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Exploratory Analysis of Hazard Factors Influencing the Safety Rating of Pedestrian Bridge

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ABSTRACT: The proliferation of signal-free corridors in Karachi, Pakistan, has necessitated the construction of foot-over bridges to facilitate pedestrian road crossings. However, these structures have gradually deteriorated due to vandalism and social factors. Pedestrians perceive them as unsafe primarily due to their poor physical condition, including the absence of guardrails, and the presence of social hazards such as beggars, addicts, and stray dogs. This study aims to assess the safety rating of a foot-over bridge by pedestrians, considering various physical and social hazard factors. An in-person questionnaire-based survey was conducted at a foot-over bridge located near a major university in Karachi. Pedestrians were asked to rate the bridge's safety as safe or unsafe based on the factors they considered most hazardous while crossing it. These factors included the absence of guardrails, and the presence of beggars, addicts, and stray dogs. Pedestrians were also queried about the optimal time for crossing the bridge (morning, evening, or afternoon). Their age was recorded. A Binary Logistic Regression (BLR) model was developed to analyze the data, and odds ratios were calculated for each hazard factor. The results of the BLR model revealed that the gender of the pedestrian significantly influenced the safety rating of the bridge compared to other variables. Female pedestrians were five times more likely to rate the bridge as unsafe compared to males. Furthermore, younger pedestrians were 0.39 times more likely to perceive the bridge as unsafe compared to older ones. The absence of guardrails increased the likelihood of rating the bridge as unsafe by 1.1 times compared to other hazards, and pedestrians crossing the bridge during the afternoon were 1.7 times more likely to perceive it as unsafe compared to morning or evening crossings. In conclusion, female pedestrians perceive foot-over bridges in Karachi as more unsafe, with the absence of guardrails being identified as the primary physical hazard. These findings underscore the importance of addressing safety concerns and improving infrastructure to enhance pedestrian safety in urban environments. It is recommended that the guard rails of pedestrian bridges should be constructed with recycled sustainable materials to prevent them from theft and improve safety, thus, creating a more resilient infrastructure.

KEYWORDS: Foot-over bridge; Hazard factors; Logistic regression; Odds ratio; Pedestrian

1. INTRODUCTION

Pedestrian bridges, also known as foot-over bridges, have become essential components of urban road networks. They are strategically placed in areas where it is unsafe for pedestrians to cross roads at street level or to maintain uninterrupted traffic flow. This is particularly evident in arterial roads, corridors, or freeways that have been rendered signal-free through the construction of flyovers and underpasses, allowing traffic to move freely without signalized intersections along the corridor. In such scenarios, pedestrians face challenges in crossing the road at ground level due to the absence of gaps across all lanes simultaneously. Conversely, in signalized corridors, traffic flow occurs in platoons, with signals creating breaks in traffic flow to facilitate pedestrian crossings. Literature suggests that pedestrians and freeways are incompatible, advocating for their separation (Sinclair & Zuidgeest, 2016). However, in urban areas of middle-income countries, pedestrians often have no choice but to navigate freeways in their daily commutes. Consequently, the provision of pedestrian bridges becomes essential for ensuring their safety.

Previous studies on pedestrian bridges have primarily investigated bridge utilization (Moore, 1953, 1965; Allos & Mohammad, 1983) and compared at-grade and grade-separated crossings (Tanaboriboon & Jing, 1994; Räsänen, et al., 2007). These studies explored pedestrians' willingness to use grade-separated facilities, either voluntarily or due to enforced barriers and regulations. Subsequent research incorporated perceived risk and examined pedestrians' safety beliefs regarding bridge usage. However, time-saving remained a significant factor contributing to the underutilization of pedestrian bridges (Räsänen, et al., 2007; Demiroz, et al., 2015; Hasan, et al., 2020).

Research on risk perception by pedestrians regarding overpasses, conducted by Mutto, Kobusingye, & Lett, (2003), revealed an increase in pedestrian accidents post-overpass construction. Pedestrians cited billboards obstructing visibility as a reason for not using the facility, making it susceptible to petty crimes. Further exploration of pedestrian risk perception was undertaken by Rankavat & Tiwari (2016), who defined risk perception as "the probability of being involved in a traffic crash while walking along or crossing the road". A subsequent study (Tiwari, 2020) compared actual crash risk with pedestrians' perceived risk, concluding an inverse relationship between the two.

Research conducted by Tanaboriboon & Jing (1994) suggests that on road networks with pedestrian crossing facilities, actions such as crossing the road at unauthorized points or disregarding traffic signals are deemed illegal. Mohammed (2018) extensively explored illegal pedestrian crossings, finding that pedestrians assess safety distances lane by lane when crossing multilane roads at grade. They noted a higher incidence of illegal crossings among males compared to females, corroborating findings from an earlier study (Tom & Granié, 2011) that primarily investigated gender's impact on illegal crossings. The overall body of literature pertinent to pedestrians indicates that males are over-represented as compared to females.

A seminal study by Onelcin (2018) shed light on the deteriorating physical state of pedestrian bridges, influencing their usage patterns. Analyzing pedestrian behavior in Izmir, Turkey, they found that more individuals opted for at-grade crossings when faced with a broken staircase on a pedestrian bridge. This underscores the pivotal role of a bridge's physical condition in shaping pedestrian choices. In Karachi, Pakistan, where approximately 120 bridges exist (Ali, 2021), the presence of vendors, beggars, and substance abusers encroaches upon pedestrian space, compromising safety. The absence of guardrails emerges as a key safety concern, as they mitigate the risk of falls and offer support to vulnerable individuals. Previous research has not sufficiently addressed the social and physical hazard factors related to pedestrians' perceived risk when using foot-over bridges in Pakistan. This gap in the literature underscores the need for the present study.

The study aims to explore the various factors associated with the safety of a pedestrian bridge from users' perspective. For this purpose, an in-person direct interview-based questionnaire survey was conducted, and the responses were collected from the pedestrians utilizing a foot-over bridge situated on University Road, a signal-free corridor, in Karachi, Pakistan. Each identified hazard factor was assigned a weighted score, and odds ratios were computed to assess the impact of gender, hazard type, and time of bridge crossing on safety ratings. A Binary Logistic Regression model was constructed to further elucidate the relationship between the hazard factors, gender, and age concerning the safety assessment of the bridge. The findings are succinctly discussed, and conclusions are drawn based on both exploratory and inferential analyses.

2. METHODS

2.1. Study Area

The study area encompasses a pedestrian bridge situated on University Road, a major arterial thoroughfare in Karachi, Pakistan. The bridge is located in front of the Student Gate of the NED University of Engineering and Technology. This bridge serves as the sole means for students and staff to safely cross the road, as no at-grade traffic control device is installed. The absence of a zebra crossing and the presence of an iron fence along the median prevent pedestrians from crossing the road at grade. These measures are implemented due to the fast-moving, high-volume traffic on University Road, where pedestrian crossings at grad pose significant accident risks. Figure 1a illustrates the precise location of the study areas, while Figure 1b provides a visual depiction of the bridge's physical condition as of September 2021. When the bridge was initially constructed, guardrails were installed; however, they were subsequently removed due to vandalism over time. At the time of the study, no guardrails were present along the deck of the bridge. Additionally, the bridge deck lacked a toe plate. To assess the impact of both physical conditions and social factors on the safety rating of the bridge, a questionnaire survey was conducted at the study location. The survey questionnaire is provided in Appendix A. This cross-sectional study employed a direct interview method to collect responses randomly from pedestrians using the bridge during morning, afternoon, and evening hours. The data collection took place in December 2021. A total of 100 responses were recorded. It was observed that around 500 pedestrians use the bridge every day, therefore, a sample of 100 pedestrians is a good representative of the total population. It is to be noted that the guardrails were later installed on the bridge.

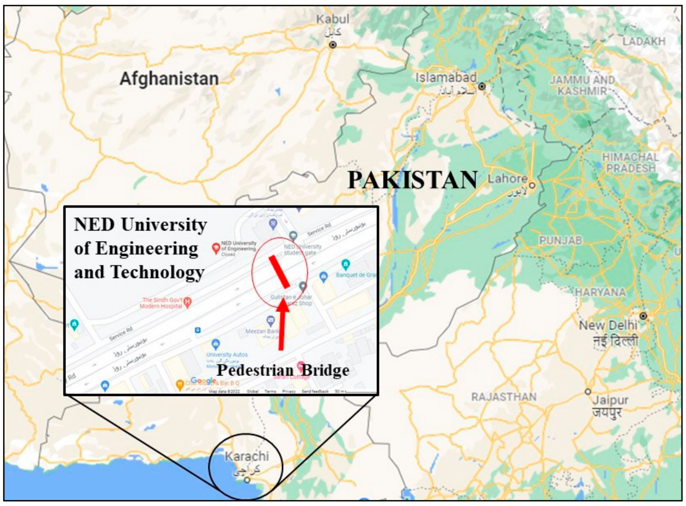

Figure 1(a). Location of the Pedestrian Bridge (source: Google Maps)

Figure 1(b). Physical Conditions of the Pedestrian Bridge (as of September 2021)

2.2. Logistic Regression

The dependent variable to be examined in this study is binary, representing whether the pedestrian bridge is safe or unsafe. Therefore, binary logistic regression is utilized to analyse the impact of independent variables on the dependent variable. The general logistic function, indicating the probability of the outcome given a single independent variable 'x' is defined in Eq. 1.

$$(1) \quad Pr(Y|x) = \frac{e^{\beta_0 + \beta_1 x}}{1 + e^{\beta_0 + \beta_1 x}}$$

where,

$Pr(Y|x)$ = Probability of dependent variable Y given independent variable x

β_o = Intercept or constant

β_1 = co-efficient of variable x

The co-efficient are estimated through the 'maximum-likelihood' technique, which provides the values of β that maximize the probability of obtaining the observed set of data (Hosmer & Lemeshow, 2000). For more than one independent variables, the above function will transform as shown in Eq. 2.

$$(2) \quad Pr(Y|x_i) = \frac{e^{\beta_0 + \beta_1 x_1 + \cdots + \beta_i x_i}}{1 + e^{\beta_0 + \beta_1 x_1 + \cdots + \beta_i x_i}}$$

where,

$Pr(Y|x_i)$ = Probability of dependent variable Y given independent variables x_i

β_o = Intercept or constant

β_i = co-efficient of variable x_i

i = number ranging from 1 to n, with n being the total number of independent variables

2.3. Odds Ratio

The odds ratio determines how strongly an outcome is associated with exposure. That is how likely is it possible for the outcome to occur given it is exposed to the situation. The larger the odds ratio the higher the odds that the event will occur with exposure (Tenny & Hoffman, 2024). Mathematically this relationship is expressed in Eq. 3.

$$(3) \quad Odds\ Ratio = \frac{odds\ of\ the\ event\ in\ the\ exposed\ group}{odds\ of\ the\ event\ in\ the\ non{-}exposed\ group}$$

3. RESULTS AND DISCUSSION

3.1. Weighted Score

During the questionnaire survey, pedestrians were asked to rate the bridge as either Safe or Unsafe based on hazard factors. Four hazard factors were identified, as shown in Table 1. Pedestrians were also queried about the optimal time of day to cross the bridge. Additionally, the age and gender of the respondents were recorded. Descriptive statistics are presented in Table 1. It was observed that 85% of the pedestrians rated the bridge as Unsafe. Among the four hazard factors, 62% of the respondents identified the absence of guard rail as the primary hazard associated with the bridge, while 19%, 17%, and 2% attributed the hazards to the presence of beggars, addicts, and stray dogs, respectively. The number of female respondents slightly exceeded that of male respondents. It was found that the optimal time to cross the bridge is during the afternoon, compared to morning and evening. This preference may be attributed to better visibility during daylight hours and fewer pedestrians on the bridge deck. Consequently, there is more space for pedestrians to walk in the middle of the bridge deck, away from the edges where there are no guardrails to prevent falls. The mean age of the pedestrians using the bridge was calculated to be 22.5 years, with a standard deviation of 4.7 years and a range of 18 to 45 years.

A weighted score was calculated for each identified hazard factor. Using a scale of 1 to 4, the hazard factor 'No Guard Rail' was assigned a score of 4, followed by 'Presence of Beggar' with a score of 3, 'Presence of Addict' with a score of 2, and 'Presence of Stray Dog' with a score of 1. The rationale for assigning the highest weight to the 'No Guard Rail' factor is its significant impact on pedestrian safety when crossing the bridge. The absence of guardrails on the bridge deck could lead to fatalities if pedestrians were to fall. Conversely, the presence of beggar, addict, or dog would not typically result in such severe consequences. This methodology bears resemblance to the risk assessment framework outlined by (Hess, 2019), wherein events of utmost risk were assigned the highest scores on a 'Risk Ladder Scale'. The number of responses for each hazard factor was then multiplied by their respective score. The resulting weighted score for each hazard factor is depicted in Figure 2, with 'No Guard Rail' attaining the highest score due to its potentially catastrophic implications compared to other hazard factors.

Question	Options	Number of Responses
Safety Rating	Safe	15
	Unsafe	85
Gender	Male	41
	Female	59
Hazard Factor	No Guardrail	62
	Presence of Beggar	19
	Presence of Addict	17
	Presence of Dog	2
Best Time to Cross the Bridge	Afternoon	70
	Morning	24
	Evening	6
Age*		100

*The mean age of the respondents were 22.5 years (Standard deviation 4.7).

Table 1. Summary of descriptive statistics of the questionnaire survey

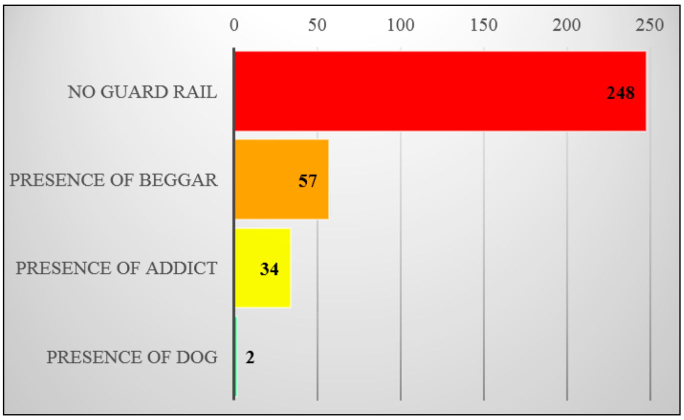

Figure 2. Weighted score of the hazard factors affecting the safety rating of pedestrian bridge

3.2. Logistic Regression Model

The analysis of the bridge rated as safe versus unsafe was conducted using a binary logistic regression model. The bridge being safe, coded as 0, served as the control response and was compared against the bridge being unsafe, coded as 1. The independent variables included gender (with male classified as 0 and female classified as 1), age (a continuous variable), hazard factor (Presence of Dog classified as 0, Presence of Beggar classified as 1, Presence of Addict classified as 2, and No Guard Rail classified as 3), and time of crossing the bridge (evening classified as 0, morning classified as 1, and afternoon classified as 2). These variables were entered into the logistic regression model using the enter method. The Nagelkerke R-Square was calculated to be 0.290. Table 2 displays the parameter estimates (β) of each variable in the model along with their corresponding p-values. The resultant model can be expressed in equation form as depicted below.

$$P_r\,(Unsafe) = e^{\{-8.738 + 2.043\,(Gender) + 0.28\,(Age) + Presence\_Dog + 2.67\,(Presence\_Beggar) + 2.274\,(Presence\_Addict) + 2.623\,(No\ Guard\ Rail) + Cros\_Time\_Evening + 0.792\,(Cross\_Time\_Morning) + 1.329\,(Cross\_Time\_Afternoon)\}} \,/\, [1 + e^{\{-8.738 + 2.043\,(Gender) + 0.28\,(Age) + Presence\_Dog + 2.67\,(Presence\_Beggar) + 2.274\,(Presence\_Addict) + 2.623\,(No\ Guard\ Rail) + Cros\_Time\_Evening + 0.792\,(Cross\_Time\_Morning) + 1.329\,(Cross\_Time\_Afternoon)\}}$$

Where,

P_r (*Unsafe*) = Probability of bridge being rated as unsafe
Gender = Male (0), Female (1)
Presence_Dog = Presence of dog (0)
Presence_Beggar = Presence of Beggar (1)
Presence_Addict = Presence of addict (2)
No Guard Rail = No Guard Rail (3)
Cross_Time_Evening = Time of crossing: evening (0)
Cross_Time_Morning = Time of crossing: morning (1)
Cross_Time_Afernoon = Time of crossing: afternoon (2)

Independent Variable	Type of variable	Estimate (β)	Significance
Gender*	Binary	2.043	0.006
Age	Continuous	0.28	0.107
Presence of Dog	Ordinal		0.465
Presence of Beggar	Ordinal	2.67	0.164
Presence of Addict	Ordinal	2.274	0.199
No Guard Rail	Ordinal	2.623	0.121
Crossing Time: Evening	Ordinal		0.446
Crossing Time: Morning	Ordinal	0.792	0.537
Crossing Time: Afternoon	Ordinal	1.329	0.254
Constant*	-	-8.738	0.046

Nagelkerke R Square = 0.290
*p-value< 0.05

Table 2. Results of the logistic regression model

Gender was the only variable found to significantly affect the safety rating of bridge use (p-value < 0.05). This finding contradicts the results obtained by (Räsänen, Lajunen, Alticafarbay, & Aydin, 2007) who found that age and gender did not predict bridge use. However, their study was conducted in an area where the option of crossing at grade was available. In contrast, in this study where crossing at grade is not an option, gender and age had a positive effect on the safety rating. Except for the intercept, all variables were found to have a positive effect on the rating of the bridge as unsafe. Examination of the gender variable reveals that the probability of the bridge being rated as unsafe is higher if the pedestrian is female. Similarly, the probability of the bridge being rated as unsafe is higher in the absence of guardrails compared to the other three hazard factors. This is because the absence of guardrails has a higher significance (0.121) compared to the presence of beggars (0.164), addicts (0.199), and dogs (0.465). Among the three options related to the time of crossing, pedestrians crossing the bridge during the afternoon are more likely to rate the bridge as unsafe compared to crossing during the evening and morning. These findings align with a study conducted among university students in Honduras (Landa-Blanco & Ávila, 2020). Logistic regression was employed to model the decision of using the bridge versus not using it. Age was not found to be significantly affecting the use of the bridge (p-value > 0.05). However, social factors such as the bridge having good illumination and bad infrastructure, along with pedestrian-related factors such as finding the use of the bridge to be stressful, were found to significantly affect the use of the bridge (p-value < 0.05). It is worth noting that beggars and hawkers often occupy the stairs, providing them with protection from falling.

3.3. Odds Ratio Analysis

Based on the logistic regression model results, gender emerged as the most significant variable influencing the bridge rating, followed by age, hazard factor, and time of crossing. Hence, odds ratios were computed for each variable, as depicted in Tables 3, 4, 5, and 6. Descriptive statistics revealed a higher proportion of female respondents than males in the survey. Consequently, the odds of rating the bridge as unsafe were calculated for female pedestrians compared to males. The analysis indicated that the odds of rating the bridge as unsafe were 5 times higher for female pedestrians than for males. According to Banerjee & Maurya (2020), females tend to walk at a slower pace compared to males. Consequently, they may require more time to cross the bridge, leading to a heightened perception of its unsafety.

Regarding age, a continuous variable, the odds were computed by dividing the pedestrians into two groups based on their age. The first group consisted of pedestrians younger than 22.5 years, while the second group comprised pedestrians older than 22.5 years. The age of 22.5 years was chosen as the cut-off because it represents the average age of the pedestrians in the study. It was observed that the odds of rating the bridge as unsafe were 0.39 times more likely if a pedestrian was young, i.e., less than 22.5 years old, compared to older pedestrians. This finding is practical, as younger pedestrians tend to be more adventurous and willing to take risks, perceiving the bridge as safer compared to older pedestrians.

	Female	Male
Unsafe	55	30
Safe	4	11
Odds Ratio = (55/30)/(4/11) = 5.04		

Table 3. Odds of rating the bridge unsafe given female versus male pedestrian

	Age <22.5	Age >22.5
Unsafe	52	33
Safe	12	3
Odds Ratio = (52/33)/(12/3) = 0.39		

Table 4. Odds of rating the bridge unsafe given 'Age <22.5' versus 'Age >22.5'

Among the four hazard factors, the highest weighted score was assigned to 'No Guard Rail' present. Consequently, odds were calculated for the bridge being rated as unsafe given the presence of 'No Guard Rail' versus the presence of 'Beggar, Addict, or Dog'. It was found that the bridge is 1.1 times more likely to be rated as unsafe if there are no guardrails present compared to other hazard factors. Therefore, the absence of guardrails is considered the primary factor affecting the safety rating of a foot-over bridge by pedestrians. Previous research (Kummeneje & Rundmo, 2019) has also examined related factors such as harassment, theft, and terrorism.

It's logical to assume that individuals such as beggars and addicts, who frequent these areas, may engage in criminal activities like theft and harassment. Such concerns could contribute to heightened perceived risks among pedestrians, particularly on bridges lacking guardrails.

Odds were calculated for the last variable, which is the time of crossing. According to Table 2, the majority of the pedestrians identified the afternoon as the best time to cross the bridge. Therefore, odds were calculated for rating the bridge as unsafe to cross during the afternoon compared to morning or evening. It was found that the bridge is 1.7 times more likely to be rated as unsafe to cross during the afternoon compared to the morning or evening. However, this result contradicts the descriptive statistics. Since each pedestrian was asked to rate the bridge first and then inquired about the hazard factor and best time to cross, it may not be suitable to directly relate the safety rating with the best time to cross the bridge.

	No Guard Rail	Beggar/Addict/Dog
Unsafe	53	32
Safe	9	6
Odds Ratio = (53/32)/(9/6) = 1.104		

Table 5. Odds of rating the bridge unsafe given hazard of 'No Guard Rail' versus others

	Afternoon	Morning/Evening
Unsafe	61	24
Safe	9	6
Odds Ratio = (61/24)/(9/6) = 1.69		

Table 6. Odds of rating the bridge unsafe given time of crossing as 'Afternoon' versus 'Morning or Evening'

Despite the majority of pedestrians rating the bridge as unsafe, its utility remains essential as there is no alternative option available for pedestrians to cross the road. This deduction aligns with findings reported in Räsänen et al., 2007, which suggests that attitudes towards using pedestrian bridges are stable characteristics. Additionally, as per Evans (1998) the choice of using a foot-over bridge as a safer option compared to crossing the road at grade may be habitual for pedestrians. Literature indicates that elements encroaching on pedestrian facilities are often found near slum areas, leading pedestrians to perceive a higher risk in these areas (Mukherjee & Mitra, 2022). The utilization of such infrastructure by other social elements for their livelihoods and other purposes raises questions about their construction. Pedestrians often prefer crossing the road at grade rather than using such infrastructure. This point is further discussed by Soliz & Pérez-López (2022), advocating for a "socially just approach" to the development of pedestrian facilities. Nevertheless, the role of pedestrian bridges in reducing pedestrian-related crashes cannot be overlooked (Zhu, 2023).

4. CONCLUSION

The findings of this study lead to the conclusion that the pedestrian bridge in question is deemed unsafe primarily due to the absence of guardrails. While secondary factors such as the presence of beggars, addicts, and stray dogs contribute to the safety assessment, their impact is comparatively minor. Consequently, it can be inferred that female pedestrians regard the use of the pedestrian bridge as less safe compared to their male counterparts, irrespective of specific hazard types. However, it's essential to exercise caution in interpreting these findings, given the skewed gender distribution in the respondent sample, with a predominance of younger females. Given that the study was conducted on a bridge situated in front of a university and lacked guardrails, the conclusions drawn are specific to this study location. Therefore, it is imperative to exercise caution when interpreting the results. It is recommended that similar studies be conducted on bridges located in diverse land use settings such as commercial, recreational, industrial, and residential areas to ascertain the factors associated with their safety ratings more comprehensively.

The installation of pedestrian bridges aimed to provide a safe means for crossing roads where signals were absent for extended periods. Crossing the bridge during morning and evening was deemed safer, likely due to increased pedestrian flow during these times. The physical deterioration of the bridges, attributed to vandalism by addicts, underscores the urgency for timely repairs and maintenance by relevant authorities. To address these challenges, it is recommended that all pedestrian bridges undergo thorough assessment, employ the methodology outlined in this research. Utilizing recycle and waste materials for guardrails and handrails can promote sustainability while enhancing safety. Additionally, policies mandating the use of theft-proof green materials in bridge construction can contribute to environmental preservation and long-term sustainability. Law enforcement agencies can develop targeted strategies to mitigate vandalism and theft-related risks associated with pedestrian bridges.

In summary, this study provides a valuable foundation for future research and practical initiatives aimed at improving pedestrian safety and enhancing urban infrastructure resilience. By integrating safety considerations into urban planning and design, cities can create more inclusive and sustainable environments for pedestrians, ultimately fostering healthier and more vibrant communities.

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APPENDIX A

Survey Questionnaire

Gender
□ Male □ Female

Age: ____Years

Q.1 How safe do you feel using this bridge?
□ Safe □ Unsafe

Q.2 What is the most risky thing about this bridge?
1) Stray Dog 2) Beggar 3) Addict 4) No Guardrail

Q.3 At which time you feel have crossing this bridge?
1) Afternoon 2) Morning 3) Evening

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