A METHODOLOGY FOR EVALUATING AND MITIGATING PEDESTRIAN CRASHES: INTEGRATING SUBJECTIVE AND OBJECTIVE SAFETY MEASURES ALONG INDIAN URBAN CORRIDORS

Developing countries, in particular, face the brunt of pedestrian-related casualties due to factors such as high population density, mixed traffic conditions, and inadequate infrastructure. A comprehensive and integrated approach to pedestrian safety assessment is crucial to address this pressing issue. This research proposes a novel methodology that combines objective and subjective measures to enhance the evaluation and mitigation of pedestrian crashes in an urban corridor with mixed heterogeneous traffic conditions in Kolkata, India. The methodology incorporates simulation and analytical approaches, integrating surrogate safety measures (SSMs) such as travel time, delay, queue lengths, and traffic conflicts with users' perceptions of the proposed mitigation measures' effectiveness and ease of use.

Objective measures offer statistically reliable insights into the efficiency and effectiveness of different mitigation measures. In contrast, subjective measures provide valuable information about pedestrian behavior and their inclination to utilize the planned facilities. The research pursues the following objectives to achieve its overarching aim to develop a safe pedestrian facility in an Indian corridor with mixed heterogeneous traffic conditions: a) Development of a framework to analyze spatiotemporal trends in pedestrian crashes and identify critical locations based on their evolution and severity, b) Creation of an integrated methodology that combines subjective and objective measures to assess pedestrian safety in the identified location, and c) Optimization of identified mitigation measures and simulation of their impact on improving pedestrian safety, considering ease of implementation, perceived effectiveness, and acceptability.

In its **first objective**, the research develops a novel three-step methodology for identifying current and future critical pedestrian crash hotspots in two cities in India. Firstly, the available multi-year crash data is digitized, and the spatial autocorrelation tool is employed to determine the pedestrian crash hotspots. Secondly, space-time cube and emerging hotspot analysis techniques are utilized to predict crash hotspots along urban streets. Finally, Hotspot Identification (HSID) methods, specifically Equivalent Property Damage Only (EPDO) and Upper-tail Critical Tests, are applied to rank the road links based on spatiotemporal crash severity. The study identifies Strand Road in Kolkata to be the most critical link under consecutive hot spot areas and, as such, was used as the prime case study location for the development of the methodology. Further, Prince Anwar (PA) Shah Road, the most critical under new hotspots, was selected to check the transferability of the methodology to ascertain its application in a broader area.

The **second and third objectives** of the research focused on addressing key challenges in pedestrian safety assessment. These objectives aimed to develop methodologies to overcome pedestrian crash data limitations, proactively assess pedestrian facility safety and integrate objective and subjective measures for a comprehensive analysis. The core component of the methodology was the VISSIM-SSAM simulation model, which was utilized to analyze vehicle and pedestrian interactions and assess the safety of pedestrian facilities. Surrogate Safety Assessment Model (SSAM), developed by Federal Highway Authority (FHWA), uses the vehicle trajectory files (.trj) to assess the probability of conflicts using surrogate measures like Time To Collision (TTC) and Post-Encroachment Time (PET). In addition, user and expert opinion surveys were carried out to understand the current perception of safety and subsequently assess the effectiveness of specific mitigation measures, which are easy to use and implement, in mitigating pedestrian crashes. The results obtained from the structural equation modeling (SEM)

analysis demonstrated a significant relationship between the latent variables representing footpath characteristics, traffic control, and crossing design with the latent variable of perceived safety. These findings reinforce the understanding that modifications in objective measures of pedestrian facility design can influence pedestrians' perception of safety in the long term. Further, Multi-Criteria Decision Analysis (MCDA) was carried out, which ranks the mitigation measures based on the perception survey results. The measures are evaluated based on ease of implementation and effectiveness, as determined by the expert survey. Similarly, the user perception survey ranks the measures based on ease of use and perceived effectiveness. The rankings from both surveys are utilized to construct modified Importance/Satisfaction matrices, allowing for the identification of the most effective, user-friendly, and easily implementable mitigation measures. Furthermore, ordinal logistic regression (OLR) is employed to assess the factors that significantly correlate with the overall perception of safety at both stretches. The final shortlisted mitigation measures from the MCDA are then compared to the results from the experts' survey and ordinal logistic regression to identify the final list of mitigation measures to be used for the alternative design of both sites. For Strand Road, Buffer and Grade Separation at crossings (foot-over bridge) were selected as the final mitigation measures for the alternative designs. Similarly, at PA Shah Road, Removing obstacles and encroachments and Law enforcement were selected to be integrated into the alternative models.

Finally, the mitigation strategies were simulated, and the predicted crashes were compared to the base simulation model results. The results from the alternative model for Strand Road indicate that Alternative 2, which involves grade separation only, significantly reduces the number of conflicts at the crossings by around 80%. Alternative 1, which uses the buffer measure only, also reduces the conflicts, but to a lesser extent (approximately 8%). However, it is worth noting that the experts ranked the buffer measure higher in terms of ease of implementation than grade separation. Therefore, a tradeoff needs to be considered when deciding which mitigation measure to prioritize for the stretch. At PA Shah Road, both Alternative 1 (removal of encroachments) and Alternative 2 (law enforcement) significantly reduce the number of conflicts by approximately 30% and 35%, respectively. However, based on ease of implementation, law enforcement is ranked considerably higher than removing obstacles and encroachments from the footpath. Therefore, law enforcement can be selected as the prioritized measure to be implemented at PA Shah Road.

Overall, integrating the VISSIM simulation model with SSAM for an overall analysis of surrogate indicators (Speed, Delay, LOS) and conflicts (TTC, PET) at crossings supported by perception and ranking techniques like SEM, ordinal logistic regression, and MCDA allowed for a comprehensive and robust pedestrian safety analysis. The methodology's successful implementation at two stretches in Kolkata showcased its practical applicability and potential for informing decision-making processes in pedestrian facility design and improvement. The findings from the research can inform decision-making processes and guide the prioritization of mitigation measures to enhance pedestrian safety in urban environments.

Keywords: Pedestrian safety assessment, VISSIM-SSAM simulation model, surrogate safety measures, Objective and subjective measures, Prioritizing mitigation methods.