Study On Pedestrian Road Crossing Behaviour Under Mixed Traffic Condition

Ayesha Qamer[1], Prof. D. Rajashekar Reddy[2]
[1]*ME Student, University College of Engineering, Osmania University*
[2]*Professor, University College of Engineering, Osmania University*

Abstract: **This study investigates the complex dynamics of pedestrian road crossing behaviour in the context of mixed traffic conditions. With urbanization and increasing vehicular density, understanding how pedestrians navigate road crossings becomes pivotal for enhancing both pedestrian safety and traffic flow. The research aims to fill existing gaps in the literature by employing a comprehensive approach to model and analyse pedestrian behaviour in diverse traffic environments. Through a thorough review of existing literature, the study identifies the need for a nuanced understanding of pedestrian road crossing behaviour, especially in mixed traffic scenarios where pedestrians interact with various types of vehicles. The research is motivated by the goal of developing insights that can inform urban planning, traffic management strategies, and the design of pedestrian-friendly environments.**

Keywords: **Pedestrian Road Crossing, Speed, Pedestrian Risk.**

I. INTRODUCTION

As urban areas undergo rapid transformation, characterized by increasing vehicular density and diverse transportation modes, the dynamics of pedestrian road crossing behaviour become a critical aspect of urban planning and traffic management. Pedestrian safety, particularly at road crossings, is a multifaceted challenge that necessitates a comprehensive understanding of how pedestrians interact with vehicular traffic, especially in mixed traffic conditions. This study addresses this pressing issue by delving into the intricacies of pedestrian road crossing behaviour within the context of mixed traffic environments [1]. The contemporary urban landscape is marked by a mosaic of transportation modes, ranging from traditional vehicles to emerging technologies such as electric scooters and autonomous vehicles. As a consequence, pedestrians must navigate an evolving and complex traffic ecosystem, making informed decisions when crossing roads. The challenges posed by mixed traffic conditions amplify the need to comprehend the factors influencing pedestrian behaviour at road crossings [2]. The existing body of literature on pedestrian road crossing behaviour has made significant contributions, but there remains a notable gap in understanding the nuances of pedestrian decision-making in mixed traffic scenarios. This study seeks to address this gap by employing a multidimensional approach that combines observational studies, surveys, and modelling techniques. Through this comprehensive methodology, we aim to unravel the factors that influence pedestrian road crossing behaviour and contribute valuable insights to enhance both pedestrian safety and overall traffic efficiency [3]. The overarching goal of this research is to provide evidence-based recommendations for urban planners, traffic engineers, and policymakers. By investigating the intricacies of pedestrian behaviour in mixed traffic conditions, we aspire to inform the design of pedestrian-friendly urban spaces, optimize traffic management strategies, and contribute to the broader discourse on sustainable and safe urban mobility.

The need for studying pedestrian road crossing behaviour under mixed traffic conditions is driven by several crucial factors, reflecting the complexities and challenges associated with contemporary urban environments. Understanding how pedestrians interact with vehicular traffic in mixed traffic conditions is essential for addressing safety concerns, optimizing traffic flow, and creating more pedestrian-friendly cities [4]. Pedestrians are vulnerable road users, and road crossings are critical points where their safety is often compromised. Mixed traffic conditions introduce a variety of vehicles with different speeds, sizes, and behaviours, increasing the risk of accidents and collisions. Studying pedestrian

road crossing behaviour is crucial for identifying potential safety hazards and developing effective safety measures. As urban areas continue to grow and evolve, the complexity of traffic conditions increases. The coexistence of various transportation modes, including traditional vehicles, bicycles, scooters, and emerging technologies like autonomous vehicles, poses unique challenges for pedestrians [5]. Understanding how pedestrians navigate this mix is vital for designing urban spaces that accommodate diverse modes of transportation. Efficient traffic flow is a key consideration for urban planners and traffic engineers. Pedestrian road crossing behaviour can significantly impact traffic flow, especially at intersections. By studying how pedestrians interact with traffic, it becomes possible to optimize signal timings, plan for pedestrian-friendly infrastructure, and enhance overall traffic efficiency [6]. The design of pedestrian infrastructure, such as crosswalks, pedestrian islands, and signalized crossings, plays a crucial role in influencing pedestrian behaviour. Studying how pedestrians respond to different infrastructure designs in mixed traffic conditions helps in identifying effective design elements that enhance safety and convenience. Evidence-based policies and urban planning decisions require a thorough understanding of pedestrian behaviour in mixed traffic conditions. This study provides insights that can inform the development of policies aimed at creating safer road environments, promoting sustainable transportation, and fostering pedestrian-friendly urban planning [7]. With the advent of smart city technologies and advancements in transportation systems, the interaction between pedestrians and vehicles is evolving. Understanding how pedestrians respond to new technologies, such as traffic management systems and autonomous vehicles, is crucial for ensuring the seamless integration of these technologies into urban landscapes. Demographic factors, such as age, mobility limitations, and cultural considerations, can influence pedestrian road crossing behaviour. As demographics change, the study helps in adapting infrastructure and policies to accommodate the diverse needs of pedestrians in mixed traffic conditions. In summary, the study of pedestrian road crossing behaviour under mixed traffic conditions is imperative for enhancing pedestrian safety, optimizing traffic flow, and informing urban planning and policy decisions in the context of dynamic and evolving urban landscapes.

II. LITERATURE REVIEW

Pedestrian behaviour has been investigated through different researches. Prior examinations directed showed current realities of the attributes influencing the intersection determine. Different investigations demonstrated that utilizing measurable methods and further exploration concentrates on led examined the passerby getting conduct through factual programming's.

K. Kamal, B. Farooq, M. Mudassar and A. Kalatian (2022), presented a study employs an ordered-logit model to analyse the impact of Automated Vehicles (AVs) in the traffic mix on pedestrians' average stress levels while crossing an urban street mid-block. Data from galvanic skin resistance sensors and virtual reality experiments are processed into a dataset categorizing stress levels as low, medium, or high, alongside information on geometric, traffic, and environmental factors. Findings suggest that as the proportion of AVs in the traffic mix rises, the average stress level experienced by pedestrians decreases.

M. Mudassar, A. Kalatian and B. Farooq (2022), In this study, explore pedestrian stress levels and variations across different road crossing scenarios using immersive virtual reality. Galvanic Skin Response (GSR) sensors were employed to measure pedestrians' stress levels. Data collection was facilitated by the Virtual Immersive Reality Environment (VIRE) tool, allowing us to gauge participants' stress levels in a controlled setting. Extensive experiments were conducted over a 5-month period involving 180 participants from various locations in Toronto to capture a diverse population sample. The gathered data were utilized to develop behavioural models aimed at understanding the impact of different variables on pedestrian stress levels. Initial modelling outcomes indicated a positive correlation between vehicle density and pedestrian stress levels—higher vehicle density led to increased stress levels among pedestrians. Additionally, sociodemographic factors showed a significant relationship with individual stress levels.

A. Kalatian and B. Farooq (2021), This study delves into pedestrian crossing behaviour, a crucial

aspect of urban dynamics that is anticipated to be influenced by the emergence of automated vehicles. Proposed an interpretable machine learning framework designed to explore the factors impacting pedestrians' wait times before crossing mid-block crosswalks in the presence of automated vehicles. Also designed a dynamic and immersive virtual reality experiment involving 180 participants from diverse backgrounds across four different locations in the Greater Toronto Area (GTA). The study analyses pedestrian waits time behaviour using a data-driven Cox Proportional Hazards (CPH) model, wherein the linear combination of covariates is substituted with a flexible non-linear deep neural network.

B. Farooq, E. Cherchi and A. Sobhani (2018), Introducing the Virtual Immersive Reality Environment (VIRE), a platform designed to create highly realistic, immersive, and interactive choice scenarios. Showcased VIRE's application in studying pedestrian preferences concerning autonomous vehicles and the related infrastructure adjustments on urban streets in Montréal, Canada. A comparison is drawn with conventional approaches, primarily text-only and visual aid methods. Our findings demonstrate that VIRE enhances respondents' comprehension of the scenarios, leading to more consistent results compared to traditional approaches.

. Maruhn, A. Dietrich, L. Prasch and S. Schneider (2020), This study introduces a pioneering approach for an augmented reality pedestrian simulator. The simulator allows participants to encounter virtual vehicles overlaid onto a real scenario, enabling safe and controlled testing within a realistic environment. Participants were tasked with initiating a street crossing if they deemed the gap between the two experimental vehicles safe. The results highlight both similarities and discrepancies in behaviour between the two conditions. Lower acceptance rates and delayed crossing initiation times were observed in the augmented reality condition. Nevertheless, the study demonstrates that augmented reality presents a promising tool for pedestrian research, albeit with limitations contingent upon specific use cases.

S. Deb, D. W. Carruth, R. Sween, L. Strawderman and T. M. Garrison (2017), A novel pedestrian simulator was developed using the HTC Vive head-mounted display and Unity software. Pedestrian head position and orientation were monitored as participants navigated a virtual signalized intersection spanning 5.5 meters. About 11% of participants reported experiencing simulator sickness and withdrew from the study. Objective measures, such as average walking speed, indicated that participant behaviour in virtual reality (VR) closely mirrored established real-world norms. Overall, the study's findings affirm the efficacy of the new virtual reality technology for researching full-motion tasks.

T. Fuest, L. Michalowski, L. Träris, H. Bellem and K. Bengler (2018), The study aimed to explore whether different driving parameters affecting trajectory could effectively convey an automated vehicle's (AV) intention regarding right of way to other traffic participants. Additionally, the study evaluated whether the visual presence of a driver impacted pedestrians' assessment of the vehicle's driving behaviour and the time required to recognize the vehicle's intention (IRT). Results indicated that intentions were not solely conveyed through the presence of a driver but also through the vehicle's driving behaviour.

Y. Jiang, E. E. O'neal, J. P. Yon, L. Franzen, P. Rahimian, J. M. Plumert, et al., (2018), The study investigated how individuals coordinate their decisions and actions while jointly navigating a co-occupied, large-screen virtual environment. Participants were tasked with physically crossing a virtual road with continuous traffic, aiming to avoid collisions with cars. Findings revealed that participant pairs often crossed the same gap together and closely synchronized their movements during crossing. These results shed light on how individuals interact and coordinate their behaviours during joint motions in a co-occupied virtual environment. Additionally, the study lays the groundwork for future research examining joint actions in shared virtual environments where participants are represented by graphic avatars.

A. R. Palmeiro, S. van der Kint, L. Vissers, H. Farah, J. C. de Winter and M. Hagenzieker (2018), The study aimed to investigate pedestrians' crossing decisions when interacting with an Automated Vehicle (AV) compared to traditional vehicles. Participants experienced each scenario once in a randomized order to assess their behaviour during initial interactions with AVs without prior training or experience. Post-experiment interviews revealed that about half of the participants believed the vehicle was sometimes

driven automatically. However, post-experiment questionnaires indicated that most participants perceived differences in vehicle appearance, which influenced their perceptions.

A. Kalatian and B. Farooq (2019), We present DeepWait, a novel framework designed to estimate pedestrians' waiting time at unsignalized mid-block crosswalks in mixed traffic conditions. Leveraging the capabilities of deep learning to capture nonlinear relationships within the data, we construct a Cox proportional hazard model with a deep neural network serving as the log-risk function. To evaluate the efficacy of our framework, we conducted tests on a dataset obtained from 160 participants utilizing an immersive virtual reality environment. Validation results indicate that our proposed framework achieved a C-index of 0.64, surpassing the standard Cox proportional hazard-based model with a C-index of 0.58. This demonstrates the superior performance of our approach in estimating pedestrian waiting times in mixed traffic conditions.

A. Millard-Ball (2018), The study utilized game theory to examine the interactions between pedestrians and autonomous vehicles, specifically regarding yielding behaviours at crosswalks. With autonomous vehicles typically exhibiting risk-averse tendencies, the model posits that pedestrians may act with relative impunity. Consequently, autonomous vehicles could potentially catalyse a transition towards pedestrian-centric urban environments. However, the strategic disadvantage of autonomous vehicles, which tends to slow them down in urban traffic, might hinder their widespread adoption.

P. Chen, C. Wu and S. Zhu (2016), The study develops both a decision model and a motion model to simulate the interaction process between pedestrians and vehicles. Cumulative prospect theory is integrated into the evolutionary game framework to model the decision-making behaviours of drivers and pedestrians during interactions, capturing phenomena like disagreement within a pedestrian crossing group. The proposed model is calibrated and validated, with results demonstrating its capability to replicate actual observed traffic. Additionally, an application is designed to showcase the model's functionalities.

A. Kalatian, A. Sobhani and B. Farooq (2018), The paper examines distracted pedestrians' waiting times before crossing the road across three conditions: 1) undistracted, 2) distracted with a smartphone, and 3) distracted with a smartphone while virtual flashing LED lights on the crosswalk are present as a safety measure. Data collection utilized an adapted in-house virtual immersive reality environment (VIRE), with 42 volunteers participating in the experiment. Several factors were identified as influencing waiting times. Results indicated that an increase in initial walk speed, the percentage of time the head was oriented toward the smartphone during crossing, larger minimum missed gaps, and unsafe crossings resulted in shorter waiting times.

III. PEDESTRIAN CROSSING BEHAVIOUR

Pedestrian crossing behaviour refers to the actions, decisions, and patterns exhibited by individuals when crossing roads or intersections. Understanding pedestrian crossing behaviour is crucial for improving road safety, optimizing traffic flow, and designing pedestrian-friendly urban spaces. Pedestrians make decisions about when and where to cross roads based on a combination of factors. These may include traffic conditions, signal timings, the presence of crosswalks, visibility, and individual perceptions of safety. Pedestrian crossing behaviour is often influenced by traffic signals and pedestrian walk/don't walk signs. Understanding how pedestrians comply with these signals helps in assessing the effectiveness of signal systems and identifying potential areas for improvement. Pedestrians choose specific locations to cross roads, and these choices may vary based on factors like the presence of crosswalks, intersections, pedestrian bridges, or other infrastructure. Studying crossing locations aids in designing appropriate and accessible pedestrian facilities [8]. Interactions between pedestrians and vehicles are critical points of concern. Observing how pedestrians interact with approaching vehicles, including making eye contact with drivers, helps in understanding communication between road users and identifying potential conflict points. Various factors influence pedestrian crossing behaviour, including traffic volume, vehicle speed, road layout, presence of pedestrian amenities, weather conditions, and individual characteristics. Studying these factors helps in identifying the determinants of pedestrian decision-making. Pedestrian behaviour may differ when individuals are walking alone versus in groups. Group dynamics, communication between pedestrians within a group, and the influence of social

factors can affect how pedestrians approach road crossings. The increasing use of smartphones and other electronic devices can impact pedestrian behaviour. Understanding how technology and distractions influence crossing decisions is important for addressing potential safety risks.

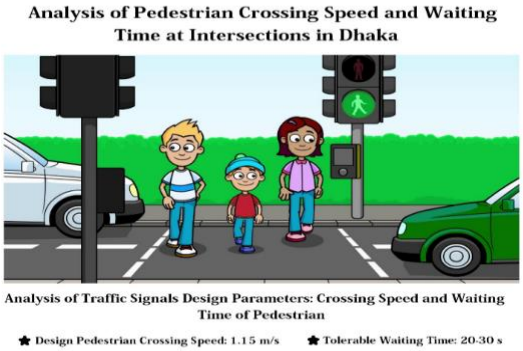

Fig 1: pedestrian crossing speed and waiting time

IV. PEDESTRIAN RISK

Pedestrian risk refers to the potential danger or hazards faced by individuals walking on or near roadways. Pedestrians are vulnerable road users, and various factors contribute to the risks they encounter. Understanding these risks is crucial for developing strategies to enhance pedestrian safety. Interactions with motorized vehicles pose one of the most significant risks to pedestrians. Collisions with cars, trucks, motorcycles, or bicycles can result in severe injuries or fatalities [9]. Factors such as vehicle speed, driver behaviour, and adherence to traffic rules influence the level of risk. Pedestrians are particularly vulnerable at intersections and crosswalks. Failure to yield by drivers, inadequate visibility, and complex traffic patterns can increase the risk of accidents. Insufficient or poorly designed crosswalks may contribute to pedestrian risk. Pedestrian risk is influenced by the extent to which both pedestrians and drivers comply with traffic signals. Disregarding signals, whether due to impatience or distraction, can lead to conflicts and accidents. Poorly designed roads, lack of sidewalks, inadequate lighting, and absence of pedestrian-friendly infrastructure contribute to increased pedestrian risk. A well-designed urban environment that prioritizes pedestrian safety helps mitigate these risks. Reduced visibility due to adverse weather conditions, low lighting, or obstructed sightlines increases the risk of pedestrian accidents. In such situations, both pedestrians and drivers may have difficulty anticipating and reacting to each other.

V.FACTORS EFFECTING PEDESTRIAN FLOW

The following are the factors effecting pedestrian flow

1. Crossing patterns

Crossing patterns in pedestrian flow refer to the ways in which pedestrians navigate and cross streets or intersections. Understanding these crossing patterns is crucial for designing safe and efficient pedestrian infrastructure. Different factors, including infrastructure design, traffic signal timings, and pedestrian behaviour, influence the various crossing patterns. Pedestrians often cross streets at locations without traffic signals, using informal or unsignalized crossings. These crossings are typically influenced by factors such as the shortest path, desire lines, and the absence of designated crosswalks [10-12]. At intersections with traffic signals, pedestrians use designated crosswalks to safely cross the road. Crossing patterns here are influenced by signal timings, pedestrian walk intervals, and the coordination between vehicular and pedestrian movements. Some intersections allow for diagonal crossings, where pedestrians can cross both the longitudinal and transverse directions simultaneously during specific phases of the traffic signal cycle. This pattern is often seen in large intersections. Pedestrians may choose to cross streets between intersections, especially if the distance to the nearest crosswalk is significant. Mid-block crossings are influenced by factors such as pedestrian desire lines and accessibility. Pedestrians may choose to wait at the curb until they perceive a safe gap in traffic, then proceed to cross the street. This pattern is common in areas without signalized crosswalks or where pedestrians prefer to cross at their convenience. (Alkheder [2022]).

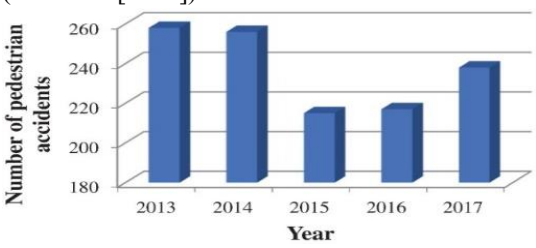

Fig 2: Graph Showing Number of pedestrian accidents

2. Crossing speed

Crossing speed refers to the rate at which pedestrians traverse a road or intersection while crossing from one side to another. It is an essential factor in the study of pedestrian behaviour and road safety, influencing both the efficiency of pedestrian movement and the potential risks associated with crossing roadways. Pedestrians may adjust their crossing speed based on the volume and speed of oncoming traffic. Higher traffic volumes or faster-moving vehicles may lead pedestrians to alter their pace to ensure a safe crossing. The design of crosswalks, including the presence of marked lines, pedestrian signals, and other infrastructure, can influence pedestrian crossing speed. Well-designed crosswalks with clear markings and signals may encourage smoother and more predictable pedestrian movements. Traffic signal timings, including pedestrian walk and don't walk intervals, can impact crossing speed. Pedestrians often adjust their pace to align with signal changes, either hurrying to cross before the signal changes or slowing down when they have the right of way. The layout of an intersection, including the width of the road and the length of crosswalks, can affect crossing speed. Longer or wider crossings may require more time for pedestrians to traverse.

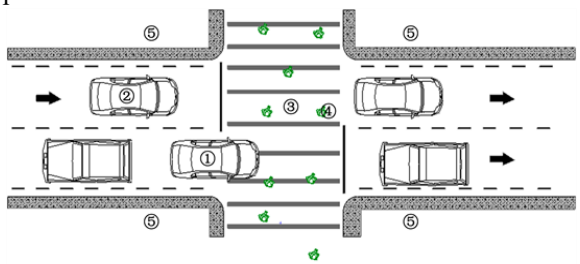

Fig 3: Parameters of pedestrian flow

3. Flow relationships

The flow relationships of pedestrian flow refer to the patterns, dynamics, and interactions that characterize the movement of pedestrians within a given space or transportation system. Understanding these flow relationships is essential for designing efficient and safe pedestrian infrastructure [13-15]. Pedestrian density is the number of pedestrians in a given area, while flow rate is the rate at which pedestrians move through that area. There is a relationship between these two variables—higher densities may lead to reduced flow rates as pedestrians navigate more slowly through crowded spaces. Pedestrian flow is influenced by walking speed. Different individuals, age groups, and situations can result in varying walking speeds. Flow relationships consider how variations in walking speed affect the overall movement of pedestrians within a space. Pedestrian capacity refers to the maximum number of pedestrians a particular space or infrastructure can accommodate efficiently. Saturation occurs when pedestrian density reaches a point where flow rates decrease, and congestion may occur. Understanding capacity and saturation is crucial for designing spaces that can handle pedestrian demand without compromising safety or efficiency. The design and layout of pedestrian infrastructure, including sidewalks, crosswalks, and pedestrian bridges, influence flow relationships [16-17]. Well-designed infrastructure encourages smoother flows, while poorly designed or congested areas may disrupt pedestrian movement. Pedestrians adapt their behaviour based on the surrounding environment. Flow relationships consider how pedestrians adjust their speed, spacing, and movements in response to factors such as crowding, obstacles, or changes in the built environment. Pedestrian flow relationships also involve understanding how individuals' cross streets and intersections. Crosswalk design, signal timings, and the presence of pedestrian-friendly features influence the patterns and efficiency of pedestrian crossings. Pedestrian flow is not only about individual behaviour but also about group dynamics. People often walk in groups, and understanding how these groups interact with the larger flow is crucial for predicting and managing pedestrian movements.

VI. CONCLUSIONS

The following conclusions are drawn from the study

1. The study delves into the complex decision-making process of pedestrians when navigating road crossings amidst mixed traffic conditions.
2. It highlights the pivotal role of various factors, including traffic volume, signal compliance, and the presence of infrastructure, in shaping pedestrian decision-making.
3. Acknowledging the diversity among pedestrian groups, the study underscores the unique considerations for specific demographics such as

children, elderly individuals, and people with disabilities.

4. The study emphasizes the significance of group dynamics and communication within pedestrian groups, recognizing their impact on decision-making processes.
5. Special attention is given to the needs of vulnerable road users, emphasizing the importance of catering to their specific requirements in road safety measures.
6. The study acknowledges pedestrian road crossing behaviour as a dynamic and evolving field, indicating the necessity for ongoing research and adaptive strategies to address emerging challenges and trends.

REFERENCES

[1]. Cherry, C.; Donlon, B.; Yan, X.; Moore, S.E.; Xiong, J. 2012. Illegal Mid-Block Pedestrian Crossings in China: Gap Acceptance, Conflict and Crossing Path Analysis, Journal of Injury Control and Safety Promotion. DOI: http://dx.doi.org/10.1080/17457300.2011.628751, 19(4): 320-330.

[2]. Dommes, A.; Cavallo, V.; Vienne, F.; Aillerie, I. 2012. Age-Related Differences in Street-Crossing Safety Before and After Training of Older Pedestrians, Accident Analysis & Prevention. DOI: http://dx.doi.org/10.1016/j.aap.2010.12.012, 44(1): 42-47.

[3]. Gupta, U.; Tiwari, G.; Chatterjee, N.; Fazio, J. 2010. Case Study of Pedestrian Risk Behaviour and Survival Analysis, Journal of the Eastern Asia Society for Transportation Studies, Vol. 8: 1-17.

[4]. Kadali, B.R.; Vedagiri, P. 2013. Modelling Pedestrian Road Crossing Behaviour under Mixed Traffic Condition, European Transport, 55(3): 1-17.

[5]. Lobjois, R.; Cavallo, V. 2007. Age-Related Differences in Street-Crossing Decisions: The Effects of Vehicle Speed and Time Constraints on Gap Selection in an Estimation Task, Accident Analysis & Prevention, 39(5): 934-943.

[6]. Rastogi, R.; Chandra, S.; Vamsheedhar, J.; Das, V.R. 2011. Parametric Study of Pedestrian Speeds at Midblock Crossings, Journal of Urban Planning and Development, 137(4): 381-389.

[7]. X. Zhuang, T. Zhang, W. Chen, R. Jiang, and G. Ma, "Pedestrian estimation of their crossing time on multi-lane roads", Accid. Anal. Prev., vol. 143, p. 105581, 2020.

[8]. S. Agarwal, and D. Vikram, "Impact of vehicular traffic stream on pedestrian crossing behaviour at an uncontrolled mid-block section", Transp. Res. Interdiscip. Perspect., vol. 9, p. 100298, 2021.

[9]. K. Tian, G. Markkula, and C. Wei, "Explaining unsafe pedestrian road crossing behaviours using a Psychophysics-based gap acceptance model", Saf. Sci., vol. 154, no. 6, p. 105837, 2022.

[10]. T. Ahmed, M. Moeinaddini, M. Almoshaogeh, A. Jamal, I. Nawaz, and F. Alharbi, "A new pedestrian crossing level of service (PCLOS) method for promoting safe pedestrian crossing in Urban Areas", Int. J. Environ. Res. Public Health, vol. 18, no. 16, p. 8813, 2021.

[11]. C. Avinash, A. Shriniwas, J. Gaurang, and P. Manoranjan, "Exploring stage-wise pedestrian-crossing behavioural patterns at vulnerable urban midblock: A perspective under heterogeneous traffic conditions", J. Transp. Saf. Secur., vol. 12, no. 7, 2019.

[12]. A. Chaudhari, N. Gore, S. Arkatkar, G. Joshi, and S. Pulugurtha, "Exploring pedestrian surrogate safety measures by road geometry at midblock crosswalks: A perspective under mixed traffic conditions", IATSS Res., vol. 45, no. 1, pp. 87-101, 2021.

[13]. K. Kamal, B. Farooq, M. Mudassar and A. Kalatian, "Ordered-logit pedestrian stress model for traffic flow with automated vehicles," 2022 IEEE Intelligent Vehicles Symposium (IV), Aachen, Germany, 2022, pp. 1831-1834.

[14]. M. Mudassar, A. Kalatian and B. Farooq, "Analysis of pedestrian stress level using GSR sensor in virtual immersive reality", *Collective Dynamics*, vol. 6, 2022.

[15]. A. Kalatian and B. Farooq, "Decoding pedestrian and automated vehicle interactions using immersive virtual reality and interpretable deep learning", *Transportation research part C: emerging technologies*, vol. 124, pp. 102962, 2021.

[16]. B. Farooq, E. Cherchi and A. Sobhani, "Virtual immersive reality for stated preference travel behaviour experiments: A case study of autonomous vehicles on urban

roads", *Transportation research record*, vol. 2672, no. 50, pp. 35-45, 2018.

[17]. P. Maruhn, A. Dietrich, L. Prasch and S. Schneider, "Analysing Pedestrian Behaviour in Augmented Reality — Proof of Concept," 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Atlanta, GA, USA, 2020, pp. 313-321.

[18]. S. Deb, D. W. Carruth, R. Sween, L. Strawderman and T. M. Garrison, "Efficacy of virtual reality in pedestrian safety research", *Applied Ergonomics*, vol. 65, pp. 449-460, 2017.

[19]. T. Fuest, L. Michalowski, L. Träris, H. Bellem and K. Bengler, "Using the Driving Behaviour of an Automated Vehicle to Communicate Intentions - A Wizard of Oz Study," 2018 21st International Conference on Intelligent Transportation Systems (ITSC), Maui, HI, USA, 2018, pp. 3596-3601.

[20]. Y. Jiang, E. E. O'neal, J. P. Yon, L. Franzen, P. Rahimian, J. M. Plumert, et al., "Acting together: Joint pedestrian road crossing in an immersive virtual environment", *ACM Trans. Appl. Percept.*, vol. 15, no. 2, pp. 8:1-8:13, Mar. 2018.

[21]. A. R. Palmeiro, S. van der Kint, L. Vissers, H. Farah, J. C. de Winter and M. Hagenzieker, "Interaction between pedestrians and automated vehicles: A wizard of oz experiment", *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 58, pp. 1005-1020, 2018.

[22]. A. Kalatian and B. Farooq, "DeepWait: Pedestrian Wait Time Estimation in Mixed Traffic Conditions Using Deep Survival Analysis," 2019 IEEE Intelligent Transportation Systems Conference (ITSC), Auckland, New Zealand, 2019, pp. 2034-2039.

[23]. A. Millard-Ball, "Pedestrians autonomous vehicles and cities", *Journal of Planning Education and Research*, vol. 38, no. 1, pp. 6-12, 2018.

[24]. P. Chen, C. Wu and S. Zhu, "Interaction between vehicles and pedestrians at uncontrolled mid-block crosswalks", *Safety science*, vol. 82, pp. 68-76, 2016.

[25]. A. Kalatian, A. Sobhani and B. Farooq, "Analysis of distracted pedestrians waiting time: Head-mounted immersive virtual reality application", *Proceedings of Pedestrian and Evacuation Dynamics 2018*, 2018.