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The Impact of Pedestrian Crossings on Speed Patterns and Roundabout Capacity

Ayoub Charef [1,2], Zahi Jarir [3], Mohamed Quafafou [4]
[1]LAMIGEP EMSI Moroccan School of Engineering Marrakesh, Morocco, A.Charef@emsi.ma
[2]Laboratory of Computer Systems Engineering (LISI) Department of Computer Science Faculty of Science Cadi Ayyad University Marrakech, Morocco, ayoub.charef@ced.uca.ma
[3]Laboratory of Computer Systems Engineering (LISI) Department of Computer Science Faculty of Science Cadi Ayyad University Marrakech, Morocco, jarir@uca.ma
[4]Department of Computer Science University of Aix-Marseille Marseille, France, mohamed.quafafou@univ-amu.fr

ABSTRACT

This study investigates how pedestrian crossings impact both the speed dynamics and capacity of roundabouts, aiming to optimize traffic flow. Pedestrians traditionally hold priority at unsignalized intersections and roundabouts, significantly affecting operational efficiency. The paper underscores the pivotal role of crosswalk placement in mitigating disruptions to vehicular flow and preventing congestion.

Data for this research were gathered from roundabouts in Marrakech, Morocco, utilizing mobile phones to track vehicle and pedestrian volumes, as well as passage times. In addition to field data, Vissim simulations were employed to enhance accuracy. Our study specifically delves into the impact of pedestrians on roundabout exit lane capacity.

The primary goal is to identify the ideal distance between roundabouts and crosswalks to maximize capacity. The findings provide valuable insights for urban planning and traffic management, addressing the dynamic interaction between pedestrian flow, crosswalk positioning, and overall roundabout efficiency.

Key words: roundabout entry capacity, pedestrian crossings, yolo detection, traffic streams analysis, VISSIM simulation.

1. INTRODUCTION

The Roundabouts, known for their enhanced safety compared to unsignalized and signalized intersections, are a preferred choice in traffic management due to reduced conflict points and lower speeds. Despite their advantages, roundabouts are not entirely immune to disruptions. A notable concern arises from pedestrian flow, which has the potential to disrupt the smooth progression of vehicles, both on entry lanes where pedestrians cross and exit lanes where they await an opportunity to cross.

While roundabouts promote safety, their counterclockwise traffic flow in Marrakech introduces complexities, influencing and being influenced by traffic from various directions. This intricate flow dynamics often lead to low traffic speeds and increased conflicts, contributing to congestion and accidents during peak hours. To ensure overall safety and efficiency, it becomes crucial for traffic regulations to effectively address and manage potential conflicts between pedestrians and vehicles at roundabouts.

Numerous review papers have extensively examined the phenomenon of traffic congestion at unsignalized road intersections and roundabouts [1],[2] and [3] with different type of search, in a study [4] a simulation was conducted to examine how speed control on congested arms of roundabouts impacts the roundabout's overall performance. The results suggest that raising the speed above a specific threshold on these congested arms can enhance traffic flow and reduce travel time. The paper of [5], [6] presents two simulation studies that investigate how driving speed affects the performance of roundabouts with varying geometrical characteristics. The findings from these case studies highlight the significance of speed control and traffic distribution on the roundabout arms in shaping their performance. Additionally, the results emphasize the correlation between driving speed and the geometrical attributes of roundabouts. Roundabouts, notable for their heavy traffic flow, particularly during peak hours, tend to experience reduced levels of service (LOS). This results in extended travel time delays, heightened costs, and increased CO2 emissions [7] and [8]. Through simulation methods, different designs and configurations were evaluated for their efficiency at two roundabouts. The study identified that the primary congestion issue at roundabouts is attributed to the infrastructure and pedestrian behavior, which obstructs the traffic flow [9] and [10]. [11] This study analyzed the impact of such crossings on 4-lane and 6-lane urban roads. Data from 22 locations across five cities were used to develop a mathematical equation, revealing a 32% capacity reduction with high pedestrian cross-flow (1550pph). Recommendations for safe pedestrian facilities were made based on volume analysis. [6], [12], [13] This study examined pedestrian crossing behavior at midblock crosswalks in Istanbul, gathering data from four one-way streets with different lane configurations. Two-hour video recordings at each crosswalk revealed insights into pedestrian preferences, traffic volume, crosswalk usage, and pedestrian characteristics, including age, gender, and distractions.

[14] This study explored pedestrian preferences for road crossing facilities, highlighting factors such as safety, convenience, and accessibility. Results from a stated preference survey in English cities revealed that participants preferred signalized crossings over footbridges and underpasses. On average, participants were willing to walk an additional 2.4 to 5.3 minutes to avoid footbridges and underpasses, with gender and age influencing willingness.

[15] Current Road designs lack pedestrian facilities, leading to conflicts between pedestrians and vehicles. This study focuses on pedestrian behavior at urban intersections, particularly the impact of signal installations on their crossing habits. Data from an intersection in Mangalore city were collected to explore changes in pedestrian road crossing behavior under mixed traffic conditions.

This study focusing on the calculation of roundabout entry capacity, specifically examining roundabouts in Tokyo and its vicinity. As part of the project, the author's method developed for conditions in Poland underwent calibration to assess its applicability to Tokyo's roundabouts [16]

The paper explores modern roundabouts where circulating vehicles hold priority, and entrance vehicles enter when a time gap exceeds the critical gap. Utilizing gap acceptance theory and queuing theory, the study introduces headway distribution styles and a calculation model for free stream ratio. Entrance capacity models, categorized by vehicle types and critical gap types, are presented with minor differences in calculation values [17] However, the majority of the research papers focus on quantifying the capacity of roundabouts but fall short in pinpointing the underlying reasons for congestion within these traffic circles. While efforts are directed toward capacity analysis, there is a notable gap in addressing the specific factors contributing to traffic bottlenecks and slowdowns at roundabouts.

The study investigates the impact of midblock pedestrian crossing areas between closely spaced two-lane roundabouts on traffic operations, safety, and the environment. Using a microsimulation approach with VISSIM, vehicle-specific power, and a surrogate safety assessment model, the research explores the integrated effects on traffic delay, carbon dioxide emissions, and relative speed between vehicles and pedestrians. Through the application of the fast nondominated sorting genetic algorithm NSGA-II, the study identifies an optimized set of pedestrian crosswalk locations. A balanced solution, considering traffic performance, emissions, and pedestrian safety benefits, suggests optimal crosswalk placements at 15, 20, and 30 m from the roundabout exit section. The study emphasizes the importance of considering midblock segment crosswalks, particularly under high traffic demand, for effective capacity, environment, and safety outcomes [18].

Pedestrians typically have priority over cars at unsignalized intersections and roundabouts, significantly impacting roundabout capacity when they cross the road. The study focuses on the influence of pedestrian flow and crosswalk location on roundabout capacity, particularly on the exiting lane. The research aims to uncover how strategic crosswalk positioning can mitigate the impact of pedestrian interruptions on traffic flow, offering valuable insights for enhancing roundabout efficiency and level of service [19].

In a specific context [20], simulated data is employed to analyze the impact of pedestrians on roundabout capacity. By introducing fictitious pedestrian flows and strategically placing crosswalks, the study delves into how these factors influence the overall capacity and level of service of the roundabout. This approach enables a detailed exploration of the intricate relationship between pedestrian presence, crosswalk positioning, and the efficiency of traffic flow in the roundabout environment.

Nevertheless, it is crucial to acknowledge that depending on simulated or fictitious data, along with manual vehicle counting in the simulation, may pose limitations and impact the overall reliability of the study's outcomes, particularly in aspects such as accurately detecting the speed of each vehicle within the traffic flow.

This study aims to address a key contributor to congestion in roundabouts, namely, the proximity of pedestrian crossing areas. By leveraging simulation methods, the research focuses on evaluating the impact of pedestrian crossings on the capacity of roundabouts. The hypothesis posits that insufficient separation between roundabouts and pedestrian crossing zones contributes to congestion, as pedestrians are given precedence over vehicular traffic in unutilized areas. Through detailed simulations and analysis, the study aims to quantify the extent to which this factor influences roundabout capacity. The ultimate goal is to provide valuable insights for optimizing roundabout design and mitigating congestion by considering the dynamic interactions between vehicular and pedestrian flows in these critical traffic zones.

This research unfolds across distinct sections, each contributing to a comprehensive exploration of roundabout efficiency and safety. In the initial section, "Research objective," we establish the research objective, elucidating the need for a nuanced investigation into the influence of varying distances between crosswalks and roundabouts on traffic flow and pedestrian safety. Following this, the "Data Collection and Data Extraction" section delineates our meticulous methodology for procuring relevant datasets, outlining the sources and parameters essential for subsequent analyses.

Moving forward, the "Data Analysis" section constitutes a pivotal phase, employing rigorous statistical methods to unravel patterns and correlations within the collected data. This analytical foundation seamlessly transitions into the "Simulation Modelling using VISSIM" section, where we delve into the technical intricacies of our simulation model setup, configurations, and parameters, providing readers with a transparent understanding of our simulation approach.

The core of our exploration unfolds in the "Discussion" section, where we interpret and elaborate on the results derived from analyses and simulations. Each subsection within this segment addresses specific dimensions, including time-dependent variations and the impact of crosswalks, fostering a comprehensive comprehension of the findings.

As we approach the paper's conclusion in the final section, "Conclusion," we synthesize key insights, discuss their broader implications, and emphasize the significance of our contributions to the optimization of roundabout design. This section also outlines potential avenues for future research, providing a forward-looking perspective for further studies in the realm of urban transportation planning.

2. Research Objective

This study aims to thoroughly investigate how pedestrians impact roundabout capacity and congestion in Marrakech. Utilizing YOLO technology, the research will accurately count vehicles and monitor their speeds at local roundabouts, enabling a detailed analysis of traffic flow patterns during specific timeframes. Additionally, the study will extend its analysis to pedestrians, including quantifying pedestrian numbers and evaluating the time taken for their route traversal. After analyzing the field data, Vissim will be utilized for simulation purposes. The simulations will involve adjusting the distance between the roundabout and pedestrian crossings to identify the optimal spacing that reduces congestion. By meticulously examining both vehicular and pedestrian dynamics, this research seeks to offer valuable insights into optimizing roundabout design and pedestrian integration, thereby enhancing traffic management in urban areas like Marrakech.

Figure 1 illustrates the location of the roundabout under study, with the red point 'A' indicating a traffic signal halting traffic flow, while the green point 'B' signifies a green light allowing vehicles to enter the roundabout simultaneously. Meanwhile, the red light at point 'A' permits pedestrians to cross using the designated pedestrian crossing (depicted by the white rectangle in the figure). Pedestrians exercising their right of way can potentially disrupt vehicle flow at certain points, leading to congestion as vehicles stop.

The main goal of this study is to simulate this scenario by increasing the distance between pedestrian crossings and the roundabout. The objective is to determine the optimal distance that minimizes vehicle stops caused by pedestrian crossings, thereby reducing congestion in the roundabout.

Figure 1: the study's roundabout location

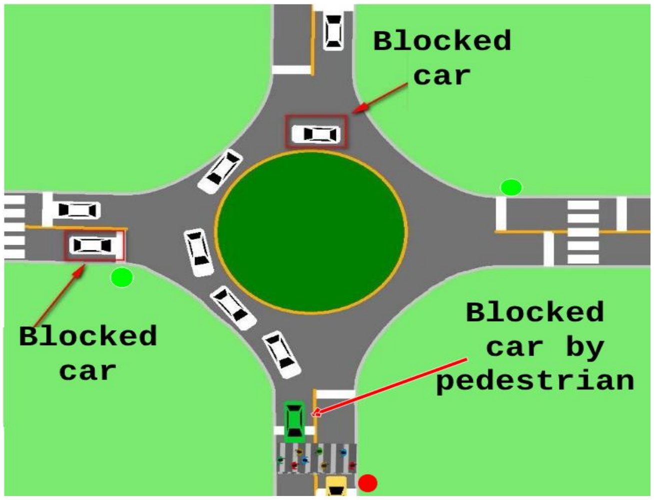

Figure 2: Pedestrians blocking vehicles

The capacity of a roundabout hinges on the flow of conflicts circulating into the central circle and the hindrance caused by pedestrians crossing those lanes. As depicted in Figure 2, the challenge of a blocked exit lane in a roundabout extends beyond the immediate capacity constraints of that lane alone; it significantly impacts the overall efficiency of the entire roundabout. When vehicles wait for pedestrians to cross roadways, obstructing the exit lane, it directly impedes the roundabout's capacity. This obstruction leads to decreased traffic flow within the central roundabout circle, as detailed in [22] and [19]. Consequently, the reduced capacity of the roundabout can trigger congestion, delays, and inefficient utilization of available capacity. Hence, addressing the issue of blocked exit lanes is crucial for mitigating these challenges. A strategic approach involves relocating crosswalks to a greater distance from the central island. Therefore, the primary objective of this study is to simulate and thoroughly examine the ramifications of increasing the distance between pedestrian crosswalks and the roundabout.

3. Data Collection and Data Extraction

The simulation utilizes data obtained from video sequences recorded at three distinct points within the same roundabout, utilizing three phones concurrently designated as A, B, and C, as illustrated in Figure 3. Point A captures video footage of the red zone, enabling the calculation of the number of vehicles entering the roundabout. Similarly, Point B records video content for the green zone, aiding in determining the number of vehicles entering the roundabout. Point C focuses on capturing video content for two areas: the blue zone to calculate the number of vehicles exiting the roundabout and the white zone, representing the pedestrian crossing. The data collected from the white zone includes the count of pedestrians and the time taken to traverse the route. The videos are specifically captured between “8:00 AM and 8:30 AM”, “9:30 AM and 10:00 AM”, and “1:30 PM and 2:00 PM”. The red zone specifically denotes a conflict point between pedestrians and vehicles.

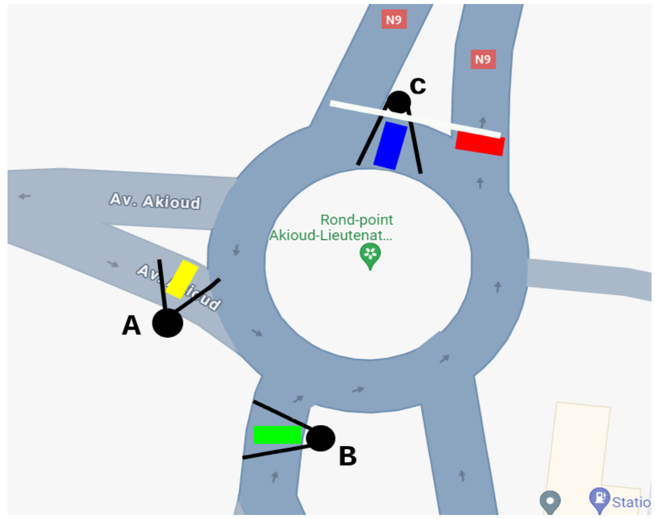

Figure 3: Video Capture Points and Zones in the Roundabout Study

4. Data Analysis

During the data analysis phase of our study, we carefully opted for the YOLO-v8 [23] (You Only Look Once) algorithm to delve into the intricacies of the video footage obtained from multiple vantage points around the roundabout. YOLO's prominence in real-time object detection made it a compelling choice for our dynamic traffic environment, ensuring swift and accurate identification of pedestrians and vehicles within each frame. The algorithm's unique approach involves dividing the image into a grid and simultaneously predicting bounding boxes and class probabilities, offering a rapid assessment that aligns seamlessly with our objective of capturing the nuanced movements in and around the roundabout.

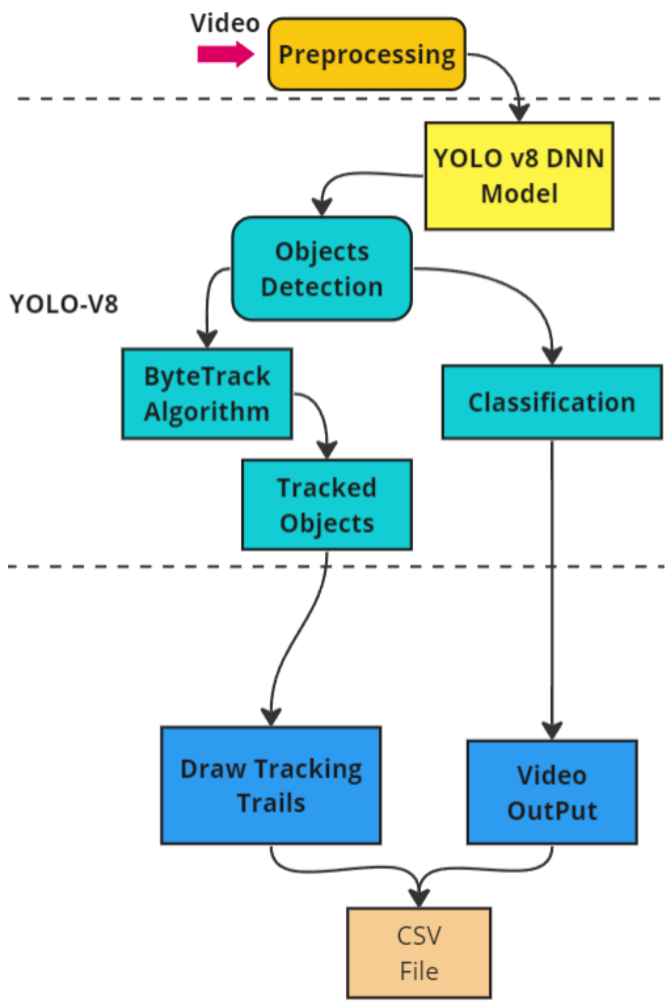

Figure 4: Counting System based on Deep

The efficiency of the YOLO algorithm becomes particularly advantageous when processing substantial amounts of video data, enabling us to maintain accuracy while ensuring timely analysis. The decision to employ YOLO underscores our commitment to using state-of-the-art technology tailored to the specific demands of our study. By leveraging YOLO's capabilities, we aim to gain a comprehensive understanding of the complex interplay between pedestrians and vehicles in the roundabout environment. This choice is rooted in our pursuit of robust, efficient, and technologically advanced methodologies [24], ensuring the success of our investigation into the impact of pedestrian-crossing distances on roundabout capacity.

Figure 4 presents the design of our advanced traffic monitoring system, utilizing cutting-edge deep learning methods, notably the state-of-the-art You Only Look Once version 8 (YOLOv8) algorithm. This sophisticated approach integrates features for vehicle detection, classification, and segmentation [25]. The system consists of four main stages:

Data Preprocessing: This initial stage involves refining and preparing the input data to enhance its suitability for subsequent analysis.

Detection Stage: Utilizing pretrained YOLOv8 deep neural network models, this stage is dedicated to accurately detecting and outlining vehicles within the monitored environment.

Vehicle Tracking Stage: Building upon the outcomes of the detection stage, this phase employs the ByteTrack algorithm for dynamically tracking moving vehicles. The tracking mechanism follows the identified bounding boxes, providing a comprehensive overview of vehicle movements.

Final Output Stage: Concluding the process, this stage generates a CSV file containing the detected and enumerated vehicles and pedestrians. The CSV file serves as a valuable output for further analyses and reporting purposes.

Table 1: COUNTING VEHICLES AND PEDESTRIAN AT STUDY LOCATION

Time	Zone	Traffic volume	Pedestrian
8 – 8:30	A	212	-
	B	236	-
	C	82	72
9:30-10	A	120	-
	B	202	-
	C	54	62
1:30-2	A	134	-
	B	212	-
	C	68	88
3-3:30	A	130	-
	B	210	-
	C	55	76

The presented table provides a comprehensive overview of traffic volume data extracted from three distinct zones labeled A, B, and C across various time intervals. This dataset encompasses both vehicular and pedestrian activity, offering insights into the dynamics of each zone during specific periods throughout the day.

From 8:00 AM to 8:30 AM, Zone A recorded a vehicle volume of 212 vehicles, Zone B registered 236 vehicles, and Zone C witnessed 82 vehicles. Moreover, Zone C experienced pedestrian traffic, with a volume of 72 pedestrians during this timeframe.

Transitioning to the 9:30 AM to 10:00 AM interval, Zone A exhibited a decrease in vehicle volume to 120 vehicles, while Zone B maintained a relatively stable volume at 202 vehicles. Zone C recorded 54 vehicles and observed a pedestrian volume of 62 pedestrians.

In the 1:30 PM to 2:00 PM timeframe, the data reveals a nuanced pattern. Zone A experienced a decline in vehicle volume to 134 vehicles, whereas Zone B showed an increase to 212 vehicles. During this period, Zone C recorded 68 vehicles and witnessed a rise in pedestrian traffic to 88 pedestrians.

The final time interval from 3:00 PM to 3:30 PM portrays a consistent trend with the preceding period. Zone A and Zone B maintained vehicle volumes of 130 and 210 vehicles, respectively. Zone C mirrored its earlier data, recording 78 vehicles and 76 pedestrians.

5. SIMULATION MODELLING

In devising our simulation parameters for the roundabout, we deliberately chose a pedestrian speed of 5 kilometers per hour, aligning it with typical walking speeds. This decision ensures a safe and controlled environment for pedestrians to comfortably navigate the area. For cars, we selected a speed limit of 40 kilometers per hour, striking a balance between efficient traffic flow and road safety within the roundabout. Additionally, we set the average car length at 4.5 meters to accommodate various vehicle sizes while optimizing road space. These parameters collectively aim to simulate a scenario prioritizing safety [6], [26], efficiency, and smooth interaction between pedestrians and motorists within the simulated roundabout environment.

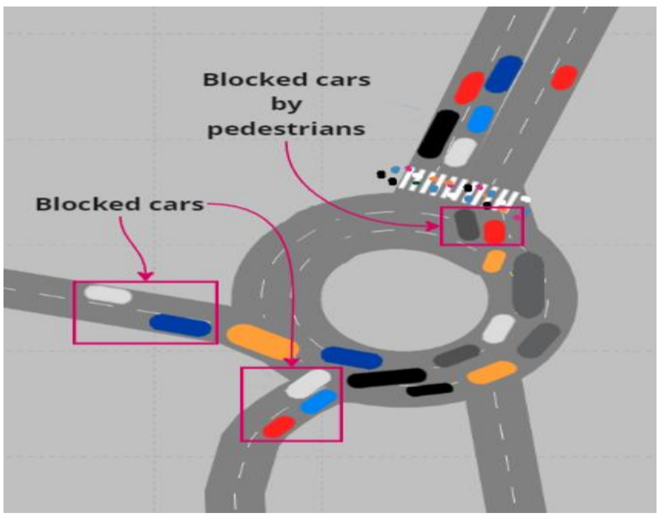

Figure 5: Vissim simulation.

Figure 5 visually portrays a VISSIM simulation illustrating a congested roundabout scenario. This visualization specifically depicts a situation where the roundabout experiences congestion, with vehicles encountering obstacles posed by pedestrians. The simulation visually depicts the challenges stemming from the interaction between cars and pedestrians within the roundabout. Notably, congestion arises as vehicles are hindered by pedestrians crossing roadways, showcasing the dynamic and complex nature of traffic flow in such scenarios. This figure serves as a visual aid to comprehend the simulated conditions, offering insights into potential congestion points and the intricate dynamics of vehicular movement and pedestrian interactions within the roundabout.

Table 2: COUNTING VEHICLES AND PEDESTRIAN AT STUDY LOCATION

Time / distance	8 – 8:30	9:30-10	1:30-2	3-3:30	With crossing
-	10.33s	9.73s	9.60s	9.51s	no
0 m	13.82s	13.13s	14.15s	12.91s	yes
10 m	13.54s	12.80s	13.80s	12.60s	yes
20 m	12.9s	12.45s	13.45s	12.25s	yes
30 m	12.15s	12.20s	13.10s	11.90s	yes
40 m	11.2s	11.50s	10.50s	10.80s	yes
50 m	10.33s	9.73s	9.70s	9.51s	yes
60 m	10.33s	9.73s	9.60s	9.51s	yes
70 m	10.33s	9.73s	9.60s	9.51s	yes
77 m	10.33s	9.73s	9.60s	9.51s	yes

The simulation results presented in Table II provide valuable insights into the dynamics of a roundabout, particularly regarding the interaction between vehicular traffic and pedestrians. The study focused on varying the distance between the crosswalk and the roundabout, aiming to understand its impact on the time required to clear the roundabout from vehicles.

Firstly, without the presence of a crosswalk (as indicated by "no" under the "With crossing" column), the simulation consistently demonstrates a decrease in the time needed to empty the roundabout as the distance increases across different time intervals. This trend suggests that, in the absence of a crosswalk, extending the distance positively influences the efficiency of vehicular traffic flow. The additional space offers vehicles more maneuvering room, potentially reducing congestion and enhancing the overall throughput of the roundabout.

In scenarios where a crosswalk is present, similar patterns emerge. With each simulation increasing the distance between the crosswalk and the roundabout by 10 meters, there is a consistent decrease in the time required to clear the roundabout. This indicates that increasing the distance correlates positively with improved traffic flow, even while accommodating pedestrians.

However, the presence of a crosswalk introduces an additional layer of complexity. While extending the distance continues to enhance traffic flow, there is a need for careful consideration of pedestrian safety. As the distance increases, the time required for pedestrians to cross the road likely also increases. Balancing the optimization of vehicular traffic flow with ensuring safe pedestrian crossings remains a crucial aspect of roundabout design.

Furthermore, the variations observed across different time intervals (8:00-8:30 AM, 9:30-10:00 AM, 1:30-2:00 PM, 3:00-3:30 PM) suggest that the impact of distance on roundabout clearing times may be influenced by specific traffic patterns and demand during different periods of the day.

6. CONCLUSION

In summary, our simulation outcomes illuminate the dynamic interaction between vehicular traffic and pedestrian safety within roundabout settings. Our investigation centered on altering the distance between the crosswalk and the roundabout, unveiling nuanced trends across distinct time periods.

Across our analyses conducted during morning and afternoon timeframes, we consistently noted a decrease in the time needed to clear the roundabout as the distance increased. This observation underscores the potential advantages of extending the spatial gap between the crosswalk and the roundabout, positively impacting vehicular traffic flow.

Significantly, our study unveiled that the optimal distance, where roundabout clearing time is minimized, varies with time. This temporal variability highlights the necessity for adaptable roundabout designs that accommodate the evolving traffic dynamics throughout the day. Recognizing and addressing the optimal distances for each time segment are crucial steps toward achieving a harmonious balance between efficient vehicular flow and pedestrian safety.

Furthermore, the presence of a crosswalk adds complexity, necessitating careful consideration to strike a delicate balance. While increased distance correlates with improved traffic flow, it's imperative to safeguard pedestrian safety. Achieving this equilibrium is pivotal for developing urban transportation systems that are both efficient and pedestrian-friendly.

In future research endeavors, integrating real-world data and considering additional factors such as specific traffic demand characteristics could yield a more comprehensive understanding of optimizing roundabout performance. As urban environments evolve, adaptive planning strategies that accommodate time-specific variations will be essential for constructing resilient and efficient transportation infrastructures.

In essence, our study contributes to the evolving discourse on roundabout design, emphasizing the significance of temporal considerations in achieving optimal traffic flow and pedestrian safety.

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