Assessing Urban Pedestrian Infrastructure: A Review of Deficiencies, Flow Dynamics, and Safety

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Abstract- Urbanization and increasing motorization pose significant challenges to pedestrian infrastructure and safety, particularly in developing countries. This paper analyzes the current state of pedestrian infrastructure, flow dynamics, safety levels, and pedestrian-vehicle conflicts in urban areas. It highlights critical deficiencies, including poor maintenance, inadequate accessibility features, and insufficient safety measures, while exploring socio-demographic influences, urban design principles, and policy impacts. The study emphasizes integrated urban planning, inclusive design, and the importance of public-private partnerships to create walkable, pedestrian-friendly cities. Through comprehensive analysis and insights, this research provides actionable recommendations for enhancing pedestrian safety, pedestrian level of service (PLOS) and mobility, fostering sustainable urban environments.

Keywords: Pedestrian infrastructure, pedestrian safety, pedestrian flow dynamics, pedestrian-vehicle conflicts, pedestrian level of service (PLOS).

1. INTRODUCTION

Urban environments worldwide are experiencing rapid growth and motorization, posing significant challenges to pedestrian infrastructure and safety. The effectiveness of pedestrian infrastructure is pivotal for fostering safe, accessible, and walkable cities. However, many urban areas, particularly in developing countries, face numerous deficiencies in their pedestrian infrastructure, including poorly maintained sidewalks, inadequate crosswalks, and insufficient facilities for people with disabilities. Addressing these issues requires a comprehensive understanding of various factors influencing pedestrian infrastructure and safety.

This research aims to analyze the current state of pedestrian infrastructure, flow characteristics, safety, level of service, and pedestrian-vehicle conflicts in urban areas. Furthermore, it explores the impact of socio-demographic factors, urban design principles, and administrative policies on pedestrian infrastructure and safety.

The study emphasizes the need for integrated urban planning approaches that prioritize pedestrian mobility, safety, and accessibility. It highlights the importance of robust infrastructure design, effective governance, and public-private partnerships in developing sustainable solutions. Through a detailed examination of pedestrian behavior, flow dynamics, and conflict severity, this research provides valuable insights for urban planners and policymakers aiming to create pedestrian-friendly urban environments.

2. LITERATURE REVIEW

2.1*Infrastructure deficiencies and challenges*

Mukti Advani et al. (2017) [1] developed a methodology for assessing walking facilities based on diverse footpath obstructions using continuous video capture on both national holidays and regular days. They categorized obstructions into groups that are easily removable and developed a Footpath Score using the Analytic Hierarchy Process (AHP). The introduction of the FOSTO index as a decision-making tool assists in both short-term and long-term planning for improving footpath walkability.

Pareek and Prabhakar (2018) [2] identify several shortcomings in pedestrian infrastructure within Jaipur, India. Concerns highlighted include inadequate signage and safety measures at intersections along current bike lanes and pedestrian routes. These findings underscore a pressing need for urban planning that prioritizes pedestrian safety and convenience. Moreover, the study emphasizes the significance of robust infrastructure design to enhance pedestrian mobility and safety amidst growing vehicular traffic. Addressing these deficiencies is crucial for fostering pedestrian-friendly environments in urban settings, ensuring accessibility and reducing

risks associated with increased urbanization and traffic congestion.

From the research of Gaurab Das Mahapatra et al. (2023) [3], it is evident that enhancing universal mobility in urban areas requires prioritizing several key factors. Firstly, the dimension and quality of footpaths, alongside the typology of adjacent buildings, emerge as critical considerations. These elements not only affect physical accessibility but also contribute to the overall pedestrian experience in urban India. Secondly, the study underscores the importance of administrative focus, suggesting that local governance and policies at the city level play a pivotal role in implementing effective universal mobility initiatives. Lastly, adopting urban development strategies that integrate public-private partnerships could provide sustainable solutions, leveraging resources and expertise from diverse sectors to improve pedestrian accessibility and urban mobility infrastructure.

Identifying deficiencies and challenges in pedestrian infrastructure is crucial for targeted interventions. Parameters for analysis may include:

- Condition and maintenance of pedestrian infrastructure, including sidewalks, crosswalks, and pedestrian bridges.
- Presence of obstacles and obstructions on sidewalks and footpaths.
- Accessibility for people with disabilities, including the presence of ramps and tactile paving.
- Consistency with urban design principles, including walkability, aesthetics, and integration with surrounding land uses.

2.2 Pedestrian level of service(PLOS)

Ankit Bansal et al. (2018) [4] conducted research on enhancing non-motorized transportation, with a focus on walking, in rapidly urbanizing areas. Their study identifies the critical factors that impact the Level of Service (LOS) of pedestrian infrastructure. Pedestrian factors are most significant for uninterrupted facilities like sidewalks and walkways, while traffic characteristics are paramount for interrupted facilities such as crosswalks and intersections. Socio-demographic variables, though least significant independently, show high correlation with other influential factors, emphasizing their interdependence. The study advocates for a combined approach that integrates both quantitative metrics (e.g., pedestrian speed, flow, density) and qualitative aspects (e.g., comfort, safety, attractiveness) to accurately evaluate and enhance pedestrian LOS. These insights are essential for future urban planning, ensuring improved efficiency and safety of pedestrian infrastructures.

The systematic review by Raad and Burke (2018) [5] of Pedestrian Level-of-Service (PLOS) models, spanning literature from 1971 to 2016, identified significant trends and gaps. Conducted across 18 countries, with notable contributions from the USA, China, and India, the research emphasized four facility types: mixed streets, footpaths, intersections, and mid-block crossings. Geometric factors, particularly footpath width, were the most common in PLOS assessments. The study highlighted a preference for empirical regression or point systems for data analysis, noting the absence of expert-led focus groups or Delphi techniques. The review underscores the need for standardized and robust PLOS measurement approaches and calls for further research to address identified gaps, enhancing the effectiveness of pedestrian facility planning and design.

From the understanding pedestrian level of service evaluates the following

- Assesses pedestrian comfort and safety, considering walkway width and surface quality.
- Evaluates pedestrian flow efficiency, including walking speed and crowd density.
- Examines accessibility and connectivity between sidewalks, intersections, and public transport.
- Considers environmental quality factors like noise, air quality, and lighting.
- Accounts for diverse pedestrian needs and behaviors, including age, gender, and group size.

2.3 *Pedestrian facilities*

Study on pedestrian facilities in Jaipur City by Nishant et al. (2020) [6] identifies significant challenges and areas for improvement. Studies have shown that footpaths in selected areas, including Tonk Road, Sodala, and Kumbha Marg, face numerous issues such as obstructions from hawkers, discontinuity, inadequate width and elevation, and parked vehicles blocking paths. These problems are exacerbated by increasing motor traffic, leading to the deterioration of pedestrian facilities. Data collected on footpath measurements and conditions revealed that many did not comply with IRC: 103 – 2012 guidelines. Addressing these issues through compliance with established norms is critical for enhancing pedestrian safety and accessibility in urban environments. Recommendations for

improvements are essential to align pedestrian infrastructure with safety standards.

Study by Piyush et al. (2021) [7] evaluating walkability and pedestrian facilities in Jaipur identifies significant challenges due to increasing vehicular traffic. Key findings indicate that only about 30% of roads in Indian cities have pedestrian footpaths, contributing to roughly 20% of road traffic accidents involving pedestrians. The study highlights that rapid population growth and rising vehicle ownership have led to reduced walkability and increased congestion. Public opinions collected underscore the necessity for improved pedestrian infrastructure, focusing on safety and convenience. Tools like Google Earth Pro were used for accurate measurements. The current transportation patterns in Jaipur are found to be energy-inefficient and environmentally detrimental. The study emphasizes the importance of proper pedestrian crossing facilities and mixed land use, which enhance safety, create a lively public domain, and reduce traffic disorder and risks. Recommendations include compliance with IRC guidelines and strategic site selection for pedestrian crossings to significantly improve pedestrian safety and walkability in Jaipur.

Pedestrian facilities may include the following infrastructures on the basis of understanding of studies.

- Pedestrian signals, zebra crossings, adequate lighting, and traffic calming measures to enhance pedestrian safety.
- Include ramps, tactile paving, and clear signage to ensure accessibility for all pedestrians, including those with disabilities.
- Design continuous pedestrian routes that connect residential areas, commercial zones, public transport hubs, and recreational areas.

2.4Pedestrian flow characteristics

Rajat Rastogi et al. (2013) [8] studies consistently highlight that pedestrian free flow speed varies significantly depending on the type of facility, with sidewalks generally facilitating higher speeds compared to precincts or non-exclusive paths. Research underscores the impact of facility width, showing that while wider paths offer more space for pedestrians, they can reduce maximum flow rates and optimum densities due to increased dispersal of pedestrian traffic.

Moreover, the relationship between pedestrian speed and density follows distinct models such as Underwood's exponential model on sidewalks and Greenshield's linear model on non-exclusive facilities, illustrating how spatial constraints influence pedestrian behavior. Bidirectional flows on facilities are noted to decrease free flow speeds and available space at higher densities, emphasizing the design challenges in accommodating pedestrian movements efficiently.

Cultural factors also play a significant role, influencing pedestrian behavior and speeds across different regions. Overall, these insights underscore the complexity of pedestrian flow dynamics and inform urban planners and policymakers in designing more effective and culturally sensitive pedestrian infrastructure.

Another study by Rajat Rastogi et al. (2011) [9] on pedestrian flow characteristics reveals a complex interplay of factors influencing walking speeds and behaviors. Studies consistently identify gender, age, group size, technology use, baggage carrying, and land use as key determinants affecting pedestrian speeds on various types of facilities such as sidewalks and precincts. These factors not only influence individual walking speeds but also impact overall pedestrian flow dynamics and facility design considerations. Understanding these nuances is crucial for optimizing pedestrian facility planning and ensuring user-centric designs that accommodate diverse pedestrian needs and behaviors across different urban contexts.

Understanding pedestrian flow characteristics and safety concerns is fundamental to designing effective infrastructure.

Parameters for analysis may include:

- Pedestrian volume and density.
- Speed of pedestrian movement.
- Crossing behavior and compliance with traffic signals.
- The presence of pedestrian-vehicle conflicts and collision hotspots.
- Perception of safety among pedestrians, including feelings of security and fear of crime.

2.5 Pedestrian vehicle conflict

Vedagiri and Kadali (2016) [10] evaluates pedestrian-vehicle conflict severity at unprotected midblock crosswalks in India under mixed traffic conditions. It identifies significant contributing factors using an ordered probit model and assesses the impacts of pedestrian behavior, vehicle and traffic characteristics, roadway features, and land use on conflict severity. Key findings reveal that pedestrian behavior, such as rolling and speed changes, significantly increases conflict severity. Higher vehicle speeds and smaller vehicle gaps also contribute to greater conflict severity. Roadway characteristics, such as the presence of a median, reduce conflict severity by allowing staged crossings. Land use type

impacts conflict severity, with residential and mixed-use areas experiencing higher severity compared to shopping areas. The study introduces a Pedestrian Crossing Safety Index (PCS), categorizing conflict severity from not severe (PCS=1) to extremely severe (PCS=6). The research aims to develop countermeasures to enhance pedestrian safety and proposes a methodology for evaluating crosswalk facilities to identify PCS levels.

Pedestrian Behaviour:

- Rolling behaviour (hesitant or intermittent crossing)
- Speed change conditions
- Number of attempts to cross the road

Vehicle Characteristics:

- Speed of the vehicle
- Type of vehicle (e.g., heavy vehicles, cars, two-wheelers)

Traffic Characteristics:

- Number of encountered vehicles
- Vehicle gaps (distance between vehicles)
- Pedestrian waiting times.

Roadway Characteristics:

- Presence of a median or traffic barrier
- Road width
- Visibility and lighting conditions

Land Use Type:

- Residential areas
- Mixed-use areas
- Shopping areas

These factors interact to determine the severity of pedestrian-vehicle conflicts, influencing the overall safety at midblock crosswalks.

2.6 Pedestrian safety

The study on pedestrian safety by Mukherji and Mitra (2022) [11] at urban intersections highlights critical factors influencing risk and potential interventions. High vehicle volumes and pedestrian-vehicular ratios significantly impact safety, with inadequate infrastructure such as the absence of traffic signals and inaccessible crosswalks exacerbating risks. Studies reveal that intersections lacking police personnel and those with higher vehicle speeds, especially in commercial areas, experience more pedestrian crashes. Additionally, poor sight distances and proximity to high-density slum populations contribute to elevated risk levels. A combined analysis of historical crash data and pedestrian-vehicle conflicts identifies trends and risk factors, facilitating the ranking of high-risk intersections. These insights guide targeted improvements to enhance pedestrian safety in urban settings.

The research on pedestrian safety by Chaudhary et al. (2019) [12] at urban midblock crossings in India identifies several critical factors influencing Pedestrian Safety Margin (PSM). Variables such as pedestrian speed, vehicular gap size, vehicle speed, age, pedestrian platoon size, pedestrian behavior, vehicle type, and driver yielding behavior significantly affect safety outcomes. Elderly and young pedestrians face higher risks due to slower crossing speeds, emphasizing age-related vulnerabilities. Pedestrians exhibit greater caution with high-speed and heavy vehicles, maintaining larger safety margins. A Multiple Linear Regression model developed from these findings explains 59.7% of PSM variance, with a Mean Absolute Percentage Error of 12.95%, indicating robust predictive capability. These insights are crucial for designing pedestrian facilities and implementing targeted measures to mitigate risks at midblock crossings, potentially reducing pedestrian fatalities in urban Indian settings.

The research on pedestrian safety by Mukesh and Katapatal (2020) [13] focuses on developing a comprehensive Pedestrian Safety Index that integrates commuter and infrastructure-related parameters. It aims to spatially analyze pedestrian safety patterns in relation to changing land use. Key findings highlight significant influences on safety, such as signal breaks, crossing types, and locations. Pedestrian behavior analysis underscores age and gender as critical factors, affecting risk-taking tendencies and compliance with crossing norms. Infrastructure availability at intersections also impacts safety metrics, with built-up density playing a secondary role. These insights inform targeted infrastructure designs to enhance pedestrian safety, particularly at intersections identified as high-risk zones like those along the Ring Road corridor.

3. CONCLUSION

Urbanization and increased motorization have profoundly impacted pedestrian infrastructure, necessitating comprehensive analysis and targeted interventions. This study highlights key deficiencies, including poor infrastructure maintenance, inadequate accessibility features, and suboptimal urban design, which compromise pedestrian mobility and safety. Critical factors influencing pedestrian flow dynamics and safety, such as pedestrian volume, speed, behaviour, and pedestrian-vehicle conflicts, are examined.

The research underscores the value of tools like Pedestrian Safety Index and Level of Service models in evaluating and improving pedestrian

infrastructure. Inclusive design and public-private partnerships emerge as essential strategies to address these challenges. By integrating advanced technologies, sustainable practices, and policy frameworks, urban planners and policymakers can create safer, accessible, and pedestrian-friendly urban environments. This study provides actionable insights to foster walkable cities, prioritizing pedestrian mobility, safety, and inclusivity.

4. FUTURE SCOPE

The future scope of research in pedestrian infrastructure and safety includes several promising directions:

Advanced Data Collection and Analysis Techniques:

- Leveraging emerging technologies such as machine learning, AI, and IoT for real-time monitoring and analysis of pedestrian flow and safety.
- Implementing continuous video surveillance and data analytics to gain deeper insights into pedestrian behavior and infrastructure performance.

Comprehensive Urban Planning Approaches:

- Developing integrated urban planning frameworks that prioritize pedestrian infrastructure within broader transportation and land use planning.
- Encouraging public-private partnerships to leverage diverse resources and expertise for sustainable pedestrian infrastructure development.

Inclusive Design and Accessibility:

- Focusing on the needs of diverse pedestrian groups, including the elderly, children, and people with disabilities, to ensure inclusive and accessible urban environments.
- Enhancing the design of pedestrian facilities to accommodate varying mobility needs and preferences.

Policy and Governance:

- Strengthening policy frameworks and governance structures to ensure effective implementation and maintenance of pedestrian infrastructure.
- Promoting community engagement and participatory planning processes to incorporate local insights and needs into infrastructure development.

Impact of Socio-Demographic Factors:

- Investigating the influence of socio-demographic factors on pedestrian behavior and infrastructure usage, tailoring interventions to address specific community needs.
- Analyzing the impact of cultural differences on pedestrian flow dynamics and safety to develop culturally sensitive infrastructure solutions.

Pedestrian Safety and Conflict Mitigation:

- Developing and validating Pedestrian Safety Indices and conflict severity models in diverse urban contexts to enhance predictive capabilities.
- Implementing targeted safety measures at high-risk intersections and midblock crossings based on empirical research findings.

Environmental and Sustainability Considerations:

- Assessing the environmental impact of pedestrian infrastructure and promoting eco-friendly design practices.
- Encouraging the integration of green spaces and sustainable materials in pedestrian infrastructure to enhance urban livability.

By addressing these areas, future research can contribute to the development of resilient, safe, and accessible pedestrian infrastructure, fostering walkable and sustainable urban environments.

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