

A Study of Pedestrian Crossing Behaviors on Major Urban Roads to Inform Road Safety Engineering Design

Jetsada Kumphong*, Punnarek Phangkham, Phot Sangkongplee

Faculty of Technical Education, Rajamangala University of Technology Isan
Khon Kaen Campus, Khon Kaen, Thailand

* Corresponding author E-mail: Jetsada.ku@rmuti.ac.th

Received 12 December 2025; Revised 6 August 2026; Accepted 2 September 2026

Abstract

Background and Objectives: Pedestrian safety is widely recognized as a critical public health and urban transport concern, particularly in rapidly growing urban areas of developing countries where pedestrian injury and fatality rates remain disproportionately high. Thailand faces significant challenges in mitigating these pedestrian safety risks. Taking Khon Kaen, which is a major regional transit node undergoing rapid expansion and vehicular growth, as a case study, the present research addresses the intensified conflicts between pedestrians and vehicles, particularly along major arterials with substandard crossing infrastructure. Although local agencies have attempted to implement safety measures, empirical studies remain limited regarding validated behavioral measurement tools that integrate psychological and context-specific environmental factors within the Thai urban context. To address this gap, the present study developed a pedestrian behavior measurement scale and investigated the socio-environmental, legal, and demographic factors influencing road-crossing decisions in urban Khon Kaen. The study indeed aimed to 1) develop and examine the construct validity of a pedestrian behavior measurement scale; and 2) investigate the relationship between pedestrian behavior factors and social, environmental, legal enforcement, and general variables (age, gender, occupation, and walking distance) on major roads in the urban areas of Khon Kaen.

Methodology: We conducted a quantitative survey among urban residents of Khon Kaen. We developed a 15-item questionnaire informed by behavioral theories, prior pedestrian safety studies, and observations of local traffic conditions. The questionnaire addressed attitudes toward crossing, risk-taking behaviors, safety awareness, and environmental concerns, including exposure to air pollution during road crossing. 400 participants completed the survey

(N=400), including students, workers, and the public, selected through random sampling. We used descriptive statistics for preliminary analysis; this was followed by Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). EFA was performed using orthogonal (Varimax) rotation, with acceptance criteria including Bartlett's Test of Sphericity ($p < 0.05$), Kaiser-Meyer-Olkin Measure ($KMO > 0.6$), and Cronbach's alpha for reliability. CFA was conducted to evaluate model fit using such indices as CFI, GFI, RMR, and CMIN/DF.

Main Results: The results reveal that the population exhibited attitudes related to safe pedestrian crossings and had frequently encountered air pollution while crossing the streets. Additionally, the EFA identified two new factors ($KMO = 0.735$, $Sig. = 0.000$) viz. Society and Environment, and Violations. The CFA indicated that the model demonstrated a good fit with the empirical data ($CMIN/DF = 1.890$, $GFI = 0.921$, $CFI = 0.901$, $RMR = 0.089$). Gender and individual pedestrian behaviors were found to be significantly associated with the Society and Environment factor ($p < 0.005$). Age was significantly related to the Violations factor ($p < 0.005$).

Conclusions: Based on our analysis of 9 questionnaire items, two distinct behavioral factors were identified: (1) Society and Environment, and (2) Violations. These factors were significantly associated with participants' gender, age group, and individual pedestrian behaviors. The study demonstrates that pedestrian behavior in Khon Kaen's complex urban environment is shaped by both environmental conditions and personal decision-making patterns. The questionnaire provides a systematic tool for measuring pedestrians' perceptions, risk awareness, and crossing behaviors. Together, the two latent factors capture how environmental influences, risky actions, and safety-oriented practices interact to shape pedestrian behavior. These empirical findings offer important insights that can inform traffic engineering strategies, guide urban management decisions, and support efforts to cultivate a stronger culture of pedestrian safety, especially in a similar context to that of Khon Kaen.

Practical Application: Our findings can inform the development of public safety campaigns and the design of pedestrian infrastructure, including raised crosswalks, pedestrian refuge islands, pedestrian signal systems, and improved street lighting. The results also support targeted enforcement efforts aimed at reducing risky crossing behaviors. By using pedestrians' perceptions and behavioral data as a foundation for urban design, planners and policymakers can enhance the safety and walkability of road systems in Khon Kaen and other cities in the future.

Keywords: Safe Crossings, Violations, Khon Kaen, Society, Urban Areas

Introduction

According to a report from the World Health Organization (WHO) in 2018, road traffic accidents cause 1.35 million deaths annually [1]. While global fatalities are high, the crisis is particularly acute in Thailand, which consistently ranks among the countries with the highest road traffic mortality rates worldwide, with pedestrian fatalities disproportionately accounting for approximately 8% of these deaths. Unlike developed nations where pedestrian safety is heavily integrated into urban design, transit hubs in Thailand—such as Khon Kaen—face unique localized challenges characterized by rapid, vehicle-centric urbanization, high vehicular density, and a severe deficit in pedestrian-friendly infrastructure.

In 2022, public awareness of pedestrian safety increased following a fatal incident in which a medical professional was killed on a zebra crossing [1-2]. This high-profile case underscored critical, systemic deficiencies within Thai road safety governance, specifically regarding weak legal enforcement against crosswalk violations, poor visibility of crossing infrastructure, and a driving culture that habitually deprioritizes pedestrian right-of-way [3]. Rather than an isolated behavioral error, this incident highlights a critical structural conflict where inadequate engineering controls—such as the passive warning systems shown in Figure 1—fail to adequately mitigate high-speed driving behaviors and safeguard pedestrians at designated crossings. [4]



Figure 1 Pedestrian Crossing Signs and Crosswalk Safety

Pedestrian-related accidents are a pressing global concern. The World Health Organization (WHO, 2018) reported that pedestrians account for over 23–26% of road traffic fatalities worldwide with the proportion increasing in low- and middle-income countries, especially in urban areas with high vehicle density. Karami et al. (2024) found that pedestrians' violations of traffic signals are associated with roadway characteristics, attitudes, and prior experiences, reflecting decision-making issues influenced by both psychological and environmental factors [5]. Similarly, Alsharif et al. (2024) emphasized that distracted walking such as crossing while using a mobile phone reduces pedestrians' distance from vehicles, slows their walking speed, and raises the likelihood of collisions by up to 46.5% in terms of traffic conflict severity compared to those who are not distracted [6].

Internationally, certain pedestrian risk behaviors have been categorized into the Pedestrian Behavior Scale (PBS), which classifies behaviors into five factors, which fall into 3 categories: Violations, Errors, and Lapses [7]. The studies, which compared pedestrian behaviors across ages, genders, and walking distances, showed that in general, older adults and women had exhibited more positive behaviors towards other road users [8]. Meanwhile, it was found that increased walking distance may lead to errors. Having an understanding of pedestrian attitudes and behaviors helps to address the needs of this road user group [7, 9-12]. Additionally, international research is also focused on two-wheeled vehicle behavior using tools, such as Motorcycle Rider Behavior Questionnaire (MRBQ), Moped Rider Behaviour Questionnaire, MRQ and Motorcycle Rider Driving Violation, CMRDV, for the purposes of policy development [13-16]. To systematically address these gaps, this study anchors the pedestrian behavioral analysis within a comprehensive conceptual framework integrating cognitive decision-making and risk perception theories. Rather than treating pedestrian actions as isolated events, our framework conceptualizes road-crossing behavior as a product of an individual's psychological evaluation of risk, which is continuously shaped by two distinct layers: internal demographic modifiers (age, gender, occupation, walking experience) and external environmental pressures (infrastructure quality and perceived legal enforcement). By modeling how these multi-dimensional factors interact to influence the sub-dimensions of the PBS, this paper establishes a theoretically grounded mechanism to explain why and how specific high-risk pedestrian behaviors manifest in a rapidly expanding regional city.

Literature Review

Factors Influencing Pedestrian Accidents and Crossing Behavior

In both developing and developed countries, multiple studies utilizing traffic accident records have significantly contributed to our understanding of pedestrian accidents and the factors that influence crossing behaviors. Over the past decade, researchers have increasingly monitored locations where pedestrian behavior is regulated. Risk analysis has expanded to encompass pedestrian accidents occurring across various road types, indicating that the determinants of pedestrian risk differ based on a range of contextual variables. These factors are synthesized in Table 1.

Table 1 Influential Factors Affecting Pedestrian Collision Risk and Crossing Behavior

Author	Road Type	Study Area and Method	Outcome Measure	Key Influencing Factor
Osorio-García et al. (2015) [17]	Street roads	Manizales, Colombia; Multiple Correspondence Analysis (MCA)	Risk associated with pedestrian crossing behavior	Road safety conditions, socioeconomic context, and gender were found to be significantly correlated with pedestrian risk profiles. Common risk behaviors included ignoring traffic signals and crossing in restricted zones.

Table 1 Influential Factors Affecting Pedestrian Collision Risk and Crossing Behavior (continued)

Author	Road Type	Study Area and Method	Outcome Measure	Key Influencing Factor
Budzynski et al. (2021) [18]	Urban areas	Poland; Two-sample t-test and Shapiro–Wilk test	Relationship between pedestrian risk and vehicle speed	Vehicle speed varied based on contextual factors including location, urban characteristics, road cross-section type, pedestrian control measures, and the presence or absence of pedestrian signals. Excessive speeding was commonly observed near crosswalks, indicating the need for improved and standardized crosswalk design. and standardized crosswalk design.
Arellana et al. (2022) [19]	Major streets	Barranquilla, Colombia; Logit model	Risk associated with pedestrian crossing behavior	Pedestrians preferred direct crossings over using footbridges. Footbridges and signalized intersections were perceived as viable alternatives when aligned with the origin or destination of a crossing route.

Table 1 Influential Factors Affecting Pedestrian Collision Risk and Crossing Behavior (continued)

Author	Road Type	Study Area and Method	Outcome Measure	Key Influencing Factor
Riaz et al. (2022) [20]	School zones	Flanders, Belgium; Pearson chi-square tests and binary logistic regression	Risk associated with pedestrian crossing behavior	Girls were more likely than boys to pause and observe traffic before crossing. Children holding an adult's hand exhibited safer behavior, whereas unaccompanied children displayed increased risk. The study emphasized the need for infrastructure improvements (e.g., raised crosswalks) and targeted educational interventions for both children and parents to promote safer crossing behavior.
Alsharif et al. (2024) [6]	Major urban signalized intersections in Vancouver with mixed traffic users.	Vancouver, Canada; Automated video analysis using Multi-Agent Adversarial Inverse Reinforcement Learning (MA-AIRL) on 741 pedestrian-vehicle interactions.	Interaction metrics: pedestrian-vehicle proximity, speed, TTC (Time-to-Collision), minimum distance, and conflict severity	Distraction type significantly affects speed, path, and conflict severity. Distracted pedestrians walk slower and closer to vehicles; drivers decelerate near them.

Table 1 Influential Factors Affecting Pedestrian Collision Risk and Crossing Behavior (continued)

Author	Road Type	Study Area and Method	Outcome Measure	Key Influencing Factor
Karami et al. (2024) [5]	Urban signalized intersections in Tehran; scenarios with straight, right-turning, and left-turning traffic.	Tehran, Iran; Online survey (n=2,250) using scenario-based visualization analyzed via Structural Equation Modeling (SEM) based on TPB and PWM.	Behavioral Intention to violate red light; constructs include attitude, subjective norm, perceived behavioral control, and facilitating conditions.	Facilitating conditions and attitude are strongest predictors; perceived behavioral control and traffic flow (More straight than turning) significantly influence violation intention.

Collectively, the studies summarized in Table 1 highlight a range of influential factors associated with pedestrian accidents in various crossing zones. Among these, gender frequently emerged as a salient factor. Females were generally found to exhibit more cautious decision-making such as increased attentiveness prior to crossing. Studies also found that age was also an important variable with older pedestrians or those of legal adulthood tending to demonstrate greater awareness of traffic safety and a more risk-averse approach when navigating road crossings.

A critical synthesis of the empirical evidence presented in Table 1 reveals distinct thematic trends and underlying methodological boundaries in contemporary pedestrian safety research. Critically comparing these findings yields strong agreements regarding demographic modifiers; for instance, both Riaz et al. [20] and standard consensus confirm that females and older pedestrians consistently demonstrate lower risk-taking and a more risk-averse approach prior to crossing. However, a major contradiction emerges when examining the interplay between infrastructure and actual pedestrian choice. While Budzynski et al. [18] emphasize that high vehicle speed near crosswalks necessitates standardized, active engineering controls, Arellana et al. [19] illustrate that pedestrians frequently experience a cognitive trade-off, routinely rejecting physical infrastructure like footbridges in favor of direct, un-signalized crossings if the designated infrastructure deviates from their immediate origin-destination line.

Furthermore, recent methodological advancements introduced by Alsharif et al. [6] and Karami et al. [5] highlight that pedestrian risk is not merely an isolated behavioral failure but a dynamic consequence of cognitive distractions (e.g., mobile phone usage slowing walking speeds by 46.5%) and psychological constructs like "facilitating conditions" derived from the Theory of Planned Behavior (TPB). The primary limitation of these prior studies is their heavy reliance on either highly controlled western transit contexts (e.g., Vancouver [6]) or purely online, scenario-based intentions (e.g., Tehran [5]). This leaves a critical gap regarding how actual pedestrian risk perception manifests under the compounded strain of substandard infrastructure and weak legal enforcement—a reality typical of secondary cities in developing nations like Khon Kaen. Consequently, the trend observed in Table 1 informs the current study of the urgent need to bridge physical engineering data with psychological drivers to construct a more localized, context-specific behavioral framework.

The Pedestrian Behavior Scale (PBS) and Its Application in Road Safety Policy

The Pedestrian Behavior Scale (PBS) is a widely adopted instrument for assessing pedestrian behavior which has been verified with a robust empirical validation [12]. Grounded in behavioral theory, PBS evaluates the psychological dimensions of pedestrian behavior, including their violations, errors, lapses, aggressive behaviors, and positive behaviors. However, the specific configurations of these dimensions may vary based on the pedestrians' national and cultural contexts. A summary of PBS-based studies and their findings is presented in Table 2 below.

Table 2 The Influence of PBS on Risky Pedestrian Behavior

Author	Number of Items and Participants	Assessed Behavior	Key Finding
Esmaili et al. (2021) [21]	47 items; 520 participants	Lapse, Transgression, Aggressive, Positive	The PBQ was validated for use among Iranian pedestrians across all age groups. Persian participants did not distinguish between violations and errors. Significant behavioral differences were observed by age, gender, and income. Negligent behavior was positively associated with self-reported pedestrian accidents. The findings suggest the potential for behavioral change following severe accidents.
Hasanat-E-Rabbi et al. (2021) [22]	20 items; 532 participants	Inattention, Aggressive Behaviors, Violations, Impermissible Behaviors	Positive attitudes toward road safety were linked to safer pedestrian practices. Younger males with lower educational attainment demonstrated more risky behaviors and expressed more dangerous attitudes toward road safety.
Shehadeh et al. (2024) [23]	40 items; 400 participants	Lapse, Transgression, Aggressive, Positive	The PBQ was validated for Jordanian pedestrians, inclusive of all age groups. Similar to the Iranian context, Jordanian participants did not differentiate between violations and errors. The scale's positive behavior dimension exhibited acceptable internal reliability ($\alpha > 0.7$). Male and younger pedestrians showed higher tendencies toward risky behavior. A lack of viable transportation alternatives was positively associated with unsafe pedestrian practices.

Table 2 The Influence of PBS on Risky Pedestrian Behavior (continued)

Author	Number of Items and Participants	Assessed Behavior	Key Finding
Zhang et al. (2025) [24]	32 items; 400 participants	Lapse, Transgression, Aggressive, Positive	Social norms, family environment, and safety-related attitudes were significant predictors of hazardous pedestrian behaviors such as violations, lapses, and aggression.

As illustrated by the empirical data in Table 2, a cross-cultural synthesis indicates that while the PBS consistently uncovers core behavioral risk categories—specifically lapses, transgressions, aggression, and positive actions—its structural dimensionality is highly sensitive to local traffic cultures. A profound methodological and cultural pattern emerges when comparing Middle Eastern contexts (Iran [21] and Jordan [23]) with East Asian contexts (China [24]). In both the Iranian and Jordanian settings, exploratory factor analyses revealed that participants did not statistically distinguish between "violations" (deliberate rule-breaking) and "errors" (unintentional misjudgments). This structural collapsing of dimensions represents a major deviation from western baseline models and points to a critical theoretical implication: in environments where traffic laws are loosely enforced or crosswalk infrastructure is ambiguous, the line between a deliberate violation and an accidental error becomes psychometrically blurred.

To move beyond a purely descriptive application of the PBS, this study integrates these behavioral constructs into a coherent conceptual framework rooted in Risk Perception and Cognitive Decision-Making processes, as mapped out in Figure 2. Within this integrated framework, a pedestrian's latent safety behavior is modeled not as an isolated event, but as a direct output of a multi-stage cognitive mechanism:

Risk Perception Pathway: Internal demographic modifiers (Age, gender, walking distance) and external social norms [24] continuously dictate how a pedestrian evaluates threat severity at a crossing zone.

Environmental & Legal Conditioning: Substandard environmental conditions (Such as the passive solar-powered signs in Thailand shown in Figure 1) and weak legal enforcement act as negative environmental catalysts. When infrastructure fails to actively command driver compliance, it inflates the pedestrian's cognitive load.

Decision-Making Output: This heightened cognitive strain directly triggers behavioral failures, manifesting either as involuntary Lapses (e.g., Inattention due to crossing anxiety) or deliberate Violations/Transgressions (e.g., Choosing to jaywalk because the designated crosswalk is perceived as equally unsafe).

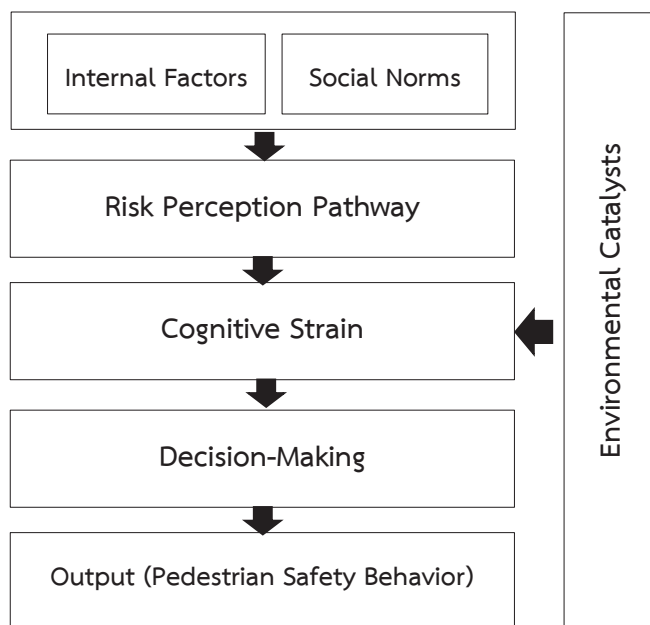


Figure 2 Conceptual Framework with Pedestrian Safety Behavior

Typically, In Thailand, driving behaviors are assessed using the Driver Behavior Questionnaire (DBQ), which consists of six factors: 1) Improper Lookout, 2) Inattention, 3) Decision Errors and Not Wearing Seat Belts, 4) Traffic Violations, 5) Aggressive Driving, and 6) Internal Distractions. All of these factors are used to plan traffic safety [25-26].

As mentioned above, Thailand does not have a standardized questionnaire for pedestrian crossing behaviors for those involved in planning road safety or making policies. This study aimed at 1) develop and examine the construct validity of a pedestrian behavior measurement scale; and 2) to investigate the relationship between pedestrian behavior factors and social, environmental, legal enforcement, and general variables (age, gender,

occupation, and walking distance) on major roads in the urban areas of Khon Kaen Province of Thailand.

Methodology

This article presents a structural hypothesis for a model of pedestrian crossing behavior on main roads, based on latent factor structures. Reason (1990) studied human behaviors and classified actions into two types: 1. Intentional actions, which include violations and mistakes, and 2. Unintentional actions, which include slips and lapses. In the same year, the human error theory was applied to the study of human errors and violations in road use. Personal factors (Gender, age) were also found to influence behavioral expression. To establish a clear conceptual clarity, this study proposes that personal factors do not merely correlate with behavior as a whole, but distinctly influence specific dimensions of intentional and unintentional crossing behaviors. Grounded in this theoretical framework and as shown in Figure 3, the general hypothesis is expanded into the following specific, testable hypotheses:

H1: Personal factors (Age and gender) significantly influence intentional pedestrian crossing behaviors (Violations and mistakes).

H1a: Younger pedestrians and male pedestrians exhibit a higher frequency of intentional violations during crossing.

H2: Personal factors (Age and gender) significantly influence unintentional pedestrian crossing behaviors (Slips and lapses).

H2b: Older pedestrians experience a higher frequency of unintentional lapses or slips during crossing.

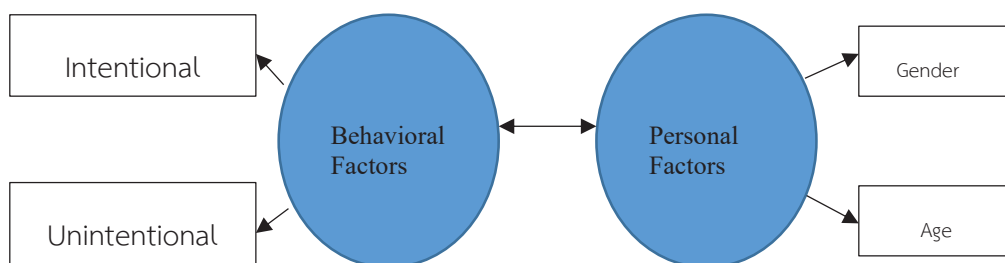


Figure 3 Conceptual Framework of the Hypothesis

Sample Population and Size

This study focused on pedestrians using crossings or zebra crossings on major urban roads in Khon Kaen, Thailand. We recruited volunteers to hand out questionnaires to pedestrians at crossings located near areas with concentrated populations such as shopping centers and educational institutions. To ensure data reliability and consistency, the data collection process was strictly controlled for timing and environmental factors. Data were collected over a two-week period, specifically during both peak hours (11.30 AM.-01.00 PM.; 04:30–06:00 PM.) and off-peak hours (01:00 PM.–02:00 PM.) on both weekdays and weekends to capture diverse pedestrian behaviors. Furthermore, data collection was conducted exclusively during clear weather conditions (Dry road surfaces and normal daylight) to control for external environmental variables, as adverse weather (e.g., Heavy rain) could abnormally alter pedestrian crossing speed and decision-making. To minimize bias from external distractions, volunteers were instructed to approach pedestrians only after they had safely completed their crossing as shown in Figure 4.

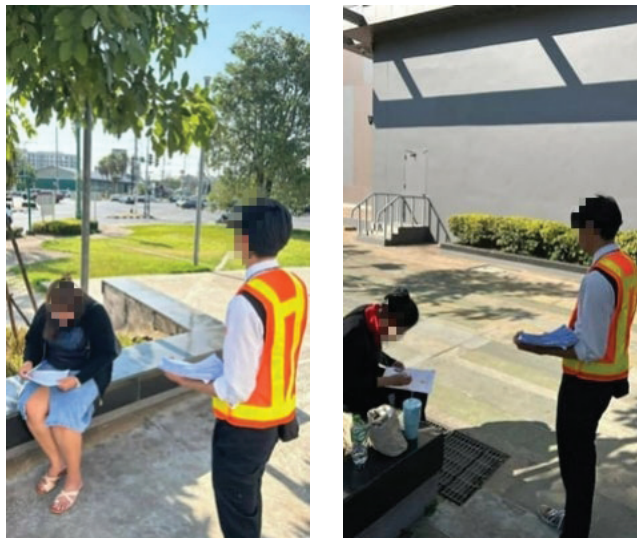


Figure 4 Examples of Field Data Collection

Only participants with actual experience crossing major roads were included; individuals without such experience were not surveyed further [27]. In general, these roads consist of more than three lanes, with high-speed traffic and heavy congestion. A quota sampling method was used to collect 400 questionnaires, complemented by simple random sampling [28]. For analysis, the sample was divided into two groups: 280 cases for Exploratory Factor Analysis (EFA) and 120 cases for Confirmatory Factor Analysis (CFA).

Research Instruments

The questionnaire consisted of two parts: 1) demographic information (e.g., gender, age, job, walking activity) and 2) crossing behavior. The developed questionnaire was based on a report related to pedestrian behaviors and consisted of 15 questions. The questions were adapted from international tools, such as PBS, and were supplemented with newly developed items that were based on survey feedback. As shown in Table 3. The final selection was comprised of questions, which were assessed using the following Likert scale: 0 = Never, 1 = Sometimes, 2 = Occasionally, 3 = Often, and 4 = Regularly [7].

Table 3 reports means and standard deviations for all 15 items. The highest-endorsed item was P15 ("You are careful when crossing at a crosswalk," Average = 3.46, S.D. = 0.88), followed closely by P11 ("Recognition of the importance of zebra crossings," Average = 3.42, S.D. = 1.06) and P2 ("Exposure to pollution/exhaust while walking," Average = 3.21, S.D. = 1.00). The lowest-endorsed item was P12 ("Fear of street vendors present at crossings," Average = 1.89, S.D. = 1.34). This pattern is itself analytically informative: the two highest-endorsed items reflect self-reported protective cognition (carefulness, recognition of crosswalk importance) rather than risk behavior, while the third-highest item reflects an environmental exposure (pollution) that is structurally outside the pedestrian's own behavioral control—an early indication, corroborated by the subsequent factor analysis, that self-reported "behavior" in this sample is substantially entangled with self-reported environmental exposure.

Table 3 Questionnaire on Pedestrian Crossing Behavior and Preliminary Survey Results

Number	Question	Average (S.D.)
P1	You often notice that the surfaces of the sidewalk are damaged.	2.97 (1.08)
P2	You often encounter pollution, such as dust or vehicle exhaust fumes, while walking.	3.21 (1.00)
P3	You often find that there are no designated crossings, zebra crossings, or clearly marked pedestrian paths.	2.52 (1.01)
P4	You often encounter hot sun or rain without shade or shelter while crossing the road.	2.81 (1.07)

Table 3 Questionnaire on Pedestrian Crossing Behavior and Preliminary Survey Results (continued)

Number	Question	Average (S.D.)
P5	You are afraid of being bitten by dogs while walking (in cases where stray dogs are present near the crossing).	2.34 (1.40)
P6	You often see vehicles parked on sidewalks or blocking the zebra crossings while pedestrians are crossing.	2.72 (1.06)
P7	You often find that pedestrian infrastructure is inconvenient or inefficient.	2.51 (1.09)
P8	You often notice that pedestrian crossings lack warning signs or crossing signs.	2.47 (1.08)
P9	You walk further than 150 - 300 meters	2.46 (1.24)
P10	You are aware that areas leading to pedestrian crossings should have speed reduction warning signs.	3.18 (1.11)
P11	You recognize the importance of zebra crossings for pedestrian safety and always use them when crossing the street.	3.42 (1.06)
P12	You have felt afraid of street vendors, who are present at zebra crossings.	1.89 (1.34)
P13	You often find yourself hesitant or afraid to cross the street.	2.50 (1.24)
P14	You often carry heavy belongings, which makes it difficult to cross the zebra crossing.	2.44 (1.18)
P15	You are careful when crossing at a crosswalk.	3.46 (0.88)

Data Analysis

Descriptive statistics, including means and standard deviations, were used for the preliminary analysis. Exploratory Factor Analysis (EFA) was conducted using computer software. The aim of the analysis was to determine factor structures and to apply orthogonal rotation (Varimax). The criteria for acceptance consisted of Bartlett's Test of Sphericity (p -value < 0.05), and the Kaiser-Meyer-Olkin Measure ($KMO > 0.6$). To ensure a rigorous and transparent factor

extraction process, items were iteratively evaluated and removed based on specific statistical and theoretical criteria. Specifically, items were retained only if their factor loadings were greater than 0.40, a threshold justified by Hair et al. [29] as practically significant for sample sizes within our range. Furthermore, items with cross-loadings were eliminated to preserve discriminant validity. Any elimination was also cross-checked against theoretical relevance to ensure the conceptual integrity of the latent constructs. Cronbach's Alpha was used for reliability analysis (Threshold > 0.60).

We conducted Confirmatory Factor Analysis (CFA) to examine the model fit with empirical data. To evaluate whether the reported model fit was satisfactory, the obtained results were critically interpreted and benchmarked against established methodological threshold criteria. The acceptable goodness-of-fit thresholds were defined based on Hair et al. (2010) [29] as follows: Comparative Fit Index (CFI) ≥ 0.90 , Goodness-of-Fit Index (GFI) ≥ 0.90 , Root Mean Square Residual (RMR) ≤ 0.05 (or Standardized RMR ≤ 0.08 ; Marginal Fit RMR $0.08 < x < 0.1$), and the ratio of chi-square to degrees of freedom (CMIN/DF) ≤ 3.0 . The empirical model fit indices were then explicitly compared against these benchmarks to evaluate model strengths, while any minor shortfalls or potential limitations in specific indices were critically discussed in relation to the sample characteristics [29-30]. In addition, simple correlation analysis was employed to assess the relationships between factors [31-32].

Results and Discussion

A total of 400 responses were collected, with 52% male and 48% female participants. The age distribution of the participants was as follows: 10-20 years of age (48%), 21-30 years of age (31%), 31-40 years of age (11%), and over 40 years of age (10%). The majority (72%) were students, while 10% were government employees and 18% had other occupations. The average walking distance per day was 1,186 meters.

Based on the Exploratory Factor Analysis (EFA) with a sample size of 280, Table 4 presents the results. The analysis yielded a KMO value of 0.735 and Bartlett's Test of Sphericity (Approx. Chi-Square = 425.288, df = 36, Sig = 0.000), considering 9 items, indicating that factor analysis was appropriate. Six items, however, did not meet the criteria and were therefore removed from the analysis. The results identified two distinct latent factors: (1) Society and Environment and (2) Violations. The factor loading values that had exceeded 0.4 were considered to be significant.

Table 4 The Results of the Exploratory Factor Analysis (N = 280)

Risk Behavior	Factor Loading	
	1	2
You often find yourself hesitant or afraid to cross the street. P13	0.771	
You often carry heavy belongings, which makes it difficult to cross the zebra crossing. P14	0.712	
You have felt afraid of street vendors, who are present at zebra crossings. P12	0.620	
You often notice that pedestrian crossings lack warning signs or crossing signs. P8	0.619	
You often find that pedestrian infrastructure is inconvenient or inefficient. P7	0.558	
You often notice that the surfaces of the sidewalk are damaged. P1		0.779
You often encounter pollution, such as dust or vehicle exhaust fumes, while walking. P2		0.726
You often find that there are no designated crossings, zebra crossings, or clearly marked pedestrian paths. P3		0.621
You often see vehicles parked on sidewalks or blocking the zebra crossings while pedestrians are crossing. P6		0.540
Eigenvalues	2.717	1.540
% Variance Explained	30.187	17.116
Cronbach's Alpha values	0.681	0.616
Total questions	5	4

The results of the Confirmatory Factor Analysis (CFA) confirmed the fit of the structural equation model, illustrating the relationships among the factors as well as the associations between variables within the model. The statistical indices showed that Factor 1 (Society and Environment) comprised items P7, P8, P12, P13 and P14, while Factor 2 (Violations) comprised items P1, P2, P3, and P6. These results are presented in Table 5 and Figure 5, which show the adjusted model, indicating that the model demonstrated a good fit with the empirical data.

Moreover, the results of the Confirmatory Factor Analysis (CFA) further validated this two-factor structural equation model. As shown in Table 5 and Figure 5, the empirical data demonstrated a satisfactory fit with the benchmarks ($\text{CMIN/DF} = 1.890 < 3.0$, $\text{GFI} = 0.921 > 0.90$, and $\text{CFI} = 0.901 > 0.90$). Although the RMR value (0.089) slightly deviated from the strict standard, the overall indices confirm that the measurement model is robust. Rather than merely listing these statistical outputs, a critical synthesis of the factor structures reveals deep insights into pedestrian psychology. Factor 1 (Society and Environment) captures the "Risk Perception and Psychological Vulnerability" of pedestrians, driven strongly by items like fear of crossing (P13, loading = 0.771) and physical burdens (P14, loading = 0.712). This indicates that pedestrian behavioral hesitation is not random but is a direct psychological reaction to unsafe environmental stimuli, such as a lack of warning signs (P8) and street vendors blocking crosswalks (P12). On the other hand, Factor 2 (Violations) reflects the "Intentional Decision-Making Process" where pedestrians deliberately violate safety norms (e.g., crossing where there are no marked paths (P3, loading = 0.621)) as a coping mechanism against broken infrastructure (P1) and vehicle obstructions (P6). Evaluated through Reason's (1990) Human Error Theory, Factor 2 maps directly onto "Intentional Violations," where the surrounding environment actively reshapes a pedestrian's risk perception, transforming a law-abiding citizen into a risk-taker due to poorly managed physical structures.

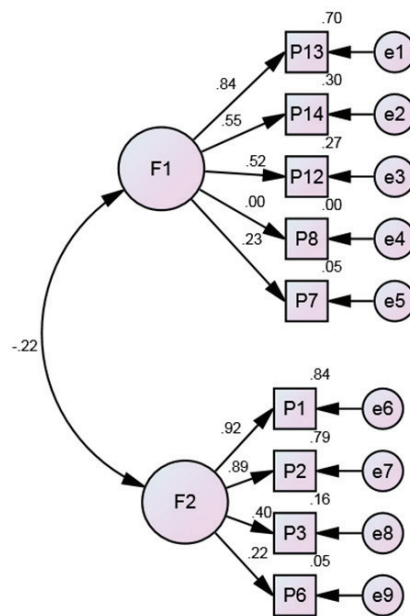


Figure 5 Confirmatory Factor Analysis (CFA) Model

Table 5 Model Fit Indices (N=180)

Model Fit Indices	Model
CMIN/DF (X < 3.0)	1.890
GFI (X > 0.90)	0.921
CFI (X > 0.90)	0.901
RMR (X < 1)	0.089

Table 6 shows that the Gender variable had significantly correlated with the Age variable, Walking distance, and Society & the Environment at a statistically significant level. Also, Age had significantly correlated with Occupations and Violations. Additionally, the average daily walking distance had significantly correlated with the variable of Society & the Environment at a statistically significant level.

Table 6 The Factor Correlation Values

	Gender	Age	Occupation	Walking distance	Society & the Environment	Violation
Gender	1	-0.083	-0.065	-0.133 [*]	0.291 ^{**}	0.092
Ages		1	0.347 ^{**}	-0.152 [*]	0.062	0.130 ^{**}
Occupations				-0.090	0.104	0.032
Walking distances				1	-0.133 [*]	-0.006
Society & the Environment					1	0.253 ^{**}
Violations						1

Note: * = P < 0.05; ** = P < 0.001

This study aimed to examine the construct validity of a pedestrian behavior measurement scale and investigate the relationships between latent factors and socio-demographic variables on major urban roads in Khon Kaen, Thailand.

Our empirical findings both extend and contrast with existing international literature. While prior studies, such as the Pedestrian Behavior Scale (PBS) applied in Serbia, catego-

rized pedestrian actions into five distinct dimensions (Violations, Lapses, Positive, Errors, and Aggressive), our factor analysis consolidated these into two primary dimensions: Society & the Environment, and Violations [7]. This divergence highlights a critical contextual difference: in developed western countries, pedestrian risks are often individualistic (e.g., lapses or aggression) [7], whereas in developing transit environments like Thailand, pedestrian risk behaviors are heavily structural, tightly merging physical environmental stressors with traffic law non-compliance.

Furthermore, Table 6 reveals crucial socio-demographic correlations that align with, yet contextualize, prior research. Gender significantly correlated with Society & the Environment ($r = 0.291$, $p < 0.001$), indicating that female pedestrians possess a much higher risk perception and anxiety toward environmental deficiencies than male pedestrians. This confirms the findings of international studies which state that women are more sensitive to surrounding environmental safety [7, 33]. Conversely, Age showed a significant positive correlation with the Violation factor ($r = 0.130$, $p < 0.001$). This finding directly contradicts previous western literature where younger pedestrians (aged 17–25) usually exhibit higher violations [7, 21]. In our study, older pedestrians in Khon Kaen displayed higher violation frequencies. A plausible explanation for this divergence is that older pedestrians suffer more from physical deterioration, forcing them to make "intentional violations" (such as crossing at unmarked mid-block sections) to avoid walking long distances to poorly maintained or inaccessible pedestrian infrastructure.

Previous studies have highlighted a common focus on analyzing pedestrian risk behavior through the lens of decision-making or behavioral intention and pedestrian–vehicle interaction, often framed within technology-driven approaches and behavioral simulations. These two perspectives can be integrated in research contexts to explain both internal factors (e.g., attitude, perceived control, risk perception) and external factors (e.g., traffic flow, distraction, crossing facility design), which are further connected to social elements or physical infrastructure similar to the present study. However, our research contributes new insight by specifically examining the relationship between pedestrian crossing behavior factors and individual demographic factors, particularly in developing countries where cultural norms of road use, law enforcement, and crossing facilities are less systematic [5-6].

Moreover, the study found that on average, the men had walked more than the women, and that this was significantly related to the factor of the Society & the Environment.

International studies have indicated that men tend to exhibit more violations and aggressive behaviors compared to women [7-8]. In response, many countries have placed emphasis on measures to protect female pedestrians, such as installing streetlights, CCTV cameras, or reflective strips as shown in Figure 6, 7 and 8 [4, 33]. In Japan, warning sounds are used to alert drivers when pedestrians are in the crosswalks [34].

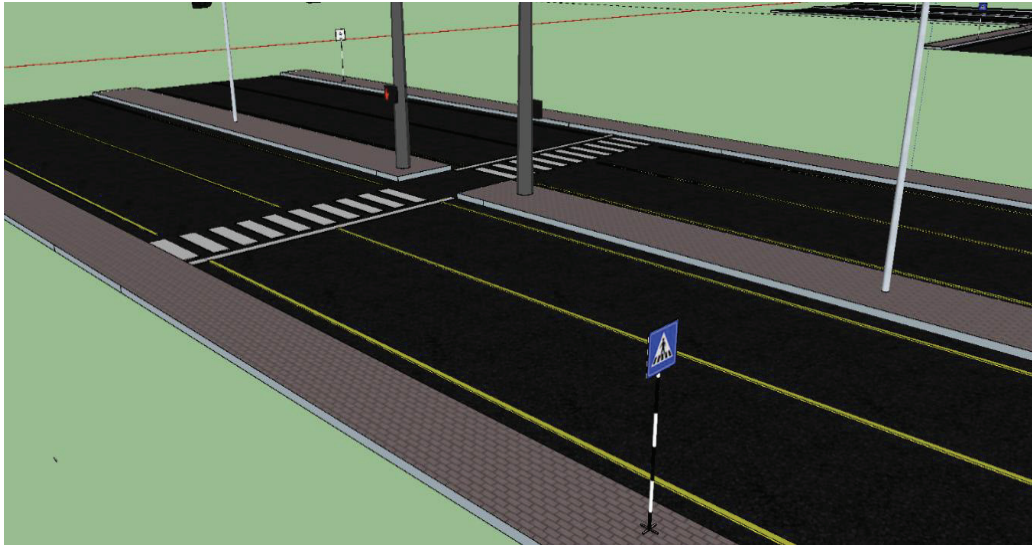


Figure 6 Example of Design for Pedestrian's Behavior at Push-Button Crossings

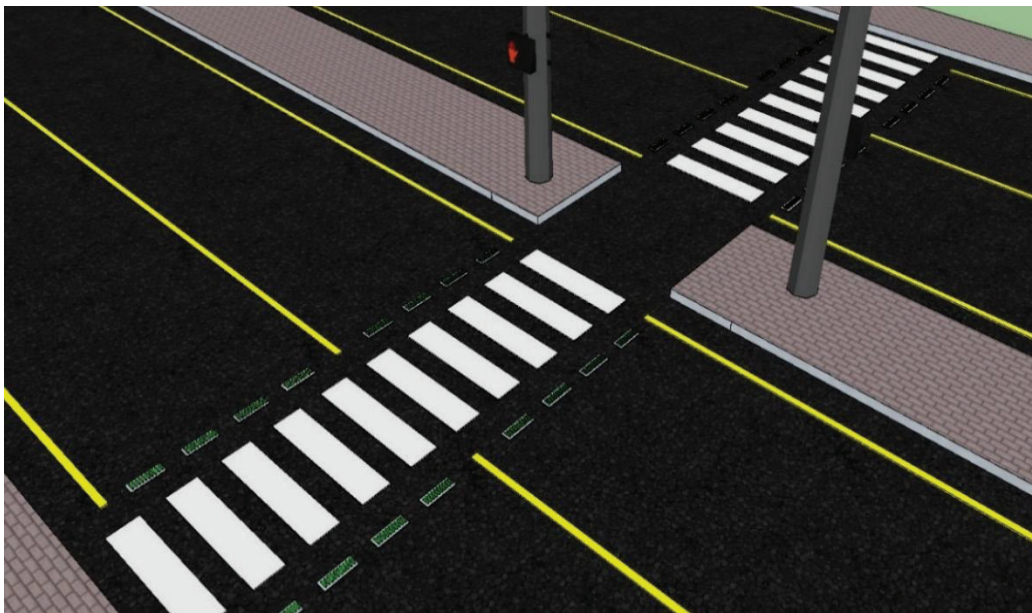


Figure 7 Example of Design for Pedestrian Crossing LED Lighting



Figure 8 Pedestrian Crossing LED Lighting in Khon Kaen University, Thailand

The findings also showed that age had shown a statistically significant positive correlation with the Violation factor, suggesting that pedestrians, who have more experience using crossings may be exposed to poorly maintained infrastructure. International studies revealed that pedestrians aged 17–25 had exhibited more violation behaviors compared to those in the age range of 25–49. This highlights the fact that maturity contributes to better decision-making and reduces risk behaviors [7, 21]. Additionally, this study revealed a statistically significant negative correlation between average walking distance and the factor of society and the environment. This implies that when pedestrians frequently encounter unfavourable walking conditions like poor pavement surfaces and air pollution, they are less likely to choose walking as a primary mode of transportation [7, 33].

Road Safety and Behavioral Determinants

To promote intentional and effective pedestrian safety interventions, in this study we identified statistically significant factors associated with crossing behavior. Our findings

revealed a negative correlation between walking distance and the factor labeled Society and the Environment, indicating that longer walking distances are associated with reduced pedestrian activity. This suggests the need to enhance environmental and social conditions to make walking a more favorable and accessible mode of transportation. Accordingly, intervention programs and safety education initiatives should target modifiable factors to encourage safer walking practices. For instance, safety campaigns might aim to foster positive attitudes toward pedestrian norms and behaviors, particularly in relation to rule adherence and risk awareness. Educational content could emphasize the dangers associated with traffic violations and pedestrian negligence such as failing to observe traffic signals or crossing in unauthorized zones. Empirical evidence indicates that many pedestrian accidents occur due to inattentiveness to environmental cues, including traffic lights and restricted crossing areas. Furthermore, limited public endorsement and infrastructural support for pedestrian overpasses contribute to direct, and often unsafe, street-level crossings. Although pedestrians frequently prefer ground-level crossings for convenience, well-placed overpasses and signalized intersections can serve as viable alternatives—particularly when aligned with pedestrian desire lines, such as between schools and commercial centers [12, 19].

Engineering Measures and Pedestrian Behavior

Building upon the behavioral findings, engineering interventions play a crucial role in facilitating safe pedestrian crossings. Targeted strategies must be implemented by relevant authorities to reduce the risk of collisions and promote safe crossing behaviors. Engineering-based countermeasures—grounded in empirical evidence—should prioritize the modification of environmental risk factors. The implementation of standardized, well-designed crosswalks, traffic-calming measures such as reduced vehicle speeds near pedestrian zones, and the installation of visible signage and lighting are fundamental components of effective road safety infrastructure. Elevated pedestrian crossings, such as footbridges, may serve as a particularly effective solution, provided they are contextually integrated with surrounding land use and pedestrian traffic patterns [18].

In parallel with research using the Pedestrian Behavior Scale (PBS), studies in driver behavior have also informed understandings of road safety [21-24]. For instance, Özkan et al. (2006) employed the Driver Behavior Questionnaire (DBQ) to identify dimensions such as errors and violations [35], while Lajunen et al. (2004) identified four key factors: aggressive

violations, ordinary violations, errors, and lapses. These findings underscore that rule-breaking behaviors are not exclusive to any one mode of transport; rather, such tendencies are common across pedestrian and driver populations alike. The influence of socio-demographic and contextual variables—particularly gender, age, educational level, and road conditions—has been consistently observed in shaping pedestrian behavior [36]. As such, addressing risky pedestrian behavior requires both individual and systemic efforts. Individual road users must cultivate discipline, follow traffic regulations, and engage in courteous road-sharing practices. If such behavioral norms are internalized across the population, pedestrian-related accidents—especially at crossing points—can be substantially mitigated. Beyond individual behavior, structural improvements to the built environment are necessary. Regular inspection and maintenance of roadways and sidewalks, ideally conducted at least annually, are critical to sustaining safe pedestrian infrastructure. Based on the study's findings, the following recommendations are proposed to address the two key dimensions associated with pedestrian safety:

1. Society and the Environment: Interventions for Society and Environment (Targeting P7, P8, P12, P13, P14): Since high factor loadings were found for pedestrian fear (P13) and physical inconvenience (P7, P14), urban planners must optimize crosswalk ergonomics. As conceptualized in our 3D engineering models (Figure 6, 7, and 8), major crossings near high-activity zones must install smart push-button signals synchronized with pedestrian walking speeds to reduce anxiety. To mitigate the fear of walking/crossing conditions, the physical environment must be upgraded by clearing street vendors from crosswalk buffer zones (P12) and installing highly visible embedded LED crosswalk lighting (Figure 7 and 8) to improve night-time visibility and driver yielding rates.

2. Violations: Interventions for Violations (Targeting P1, P2, P3, P6): The significant correlation between broken pavements (P1), vehicle obstruction (P6), and pedestrian violations dictates a shift toward strict environmental enforcement and proactive maintenance. Municipal authorities must implement smart enforcement cameras (CCTV) at zebra crossings to heavily penalize vehicles parking or stopping on crosswalk lines (P6). Since poor pavement surfaces (P1) and high pollution (P2) drive pedestrians to abort walking (Negative correlation with walking distance, Table 6), Khon Kaen urban authorities should mandate annual sidewalk audits and install continuous, shaded, barrier-protected pedestrian paths. This infrastructure design will physically deter mid-block crossing violations (P3) while

restoring the environmental quality required to encourage walking as a safe and viable mode of urban transit.

Research Contributions

Methodological contribution: The study demonstrates that a compact, nine-item instrument retained from an original fifteen-item pool through a psychometrically rigorous EFA-CFA pipeline can achieve acceptable structural fit for field deployment, in contrast to the 32-47-item PBS variants used in comparable Iranian, Jordanian, and Chinese validations [21, 23-24]. This has direct value for road-safety agencies that require rapid, low-burden diagnostic tools rather than lengthy academic instruments. **Theoretical contribution:** By showing that a factor conventionally interpreted through Reason's (1990) violation construct instead loads on environmental-exposure items, the study extends the human-error taxonomy's applicability boundary: it suggests that in infrastructure-deficient developing-city contexts, the taxonomy requires an explicit exposure dimension that is conceptually prior to, and empirically separable from, dispositional violation - a theoretical refinement rather than a rejection of the underlying framework.

Theoretical Implications

Theoretically, the study contributes to the ongoing cross-cultural validation literature on the Pedestrian Behavior Scale by adding a new documented instance of structural non-invariance, this time in a Southeast Asian secondary-city context previously absent from that literature (Table 1 and Table 2). More consequentially, it proposes and grounds in item-content evidence rather than assertion a refinement to Reason's (1990) human error taxonomy for developing-infrastructure contexts: that self-reported "violation" measures administered in environments with substantial infrastructural deficiency require explicit disambiguation between dispositional rule-breaking and environmentally imposed exposure, since the two are empirically difficult for respondents to distinguish and may load on the same latent construct if not designed against from the outset. This is a testable proposition for future confirmatory work, and one that has direct bearing on how self-report pedestrian behavior instruments should be designed and interpreted across the wider developing-world literature, not solely in Thailand.

Practical Implications

The confirmed factor structure translates directly into differentiated engineering priorities. Because the environmental-exposure factor loads on pavement condition, pollution, marking absence, and sidewalk obstruction, the most defensible engineering response is infrastructural: raised crosswalks and pedestrian refuge islands to reduce effective crossing distance and speed exposure, formalized and well-maintained crossing markings where none currently exist, enforcement of no-parking/no-obstruction zones at crossing approaches, and given the salience of pollution exposure in both the descriptive and factor-analytic results, consideration of vegetative buffering or route-level air-quality mitigation near high-volume arterials. Because the vulnerability/hesitancy factor loads on signage adequacy, perceived infrastructural inconvenience, and burden-related hesitancy, complementary interventions include improved pedestrian signal systems and street lighting, and clearer approach-side warning signage (Figure 9), both of which the source project's findings identify as consistent with respondent-reported gaps.



Figure 9 Example of Supplementary Advance Warning Sign Installation Prior to Pedestrian Crossings near School Zones

In July 2026, the Khon Kaen Road Accident Reduction Community convened a multi-sectoral stakeholder meeting integrating all agencies relevant to road safety management. One of the primary consensus conclusions reached was the imperative to upgrade pedestrian safety through engineering infrastructure, rigorous law enforcement, and public awareness campaigns targeting road users. Pedestrians constitute the primary segment of Vulnerable

Road Users (VRUs)—frequently belonging to disadvantaged and low-income populations who bear the highest risk on the road network (Figure 10).

Regarding operational enforcement, the Royal Thai Police has officially launched a digital platform enabling motorists to check outstanding traffic tickets online. Crucially, authorities emphasized that failure to settle fines will result in the withholding of vehicle tax decals (Annual registration renewal). This initiative represents a strategic collaboration between the Royal Thai Police and the Department of Land Transport to elevate traffic law enforcement through integrated digital linkage of the "new-generation traffic ticketing system," thereby enhancing transparency and auditability prior to fine payment. The system commenced full-scale nationwide operation on August 1, 2026. Notably, among the ten primary enforcement violations prioritized for strict police action is the failure to yield to pedestrians at crosswalks (Carrying a maximum fine not exceeding 4,000 THB).



Figure 10 Stakeholder Meeting of the Khon Kaen Road Accident Reduction Community

Policy Implications

The age-environmental-exposure association implies that enforcement and educational resources should not be uniformly distributed across the pedestrian population but concentrated near land uses generating high volumes of younger pedestrians - schools, universities, and youth-oriented commercial districts where this study's own sampling frame was concentrated and where the exposure association was strongest. Because the study reframes the "Violations" dimension as substantially infrastructural rather than dispositional (Table 1 and Table 2), policy resources allocated to pedestrian-directed enforcement campaigns should be rebalanced toward infrastructure maintenance budgets and away from an exclusive focus on pedestrian

conduct enforcement, which the evidence here does not support as the primary causal lever. The salience of street-vendor-related fear (P12) further suggests that municipal vendor-zoning and crossing-clearance ordinances warrant explicit coordination between road-safety and municipal-licensing authorities - an inter-agency linkage rarely made explicit in road-safety policy documents but directly implied by this study's item-level evidence.

Conclusion, Limitations and Suggestions

In this study, based on the empirical analysis of 15 questionnaire items from 400 respondents, we have successfully addressed both of our core research objectives. Initially, regarding Objective 1 (to develop and examine the construct validity of a pedestrian behavior measurement scale), the Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) successfully consolidated and validated 9 remaining core questions into two robust latent dimensions: 1) Society & the Environment, and 2) Violations. This structural model demonstrates that pedestrian risk is not a single-dimensional issue but is split between environmental stressors and intentional law-breaking actions. Critically reflecting on these factor structures, the most frequently reported experience was *"You are careful when crossing at a crosswalk,"* which demonstrates a baseline safety awareness among pedestrians. Conversely, the least reported item was *"You have felt afraid of street vendors, who are present at zebra crossings,"* indicating that physical obstacles, while inconvenient, do not completely paralyze pedestrian movement. Moreover, regarding Objective 2 (to investigate the relationships between pedestrian behavior factors and socio-demographic variables), our correlation analysis confirmed that these two latent factors are significantly shaped by gender, age, and individual walking behaviors. Critically, our findings highlight a critical intersection where female pedestrians experience significantly higher environmental anxiety, whereas older pedestrians are driven toward higher violation frequencies due to the poorly maintained infrastructure in Khon Kaen. By explicitly linking our findings back to these objectives, this study offers a valid, theoretically grounded framework that clarifies how individual demographics and structural deficits in transit environments collectively dictate pedestrian risks in a developing country context.

Beyond these confirmatory findings, close examination of item content against factor labels indicates that what has conventionally been termed a "Violations" dimension in this and related instruments more plausibly reflects environmental and infrastructural deficiency exposure than dispositional rule-breaking in this context—a reinterpretation with direct

consequences for whether road safety resources should prioritize enforcement or infrastructure. Taken together, these findings offer road safety agencies and urban planners in Khon Kaen, and in structurally comparable developing secondary cities, an empirically grounded, field-deployable basis for moving beyond reactive, single-incident-driven safety campaigns toward differentiated, evidence-prioritized engineering and policy interventions.

Limitations

Despite its significant academic and practical contributions, several limitations of this study must be acknowledged to ensure scientific transparency. Initially, the data relies entirely on self-reported questionnaires, which may introduce social desirability bias or recall bias, as participants might underreport their actual risky behaviors (Such as intentional traffic violations). Moreover, the study utilized a combined quota and simple random sampling method confined to major urban roads in Khon Kaen, Thailand. Consequently, the context-specific nature of these findings may limit their generalizability to rural areas or cities with drastically different socio-economic and infrastructural systems. Lastly, the RMR fit statistic (0.089), while within the stated threshold, is close to the more conservative benchmark used elsewhere in the SEM literature, and the study collected no independent observational or video-based behavioral data against which self-reported behavior could be validated—a gap the original project itself explicitly identifies as necessary future work.

Suggestions for Future Research

In further research, the questionnaire should be refined to include more specific items. Likewise, the instrument should be refined to reinstate high-relevance excluded content - most notably mobile-phone use while crossing, walking distance, and speed-reduction-sign awareness - using a revised item pool subjected to a fresh EFA-CFA cycle on a larger, more demographically balanced sample

Additionally, to overcome the limitation of self-reported data, future observational studies (e.g., CCTV monitoring [37]) should be conducted to compare self-reported behaviors with actual pedestrian behaviors. This multi-method approach would enhance data reliability, control for response biases, and provide comprehensive insights into pedestrian behaviors across diverse urban environments.

Acknowledgments

This research article is part of the project titled “Study of the behavior of crossing the road on the main road of Khon Kaen city.” (HEC-02-67-038). This article is dedicated to Mr. Vutidach Kumphong, who tragically passed away in a motorcycle accident.

Human Research Ethics Review

This Research protocols were reviewed and approved by Rajamangala University of Technology Isan Human Research Ethics Committee on 2 January 2025: HEC-02-67-038

References

1. World Health Organization. 2018. Global status report on road safety 2018. World Health Organization.
2. World Health Organization. 2023. Global status report on road safety 2023. World Health Organization.
3. Bangkok Post. 2023. Motorists warned of pedestrian crossing penalties [Online]. Available: <https://www.bangkokpost.com/thailand/general/2490204/motorists-warned-of-pedestrian-crossing-penalties>. [28 August 2026]
4. Fitzpatrick, K. and Park, E.S. 2021. Nighttime effectiveness of the pedestrian hybrid beacon, rectangular rapid flashing beacon, and LED-embedded crossing sign. *Journal of Safety Research*, 79, 273-286. <https://doi.org/10.1016/j.jsr.2021.09.009>
5. Karami, Z., Rejali, S. and Aghabayk, K. 2024. Investigating pedestrians’ red light running intentions at urban intersections in different traffic environments: A scenario-based analysis guided by theoretical frameworks. *Transportation Research Part F: Traffic Psychology and Behaviour*, 107, 196–223. <https://doi.org/10.1016/j.trf.2024.09.003>
6. Alsharif, T., Lanzaro, G. . and Sayed, T. 2024. Distracted walking: Does it impact pedestrian–vehicle interaction behavior?. *Accident Analysis and Prevention*, 208, 107789. <https://doi.org/10.1016/j.aap.2024.107789>
7. Antić, B., Pešić, D., Milutinović, N. and Maslač, M. 2016. Pedestrian behaviours: Validation of the Serbian version of the pedestrian behaviour scale. *Transportation Research Part F: Traffic Psychology and Behaviour*, 41, 170-178. <https://doi.org/10.1016/j.trf.2016.02.004>

8. Bradbury, K., Stevens, J., Boyle, L.N. and Rutherford, S. 2012. To go or not to go: Pedestrian behavior at intersections with standard pedestrian call buttons. *Transportation Research Record*, 2299, 174-179. <https://doi.org/10.3141/2299-19>
9. Bayomi, A., Shawky, M. and Osama, A. 2024. Investigating mid-block pedestrian crossing behaviour and safety at urban streets in Cairo. *International Journal of Injury Control and Safety Promotion*, 31, 72-85. <https://doi.org/10.1080/17457300.2023.2258857>
10. Bayomi, A., Shawky, M., Okail, M. and Osama, A. 2022. Investigating pedestrian safety-related behavior in developing countries: Egypt as a case study. *Traffic Safety Research*, 3, 000016-000016. <https://doi.org/10.55329/htwx5986>
11. Zohrehvandi, B., Hosseinnia, M., Nazari, T., Homaie Rad, E., Kouchakinejad-Eramsadati, L. and Khodadadi-Hassankiadeh, N. 2023. Investigating the behavior of pedestrians and related factors in northern Iran in 2021. *Global Health Promotion*, 30, 31-38. <https://doi.org/10.1177/17579759231153130>
12. Vandroux, R., Granié, M.A., Jay, M., Sueur, C. and Pelé, M. 2022. The pedestrian behaviour scale: A systematic review of its validation around the world. *Accident Analysis & Prevention*, 165, 106509. <https://doi.org/10.1016/j.aap.2021.106509>
13. Pervez, A., Mao, S., Lee, J.J. and Hussain, M. 2025. Young motorcyclists' behavior analysis in Pakistan based on modified motorcycle rider behavior questionnaire (MRBQ). *Accident Analysis & Prevention*, 211, 107873. <https://doi.org/10.1016/j.aap.2024.107873>
14. Setyowati, D.L., Setyaningsih, Y., Suryawati, C. and Lestantyo, D. 2024. Assessment of risky riding behaviors using the motorcycle rider behavior questionnaire (MRBQ) among university students. *The Open Public Health Journal*, 17, 1-9. <https://doi.org/10.2174/0118749445281252240316204804>
15. Chouhan, S.S., Kathuria, A. and Sekhar, C.R. 2023. The motorcycle rider behaviour questionnaire as a predictor of crashes: A systematic review and meta-analysis. *IATSS Research*, 47, 61-72. <https://doi.org/10.1016/j.iatssr.2023.01.004>
16. Yu, Z., Qu, W. and Ge, Y. 2023. Utilizing MRBQ to investigate risky rider behavior in Chinese young riders: combining the effect of Big Five personality and sensation seeking. *Journal of Risk Research*, 26, 1263-1282. <https://doi.org/10.1080/13669877.2023.2270669>
17. Osorio-García, D., Hernández-Pulgarín, G. and Escobar, D.A. 2023. Profiles of pedestrian risk behavior while crossing the street. *Safety Science*, 163, 106120. <https://doi.org/10.1016/j.ssci.2023.106120>

18. Budzynski, M., Gobis, A., Guminska, L., Jelinski, L., Kiec, M. and Tomczuk, P. 2021. Assessment of the influence of road infrastructure parameters on the behaviour of drivers and pedestrians in pedestrian crossing areas. *Energies*, 14, 3559. <https://doi.org/10.3390/en14123559>
19. Arellana, J., Fernández, S., Figueroa, M. and Cantillo, V. 2022. Analyzing pedestrian behavior when crossing urban roads by combining RP and SP data. *Transportation Research Part F: Traffic Psychology and Behaviour*, 85, 259-275. <https://doi.org/10.1016/j.trf.2022.01.012>
20. Riaz, M.S., Cuenen, A., Polders, E., Akram, M.B., Houda, M., Janssens, D. and Azab, M. 2022. Child pedestrian safety: Study of street-crossing behaviour of primary school children with adult supervision. *Sustainability*, 14, 1503. <https://doi.org/10.3390/su14031503>
21. Esmaili, A., Aghabayk, K., Parishad, N. and Stephens, A.N. 2021. Investigating the interaction between pedestrian behaviors and crashes through validation of a pedestrian behavior questionnaire (PBQ). *Accident Analysis & Prevention*, 153, 106050. <https://doi.org/10.1016/j.aap.2021.106050>
22. Hasanat-E-Rabbi, S., Hamim, O.F., Debnath, M., Hoque, M.S., McIlroy, R.C., Plant, K.L. and Stanton, N.A. 2021. Exploring the relationships between demographics, road safety attitudes, and self-reported pedestrian behaviours in Bangladesh. *Sustainability*, 13, 10640. <https://doi.org/10.3390/su131910640>
23. Shehadeh, E.A., Al-Bayatti, A.H. and Bingöl, M.A. 2024. Evaluating self-reported pedestrian behaviour and investigating factors influencing road interactions in Jordan. *Transportation Research Part F: Traffic Psychology and Behaviour*, 105, 222-245. <https://doi.org/10.1016/j.trf.2024.07.008>
24. Zhang, Q., Yan, S. and Sun, L. 2025. Effects of sSafety attitudes on crossing behaviours of students aged 10–18 Years: The moderating effects of family climate and social norms. *Behavioral Sciences*, 15, 415. <https://pmc.ncbi.nlm.nih.gov/articles/PMC12024308/>
25. Jomnonkwao, S., Uttra, S. and Ratanavaraha, V. 2021. Analysis of a driving behavior measurement model using a modified driver behavior questionnaire encompassing texting, social media use, and drug and alcohol consumption. *Transportation Research Interdisciplinary Perspectives*, 9, 100302. <https://doi.org/10.1016/j.trip.2021.100302>

26. Kumphong, J. and Satiennam, T. 2021. Study risk behaviors of private car drivers on the road at Khon Kaen University, The 12th *Academic Conference on Engineering, Science, Technology and Architecture (ESTACON 12th)*, 20 August 2021, Nakhon Ratchasima, Thailand, 1239-1249.
27. Promraksa, T., Satiennam, T., Satiennam, W., Kaewwichian, P. and Kronprasert, N. 2022. Factors influencing stopping locations of motorcycle riders on signalized urban intersection approaches. *Sustainability*, 14, 15236. <https://doi.org/10.3390/su142215236>
28. Noor, S., Tajik, O. and Golzar, J. 2022. Simple random sampling. *International Journal of Education & Language Studies*, 1, 78-82. <https://doi.org/10.22034/ijels.2022.162982>
29. Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. 2010. *Multivariate Data Analysis*, Pearson, New York.
30. Kumphong, J., Jantosut, P., Kaewklueklom, R., Tankasem, P., Kaewhanam, N. and Promraksa, T. 2024. Red light running behavior of motorcyclists on urban roads: psychological factors and risk perception. *Engineering Access*, 10, 114–123.
31. Satiennam, T., Akapin, N., Satiennam, W., Kumphong, J., Kronprasert, N. and Ratanavaraha, V. 2023. Wrong way driving intention and behavior of young motorcycle riders. *Transportation Research Interdisciplinary Perspectives*, 19, 100827. <https://doi.org/10.1016/j.trip.2023.100827>
32. Sürücü, L., Yıkılmaz, İ. and Maşlakçı, A. 2022. Exploratory factor analysis (EFA) in quantitative researches and practical considerations. *Gümüşhane University Journal of Health Sciences*, 13, 947-965. <https://dergipark.org.tr/tr/pub/gumussagbil/article/1183271>
33. Căilean, A. M., Beguni, C., Avătămăniț, S. A., Dimian, M. and Popa, V. 2022. Design, implementation and experimental investigation of a pedestrian street crossing assistance system based on visible light communications. *Sensors*, 22, 5481. <https://doi.org/10.3390/s22155481>
34. Sprenger, J., Hell, L., Klusch, M., Kobayashi, Y., Kudo, S. and Müller, C. 2023. Cross-cultural behavior analysis of street-crossing pedestrians in Japan and Germany. *IEEE Intelligent Vehicles Symposium (IV)*, 4-7 June 2023, Anchorage, AK, USA, pp. 1-7. https://www.dfki.de/~makl01/i2s/CrossCDR_IEEE_IV23_master-4-.pdf
35. Özkan, T., Lajunen, T. and Summala, H. 2006. Driver behaviour questionnaire: A follow-up study. *Accident Analysis & Prevention*, 38, 386-395. <https://doi.org/10.1016/j.aap.2005.10.012>

36. Lajunen, T., Parker, D. and Summala, H. 2004. The Manchester driver behaviour questionnaire: a cross-cultural study. *Accident Analysis & Prevention*, 36, 231-238. [https://doi.org/10.1016/S0001-4575\(02\)00152-5](https://doi.org/10.1016/S0001-4575(02)00152-5)
37. Jantosut, P., Tankasem, P., Kumphon, J., Inthavongsa, P. and Surinaud, E. 2026. Stopping at school crosswalks: Comparative impacts of visible monitoring and enforcement on drivers' yielding behaviour. *Journal of Road Safety*, 37, 40–51. <https://doi.org/10.33492/JRS-D-26-2-2717479>