Examining the Impact of Motorcycles on Start-Up Time and Headway Distribution Features at Signalized Intersections in Smart Cities

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Abstract. This study introduces the concept of smart cities to investigate the impact of motorcycle movements on start-up lost time at urban intersections. Employing a comprehensive methodology that combines data collection through camera phone technology with YoloV8 analysis, we analyse various traffic cycles to uncover a significant correlation between the predominant direction of motorcycle travel and start-up lost time dynamics. Our findings reveal that cycles with a majority of motorcycles turning right experience notably lower start-up lost times, suggesting a smoother integration of right-turning motorcycles into traffic flow. These insights underscore the importance of tailored intersection management strategies that account for direction-al preferences within mixed-vehicle flows. Optimizing traffic signal phasing to leverage the efficiency of right-turning motorcycles presents an opportunity to enhance intersection performance and overall traffic flow in urban environments. This study contributes valuable insights for the development of targeted traffic management policies aimed at alleviating congestion and improving mobility in smart cities.

1 Introduction

This Introducing the concept of smart cities, urban intersections play a pivotal role as crucial nodes in transportation networks, enabling the smooth movement of vehicles and pedestrians. Nonetheless, they often face challenges such as congestion, resulting in delays, heightened emissions, and decreased overall mobility. It's imperative to grasp the factors underlying intersection congestion to devise effective traffic management strategies and enhance urban mobility.

One significant factor affecting intersection congestion is the presence and movements of motorcycles. Despite their smaller size compared to other vehicles, motorcycles can have a substantial impact on traffic flow dynamics, particularly during peak hours. However, the specific influence of motorcycles on intersection performance, particularly regarding start-up lost time [1], remains poorly understood.

Start-up lost time, defined as the delay experienced by vehicles when initiating movement after a red signal change to green, is a critical metric for intersection efficiency. It is influenced by various factors, including vehicle type, driver behavior, and the presence of vulnerable road users such as motorcycles [2].

In this context, this study aims to investigate the relationship between motorcycle movements and start-up lost time at urban intersections. By leveraging advanced data collection techniques and state-of-the-art analysis methods, we seek to unravel the nuanced dynamics underlying motorcycle influence on intersection congestion. Through our research, we aim to provide valuable insights that can inform the development of targeted traffic management strategies aimed at reducing congestion, enhancing mobility, and improving overall intersection performance in urban environments.

The paper comprises an introduction section providing an overview of urban intersections, the significance of motorcycle movements, and the concept of start-up lost time, followed by a literature review discussing existing studies on intersection congestion and the influence of motorcycles on traffic flow. The methodology section outlines the data collection process using camera phone technology and the implementation of YoloV8 analysis. Subsequently, the results and discussion section present findings on the relationship between motorcycle movements and start-up lost time, followed by a conclusion summarizing key findings and discussing implications for intersection management and future research directions.

2 literature review

Given the increasing complexities of traffic dynamics, especially with the prevalent presence of motorcycles, urban intersections have emerged as focal

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points for extensive research. This collection of studies, conducted across diverse regions including India, Sri Lanka, Thailand, Turkey, and Indonesia, seeks to explore the intricate interplay between various traffic elements and their repercussions on intersection performance, safety, and environmental aspects [3]. Covering a spectrum of topics ranging from analyzing start-up lost time and saturation flow rates to delineating queuing behaviors and understanding the influence of motorcycles [4], these studies collectively enrich our comprehension of the multifaceted dynamics prevalent at signalized intersections and roundabouts [5].

The research landscape surrounding traffic dynamics at intersections encompasses a wide array of investigations. For instance, inquiries into start-up lost time, as evidenced in studies conducted in Sri Lanka [6] and Thailand [7], shed light on the significant delays observed during signal phase transitions. Similarly, endeavors aimed at improving motorcyclist safety at unsignalized intersections, as demonstrated in research conducted in Vietnam [8], underscore the critical importance of recognizing and mitigating hazardous riding behaviors [9].

The analysis of motorcycles' impact on saturation flow rates, as exemplified by studies conducted in Bali [10] and Denpasar [11], offers valuable insights into the intricate relationship between motorcycle behaviors and overall intersection efficiency. These findings are contextualized within broader studies on intersection capacity, such as examinations of saturation flow rate in Turkey [1] and the integration of loss time criteria in the design of signalized intersections in Sri Lanka.

Furthermore, studies exploring motorcycle queuing behaviors at signalized intersections [12] and the characteristics of mixed traffic at roundabouts in Vietnam [13] lay essential groundwork for comprehending the diverse elements influencing traffic dynamics. This compilation of related works serves as a comprehensive foundation for our study, which specifically investigates the influence of motorcycle behavior on saturation flow rates at signalized intersections in Denpasar, Bali [14].

However, it is imperative to critically evaluate the methodology utilized in this study. The dependency on sensors for motorcycle detection raises concerns regarding the accuracy and representativeness of the collected data. Sensor-based detection systems may be prone to limitations, including misclassifications and sensitivity to environmental conditions, which could potentially compromise the reliability of the findings. Additionally, the use of simulated data adds another layer of scrutiny. While simulated or synthetic data offer a controlled environment for analysis, they may not fully capture the complexity and variability of real-world scenarios. Therefore, it is crucial to question the extent to which these simulated conditions reflect the intricacies of actual traffic behavior.

Furthermore, the exclusive focus on motorcycles in analyzing start-up lost time, while providing valuable insights into their impact, may overlook broader interactions and dynamics involving other vehicles. A more comprehensive examination, inclusive of various vehicle types and driving behaviors, could provide a more holistic understanding of the factors influencing start-up lost time at signalized intersections. These methodological considerations necessitate a nuanced evaluation of the study's findings and their applicability to real-world traffic scenarios.

3 Methodology

In this study, we introduce a novel methodology for analyzing vehicle start-up time headway at signalized intersections, utilizing easily accessible technology and advanced object detection systems. Data collection was conducted using smartphone cameras positioned to capture traffic flow at various urban intersections. These devices are advantageous due to their widespread availability and high-resolution video capabilities. The video data were then processed using YOLOv8 [15], the latest iteration of the You Only Look Once (YOLO) real-time object detection system. This model is renowned for its enhanced accuracy in detecting objects in diverse and challenging environments. By applying YOLOv8, we could accurately identify and track individual vehicles' movements, enabling precise measurement of start-up time headways.

3.1 Data collection

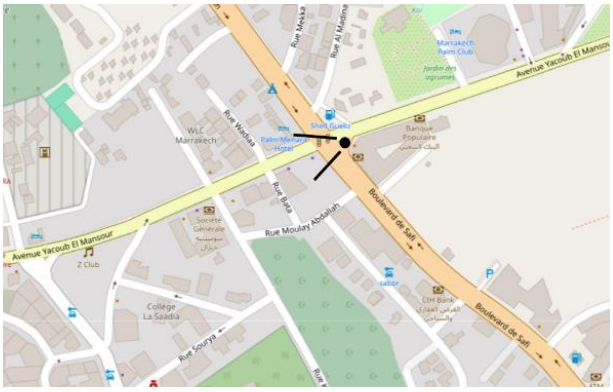

Fig. 1. Map Indicating Camera Placement for Traffic Study at Intersection

The map you've provided shows the intersection where the study is conducted. The black point indicates the camera's position, which is strategically placed to capture a comprehensive view of the traffic flow at the intersection. This vantage point is crucial as it allows for an unobstructed recording of vehicle movements, which is necessary for accurate time headway analysis using the YOLOv8 object detection system. When setting up the camera, it's essential to ensure that the full area of interest is within the frame and that the camera is stable and secure to avoid any data corruption due to movement or shaking as show in figure 1.

3.2 Data analysis

In our study, we meticulously analysis traffic patterns at signalized intersections by examining video recordings captured during peak urban traffic periods. The video data, which serve as the backbone of our analysis, were recorded in two distinct time slots: from 10:00 AM to 12:00 PM and from 4:00 PM to 6:00 PM. These intervals were strategically chosen to encapsulate the variations in traffic flow during midday and late afternoon times when vehicle and motorcycle activity significantly intensifies due to the transition from morning activities to midday errands, and from the end of the conventional workday to the evening commute.

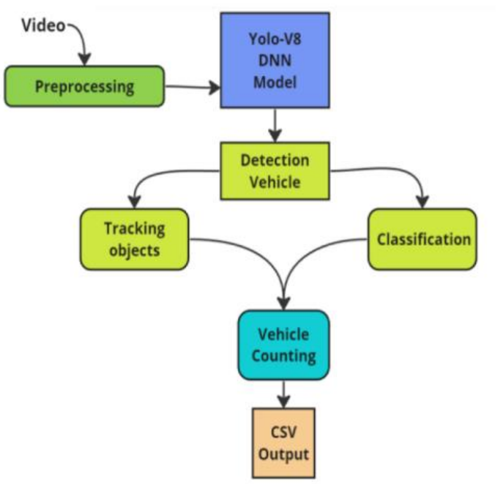

Fig. 2. Workflow Diagram for Video-Based Vehicle Detection and Tracking with Directional Analysis.

The comprehensive video data allowed us to delve into the intricacies of start-up time headway, where we carefully observed and recorded the time intervals between vehicles as they initiated movement after a complete stop at traffic signals. Special attention was paid to the presence of motorcycles within the traffic flow, acknowledging their unique maneuverability and the potential impact they could have on the start-up time of other vehicles.

Our approach for vehicle detection and analysis employs an advanced deep learning workflow that integrates video preprocessing, object detection using YOLOv8, and Deep SORT for tracking and directional analysis. Initially, raw video data are preprocessed to optimize for quality and frame rate, ensuring compatibility with the detection model. The YOLOv8 deep neural network (DNN) model, renowned for its speed and accuracy, then processes the enhanced footage to detect vehicles within the traffic scene. Each identified vehicle is subsequently tracked across frames using Deep SORT, an algorithm specialized for maintaining consistent identification, even though occlusions or varied lighting conditions. Moreover [16,17], Deep SORT contributes to the assessment of movement patterns by classifying vehicle trajectories based on directionality distinguishing between those turning left, right, or continuing straight. The culmination of this process is the accurate counting and classification of vehicles, with the results compiled into a CSV file. This structured data output enables detailed traffic flow analysis and informs potential traffic management strategies.

Table 1. start-up time headway and standard deviation by traffic flow direction and intersection entrance

Traffic Flow Direction	Cycles	Mean Value (s)	Standard Deviation (s)	Motorcycle Presence
Straight	c1	2.59	1.12	5
Left turn	c1	2.81	1.11	5
Right turn	c1	2.61	1.9	5
Straight	c2	2.78	0.96	2
Left turn	c2	2.58	1.01	2
Right turn	c2	2.85	0.99	2
Straight	c3	2.63	1.16	6
Left turn	c3	2.79	1.15	6

The table 1 presents an example data on the start-up time headway for different traffic flow directions straight, left turn, and right turn—across three cycles, denoted as c1, c2, and c3. The mean value column specifies the average start-up time headway in seconds for vehicles in each traffic flow direction and cycle. The standard deviation column provides a measure of the variability or dispersion of the start-up time headways around the mean value, again in seconds. The motorcycle presence column indicates the count of motorcycles observed during each traffic flow direction and cycle, which could potentially affect the traffic flow and start-up time headway.

Key observations from the table could include:
For cycle c1, all traffic flow directions have a motorcycle count of 5, which may suggest a consistent motorcycle traffic pattern during this period.
The mean start-up time headway varies across different directions and cycles, with the smallest mean time (2.58s) observed for left-turn traffic in cycle c2 and the highest (2.85s) for right-turn traffic in the same cycle.
The standard deviation is notably higher for right turns in cycle c1 (1.9s), which may indicate more variability in the start-up time headway for that direction and cycle.
A higher number of motorcycles (6) were observed in straight and left-turn directions during cycle c3, which might be linked to the increased mean start-up time headway for those directions in this cycle.

4 Results and Discussion

In the Results and Discussion section of our study, we delve into the empirical findings gleaned from our comprehensive analysis of traffic patterns at signalized intersections. The data, meticulously recorded during peak hours, have been statistically processed to uncover the nuanced interactions between various types of vehicles, with a particular focus on the role of motorcycles within the flow. We present a detailed examination of the start-up time headway across multiple traffic directions and cycles, offering a clear depiction of how these intervals fluctuate during the busiest segments of the day.

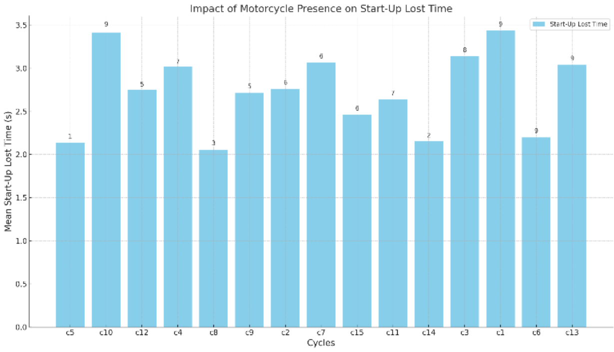

Fig. 3. Impact of Motorcycle Presence on Start-Up Lost Time Across Traffic Cycles.

Figure 3 illustrates the relationship between the presence of motorcycles and the mean start-up lost time across various traffic cycles, labeled c1 through c15. The vertical bars represent the mean start-up lost time in seconds, with the height of each bar corresponding to the duration of delay. Superimposed numbers on the bars indicate the count of motorcycles present during each cycle. The chart visually suggests a pattern where an increase in the number of motorcycles correlates with an increase in start-up lost time, highlighting the impact that motorcycles can have on traffic flow efficiency at signalized intersections.

Table 2. headway analysis of start-up lost time in traffic cycles by vehicle manoeuvre and motorcycle count

Cycles	Direction > 50%	Number of Motorcycles	Start-Up Lost Time (s)
C1	Straight	4	1.2
C2	Straight	6	1.22
C3	Left turn	5	1.25
C4	Left turn	7	1.3
C5	Right turn	10	1.1
C6	Right turn	9	1.08
C7	Straight	5	1.23
C8	Left turn	8	1.27
C9	Right turn	11	1.05
C10	Right turn	12	1.02
C11	Straight	3	1.19
C12	Left turn	6	1.28
C13	Right turn	10	1.11
C14	Right turn	9	1.06
C15	Straight	7	1.21

The table 2 displays a correlation between the predominant direction taken by motorcycles straight, left turn, or right turn and the associated start-up lost time at an intersection. It reveals a trend where cycles with more than 50% right-turning motorcycles generally result in lower start-up lost times, while cycles with a majority of straight-going or left-turning motorcycles show increased start-up lost times.

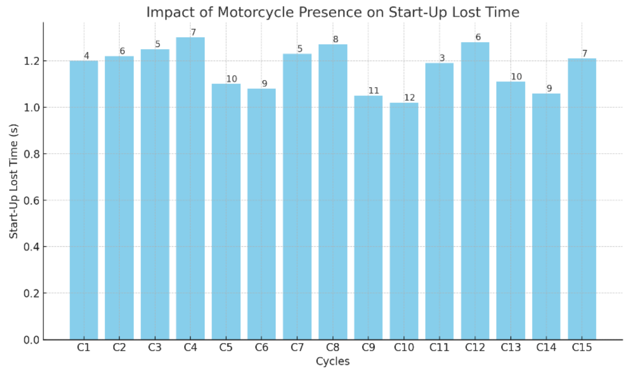

Fig. 4. Variations in Start-Up Lost Time Across Traffic Cycles With Motorcycle Count.

Figure 4 presents a nuanced view of motorcycle influence on traffic dynamics, specifically examining start-up lost time across fifteen traffic cycles. Notably, cycles such as C5 and C10, which have a high count of motorcycles, exhibit a relatively lower start-up lost time. This pattern aligns with the data indicating that a majority of these motorcycles are turning right. The implication is clear: when motorcycles predominantly turn right, their impact on start-up lost time is minimal, suggesting that right-turning motorcycles integrate more seamlessly into the flow and cause less disruption at intersections. This observation could have significant implications for the design of traffic signal phases and the management of mixed-vehicle flows at urban intersections.

5 Conclusion

In conclusion, our study employed a robust methodology combining camera phone data collection and YoloV8 analysis to investigate the relationship between motorcycle movements and start-up lost time at urban intersections. Through meticulous examination of various traffic cycles, we have unearthed a pivotal finding: the predominant direction of motorcycle travel significantly influences start-up lost time dynamics. Notably, cycles with a substantial number of motorcycles, particularly those predominantly turning right, exhibit a notably lower start-up lost time. This key insight underscores the importance of nuanced intersection management strategies that consider the directional preferences within mixed-vehicle flows. By optimizing traffic signal phasing to capitalize on the smooth integration of right-turning motorcycles, urban planners and traffic engineers can unlock substantial enhancements in intersection efficiency and overall traffic flow. These findings provide valuable insights for the development of targeted traffic management policies aimed at mitigating congestion and improving mobility in urban areas.

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