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Review on Pedestrian Safety Assessment at Signalized Intersections and Development of Improved Crossing Facilities

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ABSTRACT

Pedestrian safety at signalized intersections is a critical concern due to conflicts between pedestrians and vehicular traffic, inadequate crossing facilities, poor signal timing, and increasing traffic volumes. This review examines existing methods and approaches for assessing pedestrian safety at signalized intersections, with particular emphasis on pedestrian–vehicle conflicts, crossing behavior, traffic characteristics, geometric conditions, signal operations, and pedestrian facilities. Various safety assessment techniques, including observational studies, conflict analysis, risk-based evaluation, and quantitative safety indicators, are reviewed to identify their effectiveness and limitations. The study further evaluates existing pedestrian crossing facilities and identifies factors contributing to unsafe crossing conditions. Based on the reviewed literature, the paper highlights the need for improved pedestrian-oriented design, optimized signal timing, adequate crossing widths, refuge facilities, visibility, accessibility, and appropriate traffic-control measures. The review provides a framework for developing improved pedestrian crossing facilities and supports the planning and design of safer and more efficient signalized intersections.

Keywords: Pedestrian Safety, Signalized Intersections, Pedestrian–Vehicle Conflicts, Crossing Facilities, Safety Assessment, Signal Timing, Pedestrian Behavior, Road Safety.

I. INTRODUCTION

Rapid urbanization, increasing motorization, and continuous growth in traffic volume are major factors influencing the safety and efficiency of urban transportation systems. The rapid expansion of cities has resulted in increased population concentration, economic activities, employment opportunities, educational institutions, and commercial development within urban areas [1]. As cities expand spatially, the demand for daily travel between residential, commercial, educational, and employment areas also increases. This growth places considerable pressure on existing road infrastructure and transportation facilities. In many developing countries, particularly India, urban transportation systems are experiencing substantial changes due to increasing population, changing travel patterns, and rapid development of urban areas [2].

Urbanization has a direct influence on pedestrian movement because pedestrians constitute an important component of urban mobility, particularly for short-distance trips and access to public transport. The expansion of urban areas often increases the number of locations where pedestrians need to cross busy roads [3]. Major activity centers such as markets, schools, colleges, hospitals, railway stations, bus terminals, and commercial areas generate substantial pedestrian movements. However, the development of pedestrian infrastructure does not

always occur at the same rate as urban growth. Consequently, pedestrians may be required to cross wide and heavily trafficked roads using facilities that are inadequate in terms of capacity, accessibility, visibility, and safety [4].



Fig.1.1 Pedestrian safety

At the same time, motorization has increased substantially with urban economic development. The growing ownership and use of two-wheelers, passenger cars, buses, commercial vehicles, and other motorized modes have increased the interaction between motor vehicles and vulnerable road users. In many urban areas, two-wheelers constitute a significant proportion of traffic, while private cars and commercial vehicles occupy considerable road space. The resulting increase in motorized traffic can create greater exposure for pedestrians, particularly at intersections where vehicles perform turning movements and pedestrians cross traffic streams [5].

II. PROBLEMS WITH EXISTING CROSSING FACILITIES

Existing pedestrian crossing facilities at signalized intersections often face several limitations that reduce their effectiveness and safety. Common problems include inadequate crossing width, insufficient pedestrian signal time, long waiting periods, poor visibility, faded road markings, inadequate lighting, and improper placement of crossings. High pedestrian demand, turning vehicles, signal violations, and pedestrian non-compliance can further increase the risk of conflicts. Facilities such as refuge islands, footbridges, and underpasses may also be underutilized when they are inconvenient, poorly maintained, or lack accessibility. These deficiencies indicate the need for systematic evaluation of existing crossing facilities based on pedestrian behavior, traffic conditions, safety conflicts, accessibility, and operational performance to develop improved and safer crossing solutions [6].

III. RESEARCH PROBLEM

Despite the availability of signalized intersections and pedestrian crossing facilities, pedestrian safety remains a major concern due to frequent interactions between pedestrians and vehicles. Existing crossing facilities are often designed primarily from an operational perspective and may not adequately consider pedestrian behavior, vehicle turning

movements, crossing time, traffic volume, speed, and actual pedestrian–vehicle conflicts [7]. Conventional safety evaluation methods largely depend on historical crash data, which may not fully represent the current level of risk because pedestrian crashes are relatively infrequent and may be underreported. Furthermore, inadequate signal timing, long pedestrian waiting times, poor visibility, insufficient crossing width, and improper facility placement can encourage unsafe crossing behavior. Therefore, there is a need for a systematic and comprehensive assessment of pedestrian safety at signalized intersections using behavioral, operational, geometric, and conflict-based indicators. The research problem is to identify the critical factors contributing to pedestrian safety risks and develop improved crossing facilities that can reduce pedestrian–vehicle conflicts while providing safe, efficient, and accessible pedestrian movement [8].

IV. REVIEW OF LITERATURE

1. Mukherjee and Mitra (2019)

Mukherjee and Mitra [1] investigated pedestrian behavior and safety perceptions at safe and unsafe signalized intersections in Kolkata, India. The study compared 24 signalized intersections, including locations with and without recorded fatal pedestrian crashes, using video-based observations and pedestrian perception surveys. The researchers examined signal violation, pedestrian–vehicle interaction, waiting time, crossing conditions, and demographic characteristics as potential safety factors. The findings indicated that signal violations and dissatisfaction among pedestrians were significantly higher at intersections associated with fatal crashes. Longer waiting times, greater pedestrian–vehicle interaction, crossing conditions, and individual pedestrian characteristics were identified as important predictors of unsafe behavior. The study highlighted the importance of behavioral and environmental factors in proactively identifying unsafe signalized intersections.

2. Mukherjee and Mitra (2020)

Mukherjee and Mitra [2] conducted a comprehensive investigation of factors influencing pedestrian signal violation behavior at signalized intersections in Kolkata, India. Data were collected from 55 signalized intersections to examine the relationship between pedestrian violations and fatal pedestrian crashes. The study considered pavement markings, cycle length, sight distance, on-street parking, pedestrian characteristics, crossing conditions, and satisfaction levels. The results demonstrated a strong relationship between pedestrian signal violations and fatal pedestrian crashes. Longer signal cycles, inadequate sight distance, pavement marking conditions, and pedestrian dissatisfaction were found to influence violation behavior. The study emphasized that pedestrian signal compliance can be an important indicator for proactive pedestrian safety assessment.

3. Marisamynathan and Vedagiri (2020)

Marisamynathan and Vedagiri [3] developed a pedestrian safety evaluation methodology for signalized intersections using surrogate safety measures. The study focused particularly on Post-Encroachment Time (PET) to evaluate pedestrian–vehicle interactions and conflict severity. A cumulative logistic regression model was developed to predict mean PET values

at pedestrian crossings, and the model was validated using data from signalized intersections in Kolkata, India.

4. Raoniar and Maurya (2022)

Raoniar and Maurya [4] examined pedestrian crossing behavior at signalized intersection crosswalks, with particular emphasis on walking speed, safety margin, signal violation, and pedestrian distraction. The researchers observed 2,360 pedestrian crossings at three signalized intersections in Kolkata, India, and applied statistical and logistic regression techniques. The findings indicated that pedestrian age, distraction, vehicle size, and signal timing significantly influenced crossing behavior.

5. Raoniar et al. (2022)

Raoniar and colleagues [5] investigated pedestrian signal violation and associated pedestrian–vehicle conflicts at signalized intersections in India. The study examined pedestrian behavior at 12 signalized intersections and analyzed the relationship between violations and conflict severity using Post-Encroachment Time (PET). The results showed that pedestrian non-compliance was frequent, particularly during the later part of the red signal phase. Signal violations were associated with serious pedestrian–vehicle conflicts, while conflict severity was influenced by the speed and behavior of road users.

6. Hashemi et al. (2022)

Hashemi and colleagues [6] investigated pedestrian violations and opportunities for crossing at signalized intersections using logistic regression and point-biserial correlation techniques. The study considered pedestrian characteristics, signal conditions, intersection geometry, median type, land use, time of day, and weather conditions. The findings showed that pedestrian arrival time, median configuration, time of day, and pedestrian characteristics significantly affected signal violation behavior. The study further demonstrated that providing appropriate median facilities could reduce pedestrian violations and encourage safer crossing decisions. The research highlighted the importance of integrating geometric design and pedestrian behavior when developing effective crossing facilities.

7. Raoniar et al. (2022)

Raoniar and colleagues [7] examined pedestrian risk exposure at signalized intersection crosswalks using a hazard-based duration approach. The study was conducted in Kolkata, India, and focused on the duration for which pedestrians remained exposed to potential conflicts and the factors influencing their decision to violate pedestrian signals. Kaplan–Meier analysis and Accelerated Failure Time models were used to investigate pedestrian waiting and crossing behavior.

8. Gagliardi, Ferrante and Bella (2024)

Gagliardi, Ferrante and Bella [8] developed an observational methodology for assessing pedestrian–vehicle interactions at signalized intersections using Surrogate Safety Measures (SSMs).

9. Haque, Kidwai and Khan (2024)

Haque, Kidwai and Khan [9] conducted a comprehensive study of pedestrian safety behavior at urban signalized T-intersections in Delhi, India. Data were collected from five signalized

T-intersections using video observations and perception-based questionnaires. Statistical tests and binary and ordinal logistic regression models were applied to identify factors affecting pedestrian crossing behavior.

10. Mukherjee, Rao and Tiwari (2024)

Mukherjee, Rao and Tiwari [10] presented an inclusive review of pedestrian crossing safety at high-risk locations, focusing on crosswalks, bus stops, land use, crossing quality, traffic control, and facility placement. The review examined different research methodologies and statistical approaches used to understand pedestrian safety and summarized various interventions for improving crossing conditions. The study highlighted that pedestrian safety is influenced by the interaction between infrastructure, traffic conditions, land-use characteristics, and the surrounding crossing environment.

Table 1. Literature Review Table

Previous Study	Major Findings	Methodology	Key Limitations	Research Area
Mukherjee & Mitra (2019)	Signal violations, waiting time, and pedestrian–vehicle interaction affect safety.	Video observation + perception survey	Limited intersections	Pedestrian behavior & perception
Mukherjee & Mitra (2020)	Signal cycle, sight distance, and pedestrian dissatisfaction influence violations.	Statistical analysis	Behavior-focused	Signal violation
Marisamynathan & Vedagiri (2020)	PET is useful for evaluating pedestrian safety.	PET + Logistic Regression	Limited safety indicators	Surrogate safety measures
Raoniar & Maurya (2022)	Age, distraction, and signal timing affect crossing behavior.	Observation + Logistic Regression	Limited study locations	Crossing behavior
Raoniar et al. (2022)	Signal violations are associated with serious pedestrian–	PET-based conflict analysis	Conflict-focused	Pedestrian–vehicle conflict

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	vehicle conflicts.			
Hashemi et al. (2022)	Geometry, median facilities, and pedestrian characteristics affect violations.	Logistic Regression + Correlation	Context-specific	Crossing opportunities
Raoniar et al. (2022)	Waiting time influences risk-taking behavior.	Kaplan–Meier + AFT model	Exposure-focused	Risk exposure
Gagliardi et al. (2024)	PET/TTC are useful for proactive safety assessment.	SSM + Logistic Regression	Small sample/intersections	Pedestrian–vehicle interaction
Haque et al. (2024)	Demographic and trip factors influence crossing behavior.	Video + Survey + Logistic Regression	Limited to T-intersections	Behavioral safety
Mukherjee et al. (2024)	Infrastructure, traffic, and land-use factors influence pedestrian safety.	Literature review	Limited empirical validation	Crossing facility design

V. GEOGRAPHIC CONCENTRATION BIAS

Previous studies on pedestrian safety at signalized intersections are geographically concentrated, particularly in Indian cities such as Kolkata and Delhi, with one study conducted in Rome, Italy. The reviewed Indian studies mainly focus on Kolkata, covering pedestrian behavior, signal violations, crossing risk, and pedestrian–vehicle conflicts, while the Delhi study focuses on signalized T-intersections. This geographic concentration may limit the generalizability of the findings, as pedestrian behavior, traffic characteristics, road geometry, signal operations, land-use patterns, and crossing facilities can vary considerably across cities and countries. Therefore, findings derived primarily from Kolkata and Delhi may not be directly applicable to other Indian cities or different urban contexts without further validation [1-10].

VI. RESEARCH GAP AND CONTRIBUTION OF THE PROPOSED FRAMEWORK

Previous research has mainly examined individual aspects of pedestrian safety, such as signal violations, waiting time, pedestrian behavior, walking speed, pedestrian–vehicle conflicts, or geometric conditions. However, limited research has integrated traffic characteristics, pedestrian behavior, signal timing, intersection geometry, conflict indicators, and existing

crossing-facility performance within a single systematic framework [1-5]. The proposed framework in this paper addresses this gap by establishing a continuous process of data collection, data analysis, pedestrian safety assessment, and improved facility development. It combines field-based information such as pedestrian and vehicle volumes, speeds, waiting and crossing times, signal compliance, gap acceptance, turning movements, geometry, and pedestrian–vehicle conflicts to provide a more comprehensive assessment and support the development of safer, accessible, and pedestrian-oriented crossing facilities[7-10].

VII. SUMMARY OF REVIEW OF LITERATURE

The review of literature indicates that pedestrian safety at signalized intersections is influenced by a combination of traffic, geometric, signal-related, behavioral, and environmental factors. Previous studies have mainly focused on pedestrian crossing behavior, signal compliance, waiting time, walking speed, pedestrian–vehicle interactions, and the influence of vehicle speed and turning movements on pedestrian safety. Several researchers have also demonstrated the usefulness of Surrogate Safety Measures (SSMs), particularly Post-Encroachment Time (PET), Time-to-Collision (TTC), gap acceptance, and conflict frequency, for evaluating pedestrian safety proactively in situations where historical crash data are limited.

The reviewed studies further indicate that pedestrian signal violations, excessive waiting time, inadequate crossing time, poor visibility, inappropriate crossing locations, and deficiencies in existing pedestrian facilities can increase pedestrian exposure and the probability of hazardous conflicts. Statistical and behavioral models have been widely used to identify factors affecting pedestrian crossing decisions and conflict severity. However, most previous studies have examined individual safety parameters or specific aspects of pedestrian behavior, while relatively limited research has integrated traffic characteristics, pedestrian behavior, signal timing, intersection geometry, pedestrian–vehicle conflicts, and existing facility performance within a single assessment framework.

VIII. CONCLUSION

The reviewed studies indicate that pedestrian safety at signalized intersections is influenced by a combination of pedestrian behavior, traffic characteristics, signal timing, intersection geometry, and the quality of crossing facilities. Factors such as signal violations, excessive waiting time, pedestrian–vehicle conflicts, poor visibility, inadequate median facilities, and unsuitable crossing conditions contribute significantly to safety risks. Surrogate Safety Measures such as Post-Encroachment Time (PET) and Time-to-Collision (TTC) provide useful tools for proactive safety assessment where crash data are limited. Overall, the literature highlights the need for pedestrian-oriented intersection design, optimized signal timing, improved crossing facilities, and behavior-sensitive safety measures to reduce pedestrian conflicts and enhance overall intersection safety.

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