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Influence of Pedestrian Crossings on Speed Characteristics and Capacity of a Roundabout

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Abstract:- This study examines the impact of pedestrian crossings on roundabout speed characteristics and capacity, with a focus on optimizing traffic flow. Pedestrians traditionally have priority at unsignalized intersections and roundabouts, significantly influencing operational efficiency. The paper emphasizes the critical role of crosswalk placement in minimizing disruptions to vehicular flow and avoiding congestion.

Data for this research were collected from roundabouts in Marrakech, Morocco, utilizing mobile phones to measure vehicle and pedestrian numbers, along with passage times. Complementing field data, Vissim simulations were employed for enhanced accuracy. Our study specifically analyzes the influence of pedestrians on roundabout exit lane capacity.

The key objective is to determine the optimal distance between roundabouts and crosswalks to maximize capacity. Findings offer valuable insights for urban planning and traffic management, addressing the dynamic interplay between pedestrian flow, crosswalk positioning, and overall roundabout efficiency.

***Keywords**: 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] 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.

[13] 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.

In [14] 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 [15]

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 [16] 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 [17].

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 [18].

In a specific context [19], 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 comprehensively examine the impact of pedestrians on roundabout capacity and congestion in Marrakech. Through data collection from local roundabouts, YOLO technology will be employed to precisely count vehicles and track their speeds, enabling an in-depth analysis of traffic flow patterns during specific hours. The study will extend this investigation to pedestrians, encompassing the calculation of pedestrian numbers and assessing the time taken for their route traversal.

Following the field data analysis, Vissim will be employed for simulation purposes. The simulation will involve manipulating the distance between the roundabout and pedestrian crossings, seeking to determine the optimal spacing that minimizes congestion. By meticulously studying both vehicular and pedestrian dynamics, this research aims to provide valuable insights into optimizing roundabout design and pedestrian integration, contributing to more efficient traffic management in urban areas like Marrakech.

Fig 1 illustrates the study's roundabout location, the red point 'A' indicates a traffic signal stopping the flow, while the green point 'B' signifies a green light, allowing vehicles from this route to enter the roundabout concurrently. Simultaneously, the red light at point 'A' permits pedestrians to cross using the marked pedestrian crossing (depicted by the white rectangle in the Fig 1). Pedestrians wielding authority can potentially disrupt vehicle flow at certain points, causing congestion as vehicles come to a halt.

The primary objective of this study is to simulate this scenario by increasing the distance between pedestrian crossings and the roundabout. The aim is to identify the optimal distance that minimizes vehicle stops caused by pedestrian crossings, ultimately alleviating congestion in the roundabout.

Fig 1: the study's roundabout location

The capacity of a roundabout is intricately linked to the flow of conflicts circulating into the central circle and the impedance caused by pedestrians crossing those lanes [20], as depicted in Fig 2, the challenge posed by a blocked exit lane in a roundabout extends beyond the immediate capacity constraints of that specific lane; it significantly impacts the overall efficiency of the entire roundabout. The obstruction of vehicles in the exit lane, often caused by vehicles waiting for pedestrians to cross roadways, directly impedes the roundabout's capacity. This blockage leads to a reduction in traffic flow within the central roundabout circle, as outlined in [21] and [18], Consequently, the diminished capacity of the roundabout can result in congestion, delays, and the inefficient utilization of available capacity. Addressing the issue of blocked exit lanes becomes crucial for mitigating these challenges. A strategic approach involves repositioning crosswalks at a greater distance from the central island. Therefore, the primary objective of this study is to simulate and scrutinize the consequences of expanding the distance between pedestrian crosswalks and the roundabout.

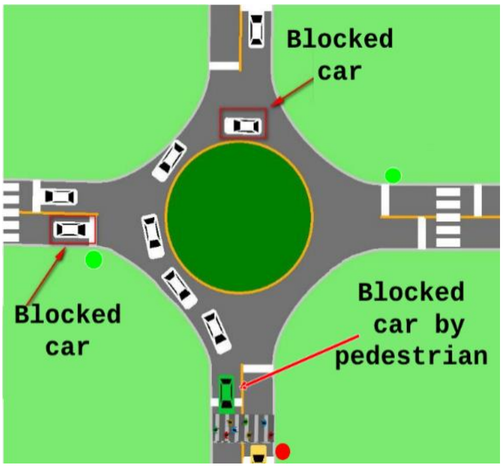

Fig 2: Pedestrians blocking vehicles

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3. Data Collection and Data Extraction

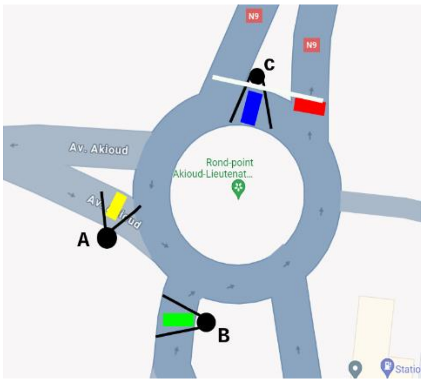

Fig 3: Video Capture Points and Zones in the Roundabout Study

The simulation utilizes data derived from video sequences captured at three distinct points within the same roundabout, employing three phones concurrently designated as A, B, and C, as depicted in Fig 3. Point A captures video footage of the red zone, facilitating 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 time of capturing these videos is specifically 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 signifies a conflict point between pedestrians and vehicles.

4. Data Analysis

In undertaking the data analysis phase of our study, we carefully considered the selection of the YOLO-v8 [22] (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.

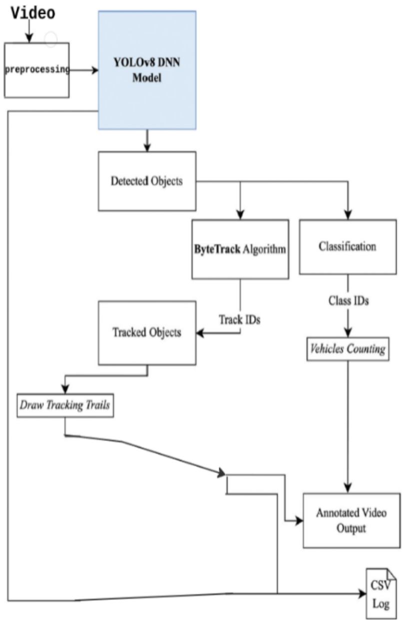

Fig 4: Counting System based on Deep

The YOLO algorithm's efficiency becomes particularly advantageous when processing substantial amounts of video data, allowing us to maintain accuracy while ensuring a timely analysis. The decision to employ YOLO underscores our commitment to employing 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 [23], ensuring the success of our investigation into the impact of pedestrian-crossing distances on roundabout capacity.

Fig 4 illustrates the architecture of our cutting-edge traffic monitoring system, leveraging advanced deep learning techniques, specifically the state-of-the-art You Only Look Once version 8 (YOLOv8) algorithm. This sophisticated approach incorporates functionalities for vehicle detection, classification, and segmentation [24]. The system comprises four key stages:

A. Preprocessing

The initial stage involves preparing and refining the input data to optimize it for subsequent analysis.

B. Detection Stage

Deploying pretrained YOLOv8 deep neural network models, this stage focuses on accurately detecting and delineating vehicles within the monitored environment.

C. Vehicle Tracking Stage

Building on the results from the detection stage, this phase employs the ByteTrack algorithm for dynamic tracking of moving vehicles. The tracking process follows the detected bounding boxes, providing a comprehensive understanding of vehicle movements.

D. Final Output Stage

This stage concludes the process by generating a CSV file that encapsulates the detected and counted vehicles and pedestrians. The CSV file serves as a valuable output for subsequent analyses and reporting.

Table I 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 provided table I encapsulates a detailed snapshot of traffic volume data extracted from three distinct zones labeled A, B, and C across multiple time intervals. This dataset captures both vehicular and pedestrian activity, offering insights into the dynamics of each zone during specific periods throughout the day.

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

Moving on 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 had 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, while Zone B showed an increase to 212 vehicles. Zone C, during this period, recorded 68 vehicles and saw 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 previous period. Zone A and Zone B maintained vehicle volumes of 130 and 210 vehicles, respectively. Zone C mirrored its earlier data with 78 vehicles and 76 pedestrians.

5. Simulation modelling

In designing our simulation parameters for the roundabout, we deliberately opted for a pedestrian speed of 5 kilometers per hour, aligning with typical walking speeds. This choice ensures a safe and controlled environment for pedestrians to navigate the area comfortably. For cars, a speed limit of 40 kilometers per hour was selected, 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 diverse vehicle sizes while optimizing road space. These parameters collectively aim to simulate a scenario that prioritizes safety[6], [25], efficiency, and smooth interaction between pedestrians and motorists within the simulated roundabout environment.

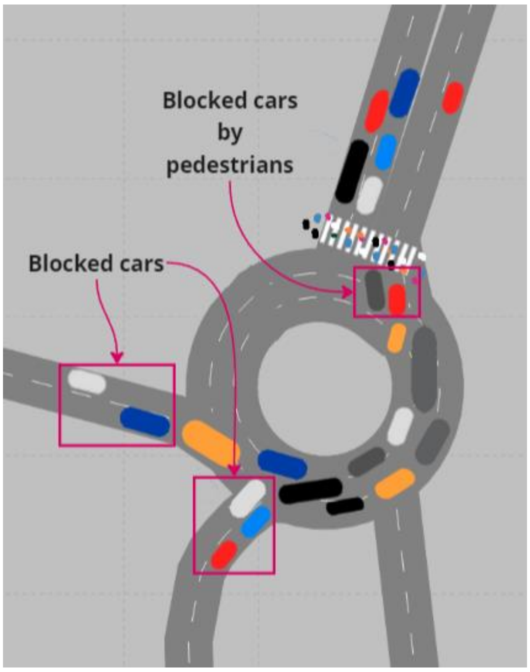

Fig 5: Vissim simulation.

Fig 5 visually demonstrates a VISSIM simulation depicting a roundabout scenario. This illustration specifically captures a situation where the roundabout is congested, with vehicles impeded by pedestrians. The simulation visually represents the challenges arising from the interaction between cars and pedestrians within the roundabout. Notably, the congestion occurs as vehicles are obstructed 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, providing insights into the potential congestion points and the intricate dynamics of vehicular movement and pedestrian interactions within the roundabout.

6. Discussion

The simulation results presented in Table II offer valuable insights into the dynamics of a roundabout, particularly concerning 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.

Table III RESULTS from simulation in VISSIM

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

Firstly, without the presence of a crosswalk (as indicated by "no" under the "With crossing" column), the simulation results at different time intervals consistently show a decrease in the time needed to empty the roundabout as the distance increases. This trend implies that, in the absence of a crosswalk, extending the distance between the crosswalk and the roundabout positively influences the efficiency of vehicular traffic flow. The additional space provides vehicles with more room to maneuver, potentially reducing congestion and improving the overall throughput of the roundabout.

In scenarios where a crosswalk is present, the results indicate a similar pattern. As the distance between the crosswalk and the roundabout increases by 10 meters in each simulation, there is a consistent decrease in the time required to clear the roundabout. This suggests that increasing the distance positively correlates with enhanced traffic flow, even in the context of accommodating pedestrians.

It's noteworthy that the presence of a crosswalk introduces an additional layer of complexity. The simulation results imply that while extending the distance continues to improve 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 also likely increases. Striking a balance between optimizing vehicular traffic flow and ensuring safe pedestrian crossings remains a crucial aspect of roundabout design.

Moreover, the variations observed across different time intervals (8 – 8:30, 9:30-10, 1:30-2, 3-3:30) 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.

7. Conclusion

In conclusion, our simulation results shed light on the dynamic interplay between vehicular traffic and pedestrian safety within a roundabout context. The investigation focused on varying the distance between the crosswalk and the roundabout, revealing nuanced patterns across distinct time intervals.

Throughout our analyses spanning morning and afternoon periods, we consistently observed a decrease in the time required to clear the roundabout as the distance increased. This finding underscores the potential benefits of extending the spatial separation between the crosswalk and the roundabout, positively influencing vehicular traffic flow.

Importantly, our study revealed that the optimal distance, where roundabout clearing time is minimized, is time-dependent. This time-specific variability emphasizes the need for adaptive roundabout designs that consider the evolving dynamics of traffic patterns throughout the day. Recognizing and addressing optimal distances for each time interval are critical steps toward achieving a harmonious balance between efficient vehicular flow and pedestrian safety.

Moreover, the presence of a crosswalk introduces an additional layer of complexity, urging careful consideration in achieving a delicate equilibrium. While increased distance positively correlates with enhanced traffic flow, it is essential to ensure that pedestrian safety is not compromised. Striking this balance is pivotal for creating urban transportation systems that are both efficient and pedestrian-friendly.

In future research endeavors, incorporating real-world data and considering additional factors such as specific traffic demand characteristics could provide a more comprehensive understanding of the intricacies involved in optimizing roundabout performance. As urban landscapes evolve, adaptive planning strategies that account for time-specific variations will play a crucial role in developing resilient and efficient transportation infrastructures.

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

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