



ORIGINAL RESEARCH ARTICLE

ASSESSMENT OF PEDESTRIAN BRIDGES IMPACT ON TRAFFIC FLOW AND PEDESTRIAN SAFETY IN MAIDUGURI, BORNO STATE, NIGERIA

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ABSTRACT

Pedestrian bridges play a vital role in improving urban traffic flow efficiency and enhancing pedestrian safety by separating pedestrian movement from vehicular traffic at busy road corridors. This study assessed the impact of pedestrian bridges on traffic flow efficiency and pedestrian safety across four corridors in Maiduguri: GSM Market, Ramat Polytechnic Junction, Gamboru Market and the University of Maiduguri Gate. The study is important because increasing urbanization, high pedestrian activity and rising traffic volumes in Maiduguri have created frequent pedestrian-vehicle conflicts, delays and safety risks that require effective infrastructure solutions. Using an observational approach, data on pedestrian counts, traffic volumes, operating speeds, conflicts and survey responses were collected during peak periods and analyzed using descriptive statistics, ANOVA and Pearson correlation. A total of 1,950 pedestrians were observed across the four locations, with bridge compliance averaging 55%, highest at the University of Maiduguri Gate (62%) and lowest at GSM Market (30%). Average uninterrupted vehicle volumes ranged from 1,050 to 1,250 veh/hr but declined to 910–1,000 veh/hr during pedestrian crossings, representing an average reduction of 16.3%. Similarly, average operating speeds dropped from 38–45 km/h under free-flow conditions to 18–25 km/h during at-grade pedestrian crossings, indicating an average speed reduction of 46.2%. Low compliance, especially in commercial areas, contributed to increased jaywalking and pedestrian-vehicle conflicts. GSM Market recorded the highest conflict rate (11.33 conflicts/hr), while the University of Maiduguri Gate had lower conflicts (8.00 conflicts/hr) and better overall performance. The findings indicated that bridge effectiveness depended on user behavior, surrounding land use, accessibility and enforcement. The study recommended better integration of pedestrian facilities, installation of barriers and fencing, stronger enforcement and sustained public awareness campaigns to improve safety and traffic flow.

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1.0 Introduction

Rapid urbanization and rising vehicle ownership have increased pedestrian vulnerability, especially in developing cities where pedestrian-vehicle interactions are frequent (World Health Organization, 2023). In Maiduguri Metropolis, high pedestrian volumes intersect with fast moving traffic along major corridors, creating significant safety risks and traffic disruptions. Pedestrian bridges are introduced to reduce conflicts and improve traffic flow (Aderamo and Atomode, 2012; Zegeer et al., 2005; Girma and Gebeyehu, 2020). However, despite their presence at locations such as GSM Market, Ramat Polytechnic Junction, Gamboru Market, and the University of Maiduguri Gate, unsafe crossings and pedestrian vehicle conflicts persist due to poor accessibility, misalignment with pedestrian desire lines, and weak enforcement (Ojo and Adebayo, 2020; Ibrahim and Mohammed, 2021).

Globally, the effectiveness of pedestrian bridges depends on design, location, accessibility and enforcement (Zegeer *et al.*, 2005; World Health Organization, 2023). While well integrated bridges can significantly reduce fatalities and improve compliance, poorly positioned ones are often underutilized (Márquez *et al.*, 2016; Kimaru and Odero, 2018). Successful cases highlight the importance of aligning bridges with pedestrian movement patterns and supporting them with complementary infrastructure (Yong, 2019; New York City Department of Transportation, 2020).

In Nigeria, inadequate pedestrian facilities, poor maintenance and informal roadside activities further limit bridge effectiveness (Olorunfemi and Daramola, 2022; Adedeji and Fadare, 2021). In Maiduguri, these challenges contribute to unsafe pedestrian behavior and reduced traffic efficiency. Despite existing infrastructure, there is limited empirical research assessing the combined impact of pedestrian bridges on traffic flow and safety. This study therefore evaluates pedestrian bridge performance across key corridors in Maiduguri by examining vehicular traffic delays resulting from at-grade pedestrian crossings, changes in operating speeds, roadway traffic efficiency, pedestrian compliance with bridge usage, and pedestrian–vehicle safety conflicts, with the aim of improving urban transport planning and pedestrian infrastructure design.

2. Materials and Method

2.1 Study Area



Figure 1: Map of Maiduguri metropolis showing the study area locations.

The study was conducted across four major pedestrian bridge corridors in Maiduguri Metropolis: GSM Market, Ramat Polytechnic Junction, Gamboru Market and the University of Maiduguri Gate. Maiduguri, the commercial and administrative hub of Borno State, has experienced rapid population growth, increased commercial activities and rising vehicle ownership, leading to high traffic volumes. These corridors were selected due to their high pedestrian density, intense land use activities and frequent pedestrian vehicle conflicts. Pedestrian counts were conducted during morning (7–8 a.m.), afternoon (2–3 p.m.), and evening (6–7 p.m.) periods representing major commuting and commercial activity periods within the city.



Plate 1: Pedestrian bridge at GSM market corridor, Maiduguri

- I. **GSM Market:** A bustling commercial hub with continuous vehicular and pedestrian interactions. Observations revealed frequent at-grade crossings despite the presence of a pedestrian bridge, largely due to traders and customers seeking shorter routes (Ibrahim and Mohammed, 2021).



Plate 2: Pedestrian bridge at Ramat Polytechnic corridor, Maiduguri

- II. **Ramat Polytechnic Junction:** A major institutional and transport node with substantial student mobility. Large groups of pedestrians often disrupt traffic during morning and afternoon peaks, challenging the bridge's effectiveness (Usman and Haruna, 2020).



Plate 3: Pedestrian underpass at Gamboru market, Maiduguri

- III. **Gamboru Market:** Characterized by dense commercial activity and informal roadside trading, forcing pedestrians onto the carriageway and contributing to congestion and unsafe interactions (Adedeji and Fadare, 2021).



Plate 4: Pedestrian bridge at the University of Maiduguri corridor, Maiduguri

- IV. University of Maiduguri Gate: High student and pedestrian movements occur alongside commercial activities, with many pedestrians crossing at grade, leading to periodic traffic interruptions despite the bridge (Shettima and Ali, 2019).

2.2 Research Design

A descriptive and observational research design was adopted to assess the effectiveness of pedestrian bridges on traffic flow and pedestrian safety in Maiduguri. Field observations were used to capture real time interactions between pedestrians and vehicles along the selected corridors. Data were collected over three consecutive weekdays during peak periods (7:00–8:00 a.m., 2:00–3:00 p.m., and 6:00–7:00 p.m.) using trained observers and standardized recording sheets. Traffic volumes and pedestrian movements were manually counted at 15-minute intervals in line with Highway Capacity Manual procedures for peak hour traffic studies, distinguishing between bridge users and at-grade crossings (HCM, 2010). Vehicle speeds were estimated using the travel time method, consistent with standard urban traffic survey practice (ITE, 2000). The study used a total of 300 valid responses from questionnaires survey, which remained adequate for the planned statistical analyses. The minimum sample size is determined using Cochran’s formula for sample size of unknown population (Chaokromthong and Sintao, 2021) based on equation 1.

$$n = \frac{Z^2 \times P(1-P)}{E^2} \quad 1$$

Where n is minimum sample size, P is the Standard deviation taken as 50%, E is the Margin of error taken as 5% and Z is the zero score corresponding to the desired confidence level. For a confidence level of 95%, Z-score corresponds to 1.96. However, the adoption of 300 pedestrian samples is justified based on time and cost constraints, which is commonly found in transportation studies (Okura *et al.*, 2009).

2.3 Data Analysis

Data were analysed to evaluate traffic performance, pedestrian safety and bridge utilization using standard transportation engineering and statistical methods. Key traffic indicators included vehicle delay, average speed, bridge utilization rate and pedestrian vehicle conflict frequency. Vehicle delay was estimated as the difference between free flow travel time and observed travel time during pedestrian interference, expressed in equation 2.

$$D = T_o - T_f \quad 2$$

Where D = delay, T_o = observed travel time, and T_f = free flow travel time, consistent with Highway Capacity Manual procedures (HCM, 2010). Average speed was determined using the travel time model in equation 3.

$$V = \frac{L}{T} \quad 3$$

Where V = speed (km/h), L = length of road segment and T = travel time (ITE, 2000). Bridge utilization rate was computed as the percentage of pedestrians using the bridge relative to total observed pedestrians, using equation 4.

$$BUR = \frac{P_b}{P_t} \times 100 \quad 4$$

Where P_b = bridge users and P_t = total pedestrians observed. Pedestrian–vehicle conflict frequency was measured as the number of crossing conflicts recorded per hour using principles of Traffic Conflict Theory (Peden *et al.*, 2020).

To compare performance across the four corridors, one way Analysis of Variance (ANOVA) was applied at a 95% confidence level ($p < 0.05$) to determine whether significant differences existed among locations. The ANOVA F-statistic was expressed in equation 5.

$$F = \frac{\text{Between-group variance}}{\text{Within-group variance}} \quad (\text{Montgomery, 2013}). \quad 5$$

Pearson correlation analysis was used to examine relationships between bridge utilization and traffic indicators such as speed and conflict rate using equation 6.

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \tag{6}$$

where r ranges from -1 to +1, indicating the strength and direction of association. Graphical tools such as bar charts and histograms were also used to present trends in traffic flow, pedestrian behaviour and safety conditions clearly.

2.4 Theoretical Framework

The study was guided by Traffic Conflict Theory, which posits that collision likelihood increases with the frequency of pedestrian-vehicle interactions (Peden et al., 2020), and pedestrian desire line concepts, which explain pedestrian route choices.

3. Results and Discussion

3.1 Pedestrian Traffic Characteristics

A total of 1,950 pedestrian crossing observations were recorded across the four study locations during the observation periods. Table 1 and figure 2 presents a summary of pedestrian observations across the four study locations, showing the total number of pedestrians recorded, the number who used the pedestrian bridge, those who crossed at grade level and the corresponding bridge usage percentage at each corridor.

Table 1: Summary of Pedestrian Observations across Study Locations

Site	Total Pedestrians Observed	Used Bridge	Crossed at Grade	at Bridge Usage (%)
GSM Market	500	150	350	30
Ramat Polytechnic	480	228	192	60
Gamboru Market	450	225	225	50
University of Maiduguri Gate	520	322	198	62

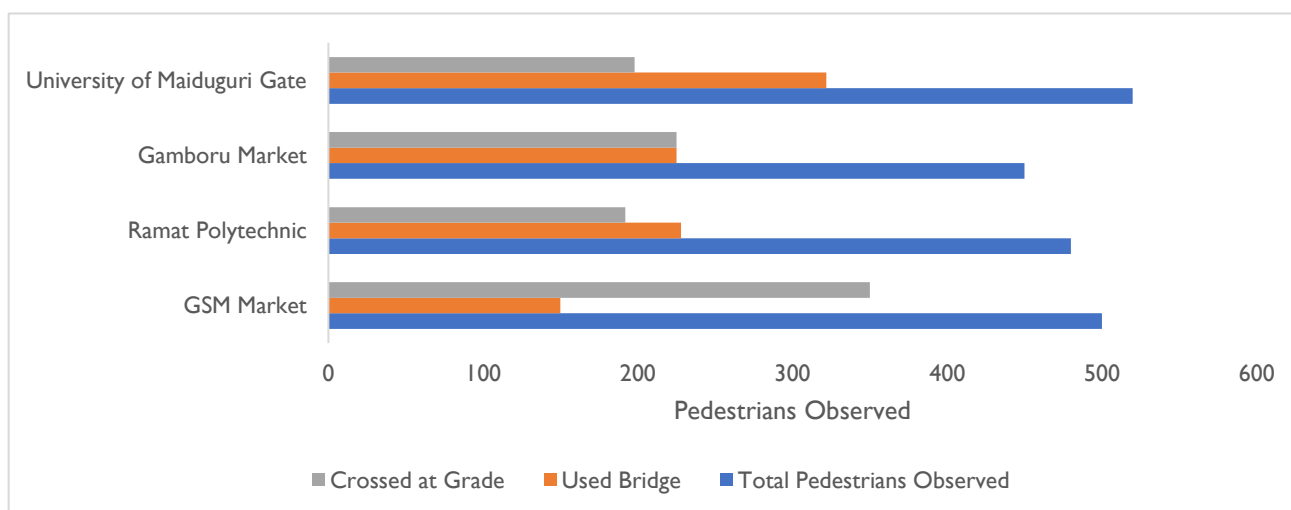


Figure 2: Bridge Usage Rates across Study Locations.

Table 1 and Figure 2 show significant variation in pedestrian bridge utilization across the study locations, with the highest compliance recorded at the University of Maiduguri Gate (62%) and the lowest at GSM Market (30%). This suggested that surrounding land use influenced pedestrian behavior, as institutional areas tended to promote safer crossings, while commercial zones encouraged at-grade crossings for convenience. These findings aligned with Ibrahim and Mohammed (2021), who noted higher compliance in school environments, and Shettima and Ali (2019), who observed low bridge usage in market areas due to preference for shorter

routes. Overall, the results indicated that bridge effectiveness depends on proper alignment with pedestrian movement patterns and land use, not just infrastructure provision.

3.2 Vehicle Flow Characteristics

Vehicle volumes were observed under two conditions: uninterrupted flow and real conditions influenced by pedestrian crossings. Table 2 and Figure 3 presents a summary of the uninterrupted flow and pedestrian crossings observed across the four study locations.

Table 2: Average Vehicle Volumes

Site	Uninterrupted Flow (veh/hr)	With Pedestrian Crossings	Reduction (%)
GSM Market	1250	980	21.6
Ramat Polytechnic	1100	950	13.6
Gamboru Market	1050	910	13.3
University of Maiduguri Gate	1200	1000	16.7

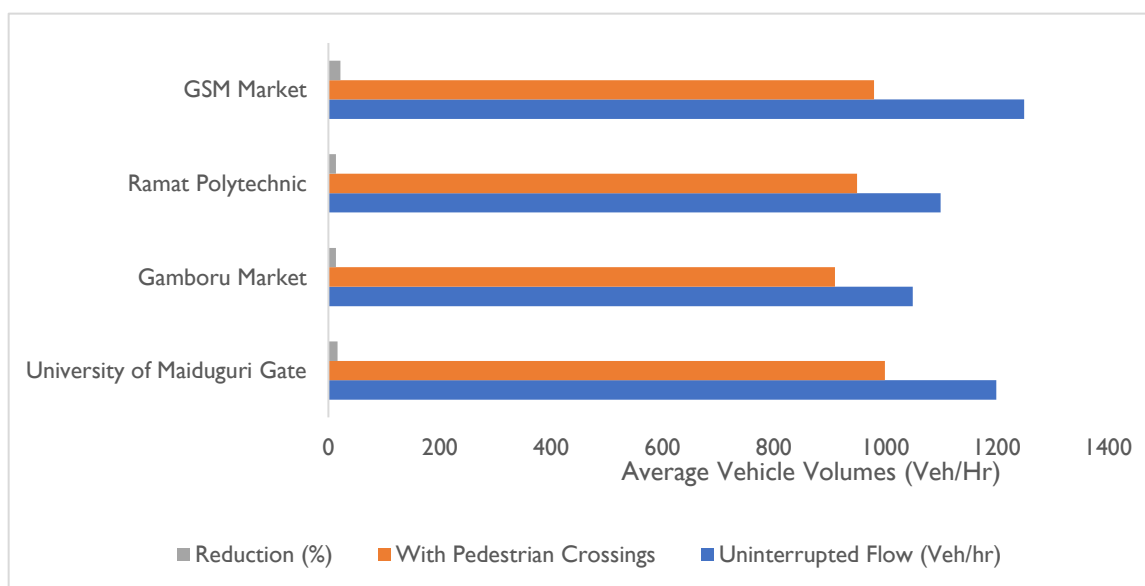


Figure 3: The comparison of uninterrupted flow versus flow interrupted by pedestrian crossings

The reduction in traffic volumes recorded in Table 2 when pedestrians crossed at grade demonstrated the disruptive effect of human interference on vehicular flow. The largest volume reduction occurred at GSM Market (21.6%), reinforcing the earlier finding that this corridor experiences the highest level of pedestrian intrusion. The reductions observed across all locations support Aderamo and Atomode’s (2012) assertion that pedestrian interruptions significantly diminish roadway capacity on urban arterials. Similarly, the marked decline in traffic throughput is consistent with Adedeji and Fadare’s (2021) observation that vehicle flow in commercial corridors is particularly sensitive to uncontrolled pedestrian movements. The results therefore confirmed that improving pedestrian compliance particularly in high activity commercial areas will directly enhance traffic operational efficiency, as suggested in previous empirical studies.

3.3 Operating Speed Analysis

Average vehicle speeds under both conditions are summarized in Table 3.

Table 3: Average Vehicle Speeds

Site	Uninterrupted Speed (km/h)	Speed with Pedestrians (km/h)	Reduction (%)
GSM Market	38	18	52.6
Ramat Polytechnic	45	25	44.4
Gamboru Market	42	22	47.6
University of Maiduguri Gate	40	24	40

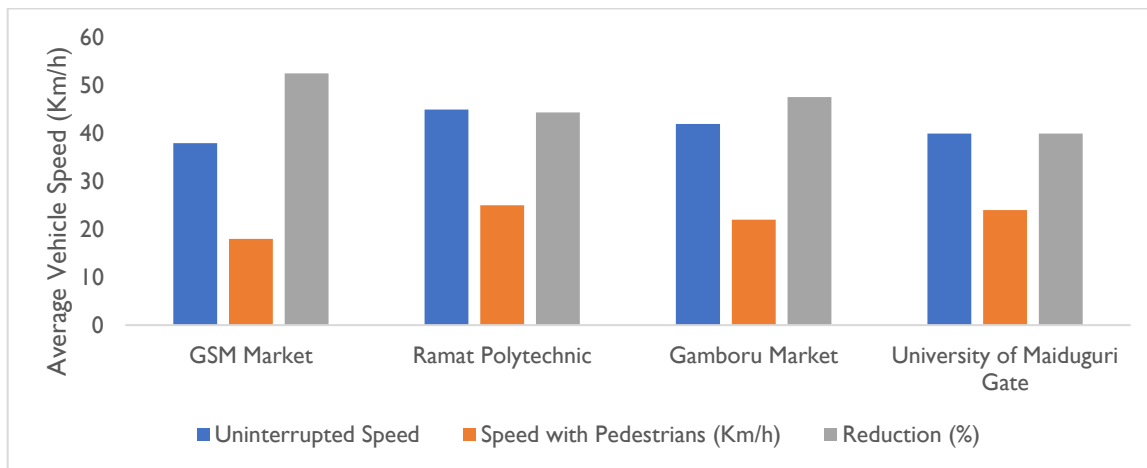


Figure 4: Speed differences across sites

Table 3 and Figure 4 showed significant reductions in vehicle speeds due to at-grade pedestrian crossings, with an average decrease of 46.2% and over 50% at GSM Market. This indicated frequent driver interruptions caused by pedestrian movement. These findings aligned with Zegeer *et al.* (2005) and Olorunfemi and Daramola (2022), who reported that pedestrian activity leads to stop-and-go traffic, speed variability and reduced flow efficiency. Overall, the results confirmed that pedestrian intrusion significantly disrupts traffic operations in mixed use urban corridors.

3.4 Pedestrian Vehicle Conflict Analysis

Pedestrian–vehicle conflicts were classified into minor, serious and critical conflicts based on observed severity of interaction, including vehicle braking intensity, pedestrian evasive action and closeness of encounter, as summarized in Table 4. Minor conflicts involved slight speed adjustments, serious conflicts involved abrupt braking or sudden pedestrian movement, while critical conflicts involved near collision situations requiring immediate evasive action.

Table 4: Pedestrian Vehicle Conflict Summary

Site	Minor Conflicts	Serious Conflicts	Critical Conflicts	Total Conflicts	PVCR (conflicts/hr)
GSM Market	33	17	6	56	11.33
Ramat Polytechnic	26	13	4	43	8.67
Gamboru Market	29	14	5	48	9.60
University of Maiduguri Gate	24	12	4	40	8.00

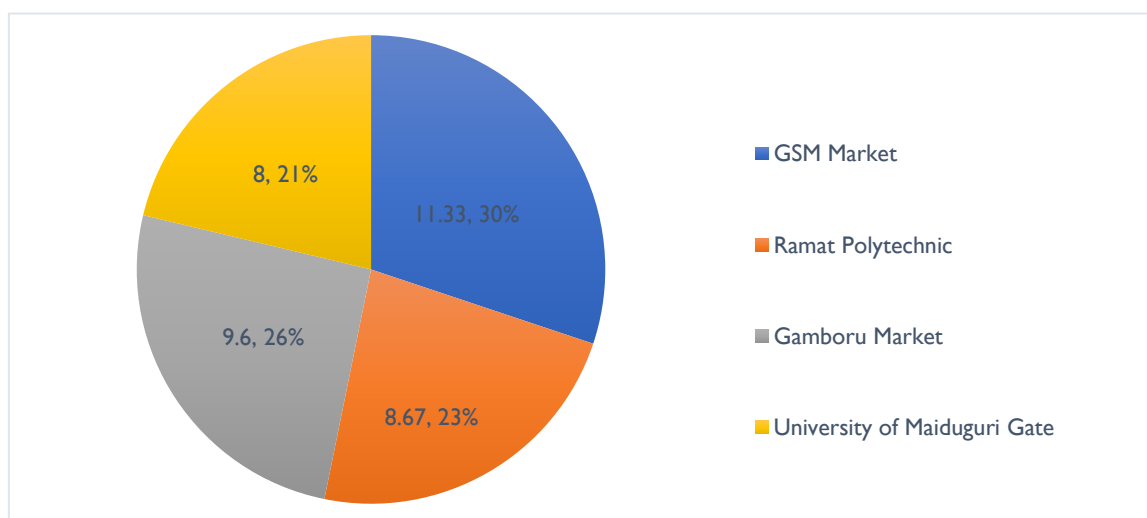


Figure 5: Pedestrian Vehicle Conflict Rate (PVCR) across sites

Table 4 indicated that pedestrian–vehicle conflicts were highest at GSM Market, with a PVCR of 11.33 conflicts per hour, while the University of Maiduguri Gate and Ramat Polytechnic record lower but notable rates. The prevalence of medium and high severity conflicts at GSM Market suggests unsafe at-grade crossings involving fast moving, non-yielding vehicles. These findings support Traffic Conflict Theory (Peden *et al.*, 2020) and agreed with Adedeji and Fadare (2021) and Ojo and Adebayo (2020), who identified commercial corridors as high-risk areas due to dense pedestrian activity and poor compliance with crossing facilities. Overall, the results confirmed that low bridge usage increases safety risks in high traffic commercial zones.

3.5 Survey Response Analysis

A total of 300 respondents explained reasons for not using pedestrian bridges.

Table 5: Survey Reasons for Bridge Non-Usage

Reason	Percentage of Respondents (%)
Inconvenience / Extra time	75
Perception of No Immediate Danger	40
Poor Maintenance / Security	25
Trading or Hawking on Bridge	15

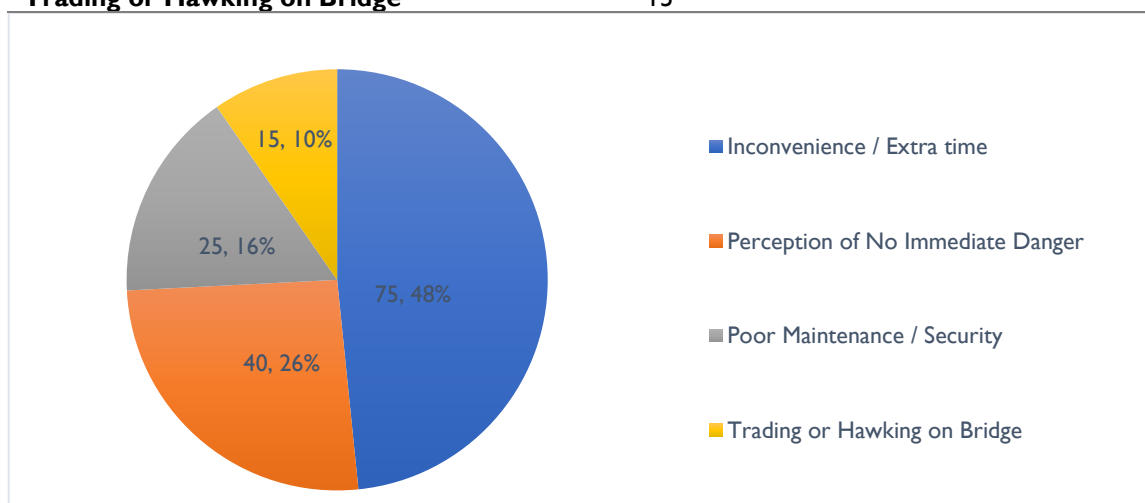


Figure 6: Survey results indicate that non-compliance is mainly driven by convenience

Survey results in Table 5 showed that perceived inconvenience mainly longer walking distance or climbing effort was the primary reason for non-use of pedestrian bridges (75%). This confirmed that most at-grade crossings are intentional rather than accidental and aligned with Ibrahim and Mohammed (2021), who noted that pedestrians prefer faster, direct routes. Additionally, 40% of respondents perceived little risk in crossing at grade, supporting Usman and Haruna (2020) on the role of risk perception in compliance. Concerns about maintenance and security also reflected Adedeji and Fadare (2021), who linked poor bridge conditions to reduced usage. Overall, these factors explained low bridge utilization and associated traffic and safety challenges.

3.6 ANOVA Results

This test showed whether differences between corridors are statistically significant.

Table 6: One Way ANOVA Results for Corridor Performance Indicators

Variable		F-value	p-value	Significance
Pedestrian Utilization	Bridge	6.42	0.008	Significant
Average Traffic Speed	Vehicular	5.17	0.014	Significant
Pedestrian Conflict Rate	Vehicle	7.58	0.004	Significant

The ANOVA results in Table 6 showed statistically significant differences among the four study corridors in pedestrian bridge utilization, average vehicular traffic speed, and pedestrian–vehicle conflict rates. The

relatively high F-values for bridge utilization (6.42), vehicular traffic speed (5.17), and conflict rate (7.58) indicated notable variation between corridor performance levels compared with variation within corridors. Since all corresponding p-values are less than 0.05, these differences are statistically significant at the 95% confidence level. This confirmed that the operational effectiveness of pedestrian bridges varied across locations due to differences in surrounding land use, traffic conditions and pedestrian behavior.

Table 7: Pearson Correction between Bridge Utilization and Traffic Performance

Variance	Pearson r	Interpretation
Bridge utilization vs traffic speed	0.61	Moderate positive relationship
Bridge utilization vs conflict rate	-0.71	Strong negative relationship

Table 7 showed the Pearson correlation between bridge utilization and traffic performance indicators. The positive correlation with vehicular traffic speed ($r=0.61$) indicated that higher bridge usage was associated with improved traffic flow and higher average speeds due to fewer at-grade pedestrian interruptions. The negative correlation with pedestrian–vehicle conflict rate ($r=-0.71$) showed that increased bridge utilization significantly reduced unsafe pedestrian–vehicle interactions. These findings are significant because they confirmed that greater use of pedestrian bridges improved both traffic efficiency and pedestrian safety.

3.7 Comparative Performance Evaluation

- a. Best Performing Corridor: University of Maiduguri Gate

Highest bridge usage (62%), lowest conflict rate (8.0/hr) and least at-grade crossing

- b. Worst Performing Corridor: GSM Market

Lowest bridge usage (30%), highest PVCR (11.33/hr), largest vehicle volume reduction (21.6%) and highest speed reduction (52.6%). In summary, the average bridge utilization across all sites is 55%, with commercial zones displaying low compliance and high traffic disruption.

4. Conclusion

This study assessed the performance of pedestrian bridges in Maiduguri Metropolis in terms of usage, traffic flow, and pedestrian–vehicle conflicts. The findings showed that although pedestrian bridges improved safety and traffic operations, their effectiveness depended significantly on pedestrian compliance, surrounding land use and accessibility. Average utilization was 55%, with higher usage linked to better traffic flow and fewer conflicts, while low usage in commercial areas led to jaywalking, delays and increased conflicts. The study concluded that infrastructure alone is insufficient without supportive behavioral and environmental conditions. The study therefore recommends measures to improve pedestrian compliance with bridge usage, proper integration of bridge locations with pedestrian movement patterns and stronger traffic management strategies to enhance safety and corridor performance.

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