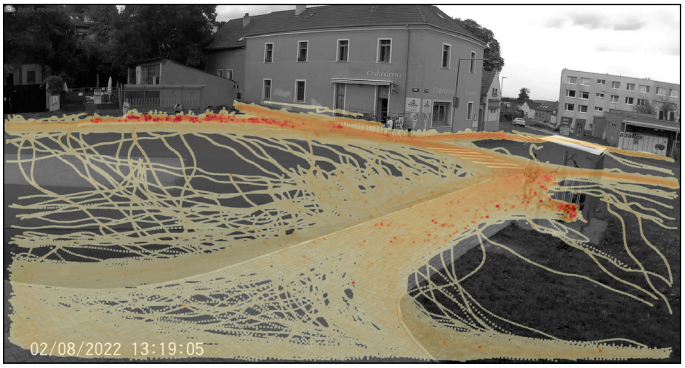

Figure 17: Overlayed trajectories using the Data from Sky software and Python, specifically for pedestrians during the traffic survey – Camera 3.

In the evaluation of the traffic survey, a heat map was generated to delineate the predominant pedestrian trajectories within the Odolená Voda square, encompassing both the Upper and Lower squares. This visualization technique facilitates the identification of primary pedestrian routes and highlights zones of increased movement concentration. The heat map offers invaluable insights into pedestrian trajectories within the square and can be instrumental for the strategic planning and design of shared urban spaces. Advanced analytical tools, Data from Sky software and Python programming, were employed to analyse and illustrate the predominant trajectories, with a particular focus on pedestrian movement. Unlike public transport vehicles, which typically adhere to predefined routes, pedestrians often deviate from anticipated paths, rendering their movement patterns more intricate for analysis in this manner. This predictability not only streamlines the analytical and planning processes but also constrains adaptability to evolving conditions and requirements (Figure 15, Figure 16 and Figure 17).

On the Heat Map of trajectories in Odolena Voda, the red areas serve as indicators of the most frequented sections where the highest concentration of pedestrians gather. These areas are pivotal for analyzing movement and interaction within the space.

A study at Odolena Voda's square revealed intricate movement patterns of pedestrians, public transport vehicles, and other traffic. This analysis identified key congestion points and heavily trafficked areas, evolving throughout the day. These insights are crucial for urban planning, offering data to enhance pedestrian safety, optimize transit routes, and improve overall mobility.

The safety inspection utilized advanced camera surveillance to analyze road traffic participant trajectories over seven hours. It uncovered significant pedestrian activity during lunch hours and peak vehicular traffic linked to commercial activities, highlighting areas for infrastructure improvement. Notably, deviations from designated crosswalks and consistent bus trajectories were observed, suggesting areas for safety enhancements and confirming an effective public transport system.

A heat map from the study pinpointed the most frequented areas, aiding in strategic planning for safer and more efficient urban mobility in Odolená Voda.

4. DISCUSSION

Reflecting on relevant literature, it becomes apparent that shared spaces significantly influence urban mobility and safety. The findings from Greek researchers that shared spaces enhance pedestrian safety and encourage more consistent driving behavior align with observations made in the study of Dolní Náměstí, Odolená Voda. This study corroborates the notion that such environments can lead to safer, more pedestrian-friendly urban areas, emphasizing the importance of shared spaces in influencing road user behavior positively (Tzouras, Kepaptsoglou, Vlahogianni, 2023).

The methodological parallels with the Italian and German research, which utilized video data to assess road user trajectories, find confirmation in the Dolní Náměstí analysis. The latter's detailed traffic flow and pedestrian movement analysis extend the understanding of shared spaces' operational nuances, underlining a shared objective to reduce accident risks while enhancing safety (Orsini, Batista, Friedrich, Gastaldi, Rossi, 2023).

In this article, places have been identified that are used by pedestrians for crossing the road but are not officially intended for this – are not pedestrian crossings. In these places, traffic accidents involving a collision between a vehicle and a pedestrian have already been registered in the

past (Odolená Voda, Dolní Náměstí). In the case of a shared zone, the crossing points would not be precisely defined, and pedestrians could cross at any point. This counterintuitively would increase pedestrian safety, which corresponds to the results in the articles by Joseph and Hamilton, Moderman or Batista and Friedrich (Batista, Friedrich, 2022) (Hembrow, 2008).

A review of existing literature uncovers a notable omission in the quantitative analysis of shared spaces' capacity, particularly from a mathematical standpoint. This article sets the groundwork by identifying collision points within shared spaces, as evidenced in the Dolní Náměstí study, paving the way for an in-depth mathematical exploration of shared spaces' capacity in subsequent articles. This strategic pivot towards a quantitative capacity assessment is intended to fill a critical gap in urban mobility research, offering a guide the development and optimization of shared spaces.

5. CONCLUSION

This comprehensive analysis of Dolní Náměstí in Odolená Voda underscores the potential advantages of introducing shared spaces, which are instrumental in reducing vehicle speeds, improving pedestrian safety, and consequently decreasing the incidence of accidents. The study provides a detailed exploration of the trajectories of individual participants, focusing on various key aspects.

In assessing traffic flow and trajectories, notable findings emerged from the Velkoveská and Pod Tvrzí intersection as well as the Úžická and Velkoveská junction. At the former, a maximum traffic flow of 109 vehicles per hour was observed, mainly from Velkoveská towards Kopeč, while the latter witnessed a peak of 215 vehicles per hour from Dolní Náměstí towards Velkoveská. These intersections predominantly maintained an optimal Traffic Quality Level (ÚKD) 'A', indicating efficient management of traffic flow, with occasional deviations to 'B' level in certain directions.

The study also analyzed traffic accident data, drawing from the 'Traffic accidents in the Czech Republic' web application. Over the last decade, nine incidents were reported at Dolní Náměstí, highlighting a correlation between traffic accidents and commonly used pedestrian crossing points. This finding points to the need for improved infrastructure to enhance pedestrian safety.

The safety inspection and road safety audit aspects of the study provided critical insights. The safety inspection highlighted areas requiring intervention, emphasizing the importance of regular, detailed inspections for effective urban planning. The road safety audit, focusing on the 'Odolená Voda – Reconstruction and Modification of Dolní Náměstí' project, identified a total of 22 risks, with significant concerns regarding parking space reduction, unclear traffic signage, and gaps in the reconstruction documentation.

Detailed trajectory analysis was conducted, documenting a total of 9,336 movements. This analysis was crucial in identifying key trends and patterns. Among these, pedestrians accounted for 2,364 distinct movements, highlighting their significant presence in the square. This high number of pedestrian movements emphasizes the need for careful consideration of pedestrian needs in urban planning, particularly in shared spaces where their safety and comfort are paramount (Figure 18).

The study recorded 160 bus movements, reflecting the role of public transport in shaping the trajectories s of the square. The study also recorded movements of other vehicles, including 4,611 cars, 106 motorcycles, 647 vans, 21 heavy trucks, and 384 light trucks. These figures indicate the diverse range of vehicles that utilize the square, each contributing to the overall traffic trajectories.

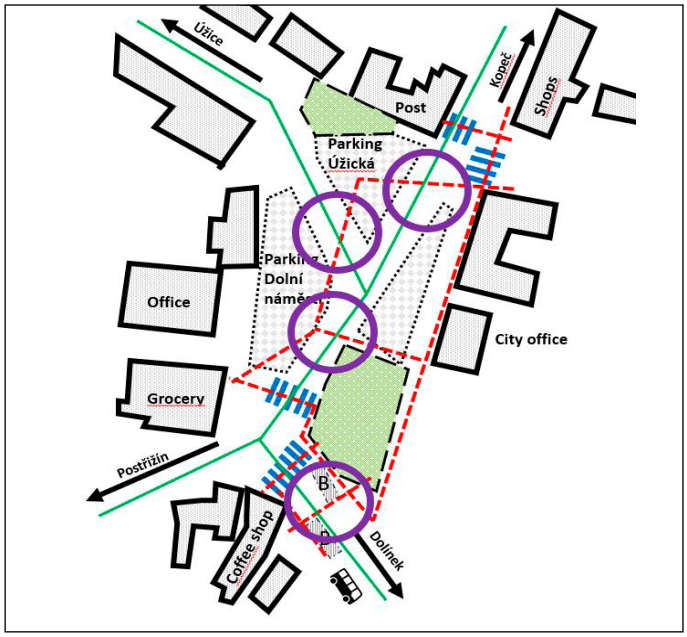

Figure 18: Diagram of the most frequent expected collision points (purple circles) determined based on the examined trajectories of pedestrians (red dashed curve) and personal cars, public transport vehicles, and vans (green solid curve) on Wednesday, August 2, 2023.

The survey revealed frequent collision points involving pedestrians, public transport vehicles, personal cars, and vans, which are vital for assessing the capacity for a shared space. The analysis of these trajectories and collision points, illustrated in the accompanying figures, provides a clear picture of the complex interplay of different road users within Dolní Náměstí.

Conclusively, the study offers a comprehensive perspective on the current state of traffic flow, safety, and pedestrian trajectories in Dolní Náměstí. It underscores the potential of shared spaces in enhancing urban safety and cohesion, paving the way for future urban planning strategies aimed at creating safer and more integrated environments. The ongoing exploration of shared spaces will continue, refining approaches to enhance urban life and safety in Odolená Voda and beyond.

6. ACKNOWLEDGMENT

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