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COMPARATIVE STUDY ON GRADE SEPARATION CROSSINGS AMONG PEDESTRIANS IN DIFFERENT LOCATIONS IN KANDY MUNICIPALITY AREA

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ABSTRACT

Cities are increasingly prioritising pedestrian amenities and urban rehabilitation to address the global issue of road accidents, which claim over 1.35 million lives annually, predominantly in low- and middle-income countries. Sri Lanka faces significant pedestrian safety challenges, with over 100 deaths and 1,000 injuries annually at pedestrian crossings. Grade-separated crossings offer promise in reducing pedestrian collisions and traffic congestion; however, the current pedestrian facilities in Sri Lanka are inadequate. This case study focuses on enhancing future urban designs and infrastructure by evaluating grade-separated crossings in the Kandy municipality. Kandy's unique road traffic characteristics make it an ideal study area. This study examined two underpasses and two overpasses across different urban contexts using on-site observations and questionnaire surveys. Criteria-based assessments and statistical analyses (including chi-square and V-creamer's tests) were used to identify the factors influencing pedestrians' choice of crossing facility. Research in the Kandy municipality found overpasses (73.5%-75.0% usage) to be more effective than underpasses (21.2%-57.1%), addressing user concerns about security, hygiene, and aesthetics. The key factors influencing pedestrian use included ventilation, lighting, crossing time, comfort, and accessibility. Penalties were the most effective incentive, followed by security measures and centre median barriers. Demographic factors such as sex, age, and health significantly influenced pedestrian decisions. Insights inform city planners and policymakers to improve infrastructure design.

Keywords: *Grade-separated crossings, underpasses, overpasses, effectiveness, pedestrian safety, utilisation*

1. INTRODUCTION

1.1. Background

It is a well-established fact that traffic accidents account for approximately 1.35 million fatalities and an additional 50 million injuries worldwide annually. Approximately 93% of road traffic accident deaths occur in low- and middle-income countries, despite these countries having approximately 60% of the world's vehicles [1]. Road traffic collisions stem from a combination of factors, including road layout, vehicles, road users, and their interactions. Pedestrians, although integral to traffic dynamics, are often overlooked in discussions of road accidents. Consequently, contemporary urban development initiatives have placed a heightened emphasis on pedestrian infrastructure, with concerted efforts directed towards rehabilitating cities to better accommodate pedestrians.

Pedestrian facilities are essential components of urban infrastructure designed to enhance the safety, accessibility, and convenience of walking in cities and communities. Key pedestrian facilities include sidewalks, crosswalks, pedestrian signals, footbridges, and underpasses. These facilities are integrated into urban landscapes to facilitate safe pedestrian movement, encourage active transportation, and promote social interactions. Well-designed pedestrian infrastructure not only supports sustainable modes of transportation but also contributes to the overall liveability and vibrancy of urban space.

Underpasses and overpasses are pedestrian infrastructures designed as crossing facilities to ensure safety from vehicle-pedestrian collisions. Pedestrians typically prioritise the quickest route to their destination, often neglecting safety. Several studies have explored the factors influencing the effective utilisation of underpasses and overpasses by wildlife. One such study revealed a strong preference for elevated crossings because of perceived safety and security advantages [2]. Conversely, another study identified factors such as inadequate security measures, time constraints, limited access, and the presence of street vendors as reasons for the preference of underpass use over overpass use [3]. Despite these findings, the overall effectiveness of underpasses and overpasses remains relatively stable. This underscores the importance of examining the level of success in terms of usage and the underlying factors that influence this success. Thus, there is a pressing need to investigate and address these gaps in our understanding.

Pedestrian safety is a critical concern across South Asia, where vulnerable road users account for a substantial portion of road fatalities. According to the World Health Organisation, the South-East Asia Region recorded approximately 330,000 road traffic deaths in 2021, with pedestrians accounting for a significant share of these

fatalities [4]. Sri Lanka reflects this regional pattern, with vulnerable road users, including pedestrians, representing nearly 87% of total road crash fatalities between 2010 and 2020 [5], and an estimated average of approximately 686 pedestrian deaths reported annually [6]. Studies further indicate that pedestrian-related crashes contribute between 17% and 21% of all road accidents in Sri Lanka, with over 75% of them occurring at mid-block locations [7]. Within the Kandy Municipality Area, seven pedestrian underpasses (including two currently under construction) and seven overpasses have been developed to enhancewith the intention of enhancing pedestrian safety. However, past research suggests that grade-separated pedestrian facilities often experience low utilisation when issues such as poor accessibility, inadequate maintenance, and inconvenient placement are present [8]. Therefore, this study evaluates the effectiveness of pedestrian underpasses and overpasses across selected sites in Kandy, a city characterised by a dense urban environment, significant pedestrian activity, and complex mobility challenges.

1.2. Problem Statement

The existing literature provides extensive evidence of the effectiveness of pedestrian infrastructure and the modelling of pedestrian behaviour in diverse urban environments worldwide [9], [10]. Studies have examined factors such as pedestrian crossing choices, safety perceptions, and the performance of grade-separated facilities, such as overpasses and underpasses, in enhancing pedestrian safety [8], [11]. However, despite this broad global body of work, a significant research gap remains concerning pedestrian behaviour in Kandy, Sri Lanka. Current studies have not adequately explored pedestrian preferences or the suitability of grade-separated pedestrian crossings in this unique urban setting. Consequently, there is limited understanding of how pedestrians in Kandy interact with different types of crossings, including underpasses and overpasses, and whether these facilities effectively meet the needs of users. This study aims to address this gap by investigating pedestrian behaviours, preferences, and the appropriateness of grade-separated pedestrian crossings in Kandy City.

1.3. Objectives

- This study aims to identify the effectiveness of grade-separated crossings in the Kandy municipality area, focusing on their impact on pedestrian safety and traffic flow.
- To evaluate the satisfaction levels of pedestrians with underpasses and overpasses in the Kandy area by examining the overall user experience.

- To identify and analyse the factors that encourage pedestrian usage of grade-separated crossings in the Kandy municipality area.
- Analyse the factors influencing pedestrian decision-making when utilising grade-separated crossings in the Kandy municipality area, including the age, gender, and health condition of the pedestrians.
- Recommendations are made for enhancing the maximum utilisation of future designs and infrastructures.

1.4. Scope

The scope of this case study was restricted to the examination of two underpasses and two overpasses situated in diverse urban contexts within the Kandy municipality area. Data collection primarily relied on two methods: site observations and questionnaire surveys. Site observations involved gathering data during weekdays, including both peak and off-peak hours, to provide comprehensive insights into pedestrian behaviours and traffic patterns at the selected locations. Additionally, questionnaire surveys will be administered exclusively to residents of Kandy who are aged over 18 years. These surveys were designed to elicit valuable information regarding pedestrian preferences, perceptions, and experiences with the pedestrian facilities under investigation. By focusing on these specific underpasses and overpasses and utilising a combination of observational and survey-based approaches, this study aims to offer a detailed understanding of pedestrian behaviour and the effectiveness of grade-separated facilities in the Kandy municipality area.

2. METHODOLOGY

2.1. Selection of Site

For this comparative study, two underpasses and two overpasses were selected from diverse urban contexts within the Kandy municipality. The selection criteria prioritised variations in pedestrian demographics, traffic density, and urban infrastructure to comprehensively assess the effectiveness of different grades of separated pedestrian crossings.

Kandy currently features seven underpasses and overpasses, designed to mitigate pedestrian-vehicle conflicts and facilitate safe crossing. The sites chosen for this study were strategically selected based on the types of pedestrians utilising these facilities, ensuring that the findings reflected varied user needs and behaviours. This study specifically focused on different categories of pedestrians, daily commuters, students, shoppers, and patients who exhibit distinct crossing behaviours influenced by accessibility, safety perceptions, and surrounding land use patterns.

Most of the underpasses are located within the Kandy city area, with one situated in front of the Peradeniya Hospital, serving a large number of patients and visitors. Another recently constructed underpass is positioned near a school, primarily catering to student pedestrian traffic. Similarly, most overpasses are located in close proximity to schools, reflecting the city's emphasis on enhancing pedestrian safety for school children and managing high pedestrian movement in these areas.

Selected Underpasses

1. Underpass at Kandy Market: This site was selected because of its location in a densely populated commercial area characterised by high pedestrian and vehicular movement. The underpass is frequently used by a diverse range of pedestrians, including local vendors, tourists, and commuters. Its effectiveness is influenced by factors such as congestion, pedestrian behaviours, and accessibility.
2. Underpass at Peradeniya Hospital: Located near a major medical facility, this underpass was chosen to analyse its impact on pedestrian safety, particularly for vulnerable groups such as older adults and hospital visitors. The surrounding congestion levels and the necessity of uninterrupted pedestrian flow make this an essential case for evaluation in the study.

Selected Overpasses

3. Overpass near Kandy Girls' High School: This overpass experiences high pedestrian movement, particularly during school opening and closing hours. This study considers how school children and their accompanying guardians utilise the facility and assesses the influence of structured pedestrian movement patterns on crossing behaviour.
4. Overpass near Kandy Courthouse: Situated along a major thoroughfare with significant vehicular flow, this overpass is vital for ensuring pedestrian safety in an area characterised by administrative offices and legal institutions. It serves as a crucial crossing point during peak traffic hours, making it an important topic for evaluation.

By selecting these locations, this study aims to provide a holistic understanding of the usability and effectiveness of grade-separated crossings in Kandy, offering insights into how pedestrian preferences and behaviours vary based on urban setting, purpose, and infrastructure design. This selection framework ensures that the findings can be used to improve pedestrian safety and urban mobility strategies in Sri Lanka. Figure 1 illustrates the locations of the selected underpasses and overpasses, providing a visual representation of their placement in the urban landscape.

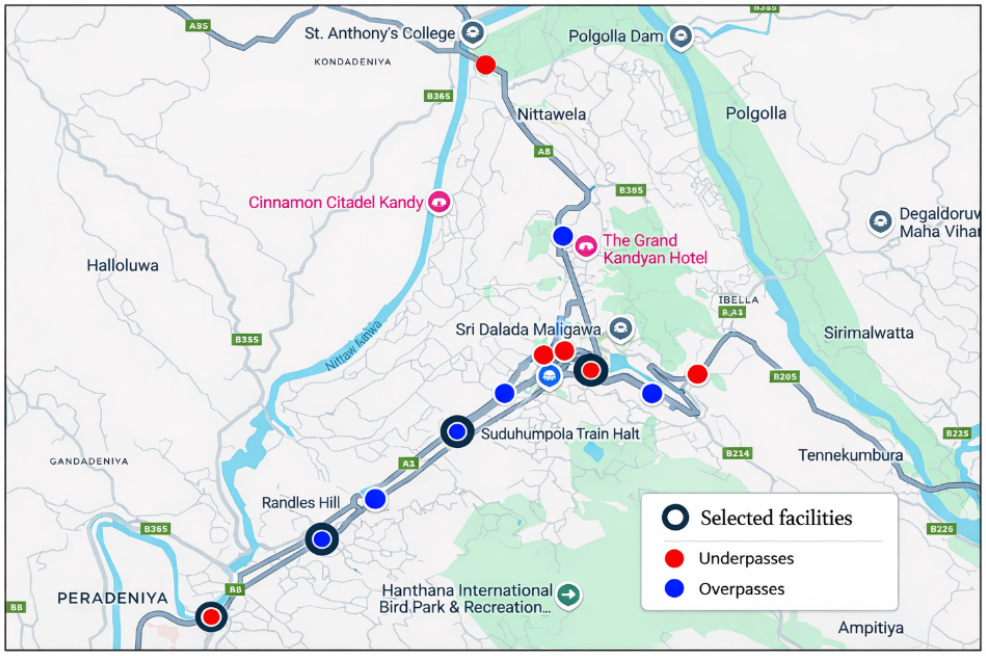

Figure 1: Selected locations for study

2.2. Data Collection

The primary method employed to assess the effectiveness of grade-separated crossings within the Kandy municipality area involves site observation and data collection. This process entails manual counting to record both user and non-user volume data, which is achieved through video documentation during peak and off-peak hours. Non-user data collection involved observing individuals crossing the road within approximately 50 m of the overpass or underpass.

The collected data were summarised and organised using a structured format. This approach allows for a systematic analysis of pedestrian behaviour and traffic patterns surrounding grade-separated crossings, facilitating the evaluation of their effectiveness in facilitating safe pedestrian passage.

This method of data collection provides valuable insights into the utilisation of grade-separated crossings and their impact on pedestrian movement within the Kandy municipality area.

The specific peak and off-peak hours selected for data collection are listed in Table 1. This table delineates the designated time periods during which site observation data were gathered to analyse pedestrian behaviour and traffic patterns surrounding grade-separated crossings within the Kandy municipality area. By identifying these peak and off-peak hours, this study aims to capture variations in pedestrian activity and

vehicular traffic volume, providing comprehensive insights into the effectiveness of grade-separated crossings under different conditions.

Table 1: Selected peak and off-peak hours for the data collection

Grade-separated crossing	Weekday	
	Peak hour	Off-peak hour
Underpass in front of the Kandy market	16:30 to 17:30	14:30 to 15:30
Underpass in front of Peradeniya Hospital	11:30 to 12:30	14:30 to 15:30
Overpass near Kandy Girls' High School	13:20 to 14:20	15:30 to 16:30
Overpass near the Kandy courthouse	08:30 to 09:30	10:30 to 11:30

A questionnaire survey was conducted among the residents of Kandy. According to the Department of Census and Statistics, the population of Kandy is 1,375,382. Based on Equation 1, a minimum of 384 responses was required. Additionally, the survey aimed to identify the key factors influencing pedestrians' choices when selecting grade-separated facilities.

$$n = \frac{N*Z^2*p*(1-p)}{(N-1)*E^2+Z^2*p*(1-p)} \text{ ---------- (1)}$$

where:

- n = required sample size
- N = population size
- Z = Z-score (based on confidence level; e.g., 1.96 for a 95% confidence level)
- p = estimated proportion of the population (e.g., 0.5, assuming maximum variability)
- E = margin of error (e.g., 0.05 for ±5% margin of error)

2.3. Data Analysis

Data collected from site observations were used to demonstrate the effectiveness of grade-separated crossings. This analysis was conducted using the equation provided below. By applying this equation to the collected data, this study aims to quantitatively assess the effectiveness of grade-separated crossings in facilitating safe pedestrian passage and mitigating vehicular traffic congestion within the Kandy municipality area.

$$\text{Degree of effectiveness} = \frac{\text{Users}}{(\text{Users}+\text{Non users})} \text{ ---------- (2)}$$

According to the degree of effectiveness, grade-separated crossings are categorised as follows:

Table 2: Effectiveness classified categories [12]

Effectiveness (%)	Categories
0 - 20	Very Ineffective
21 - 40	Ineffective
41 - 60	Effective enough
61 - 80	Effective
81 - 100	Very effective

The collected data from the questionnaire survey (Annexe 01) will be analysed using the chi-square test to examine several relationships.

i. Age versus pedestrian decision when choosing a facility.

ii. Gender versus pedestrian decision when utilising facilities.

iii. Health condition versus pedestrian decision when using the facility.

Subsequently, Cremer's V test was applied to determine the strength of the aforementioned relationships. The identified factors were analysed using Microsoft Excel to highlight the most crucial elements influencing pedestrians' choices regarding grade-separated facilities.

Furthermore, the study interpreted which grade-separated system is most suitable for Kandy based on the responses gathered through the questionnaire survey. This comprehensive analysis aims to provide valuable insights into the factors influencing pedestrians' decisions and preferences regarding grade-separated facilities in the Kandy municipality area.

3. RESULTS

Pedestrian facilities, such as overpasses and underpasses, play a crucial role in ensuring the safety and convenience of pedestrians, particularly in bustling urban areas. In this study, we assessed the effectiveness of pedestrian facilities in Kandy, focusing on four key locations: the underpass in front of Kandy Market, the underpass near Peradeniya Hospital, the overpass in front of Kandy Girls' High School, and the overpass near Kandy Courthouse.

3.1. Site Observations

Following the completion of the video recordings, the observational data were meticulously summarised and organised into tables based on specific locations. This meticulous organisation of data by location provides detailed insights into the varying dynamics and characteristics of pedestrian movement within the study area.

Table 3: Site observation data

Location	Time period	Users	Non-users
Underpass in front of Peradeniya Hospital	11:30 to 12:30	253	194
	14:30 to 15:30	148	107
Underpass in front of Kandy Market	14:30 to 15:30	625	1824
	16:30 to 17:30	561	2589
Overpass near Kandy Court House	8:30 to 9:30	77	29
	10:30 to 11:30	84	29
Overpass near Kandy Girl's High School	13:20 to 14:20	418	119
	15:30 to 16:30	5	22

The effectiveness level was determined by observing the selected overpasses and underpasses. This assessment revealed the current effectiveness of each overpass/underpass.

Table 4: Effectiveness of the facilities

Location	Category	Overall Effectiveness %
Underpass in front of Kandy Market	Ineffective	21.2%
Underpass in front of Peradeniya Hospital	Effective enough	57.1%
Overpass near Kandy Court House	Effective	73.5%
Overpass near Kandy Girl's High School	Effective	75.0%

The underpass situated in front of the Kandy Market, despite being located in a busy area, exhibits low usage, with only 21.2% of pedestrians utilising the facility. This low uptake suggests an inefficiency in providing a viable alternative for pedestrians to cross the road. Further investigation into the factors contributing to this underutilisation is warranted to improve its effectiveness and address the needs of pedestrians in its vicinity.

Table 5: Users and non-users volume of the underpass in front of Kandy Market

Observed Time Periods	Users	Non-users	Effectiveness
14:30 to 15:30	625	1824	25.5%
16:30 to 17:30	561	2589	17.8%
	1186	4413	21.2%

In contrast, the underpass in front of Peradeniya Hospital demonstrated moderate effectiveness, with 57.1% of pedestrians utilising the facility. The peak usage observed during hospital opening hours indicates the importance of strategically situating pedestrian facilities to cater to specific activity patterns. However, the

presence of a notable percentage (42.9%) of pedestrians not using the underpass highlights potential usability issues or deficiencies that must be addressed to maximise its utility.

Table 6: Users and non-users volume of the underpass in front of Peradeniya Hospital

Observed Time Periods	Users	Non-users	Effectiveness
11:30 to 12:30	253	194	56.6%
14:30 to 15:30	148	107	58.0%
Total	401	301	57.1%

The overpass in front of Kandy Girl's High School is highly utilised during school opening and closing hours, reflecting its effectiveness in accommodating peak pedestrian flows. However, during off-peak hours, usage significantly declined, with 81.5% of pedestrians opting not to use the facility. This discrepancy underscores the need for supplementary measures to encourage consistent use and enhance pedestrian safety throughout the day.

Table 7: Users and non-users volume of the overpass in front of Kandy Girl's High School

Observed Time Periods	Users	Non-users	Effectiveness
13:20 to 14:20	418	119	77.8%
15:30 to 16:30	5	22	18.5%
	423	141	75.0%

The overpass near the Kandy Courthouse emerged as an effective pedestrian facility, with 73.5% of pedestrians utilising the bridge. Situated along a busy two-lane, two-way highway characterised by high vehicle speeds, the overpass serves as a crucial pedestrian safety measure in the area. The relatively lower total pedestrian volume compared to other locations may be attributed to the specific nature of the surrounding areas. Nonetheless, the high utilisation rate underscores the importance of providing safe crossing options in high-risk traffic environments for pedestrians.

Table 8: Users and non-users volume near the Kandy Courthouse

Observed Time Periods	Users	Non-users	Effectiveness
8:30 to 9:30	77	29	72.6%
10:30 to 11:30	84	29	74.3%
	161	58	73.5%

The evaluation of pedestrian facilities in Kandy revealed varying degrees of effectiveness across different locations. While some facilities demonstrate satisfactory usage rates, others exhibit notable underutilisation or dependency on specific patterns of activity. Addressing these disparities requires a comprehensive approach that considers factors such as location, accessibility, and user preference. By leveraging these insights, urban planners and policymakers can develop targeted interventions to enhance pedestrian mobility, safety, and overall urban liveability in Kandy and similar settings.

3.2. Questionnaire Survey

The subsequent graphs illustrate the distribution of the responses obtained from the survey. These visual representations provide a clear depiction of how the participants responded to the various questions and factors analysed throughout the study.

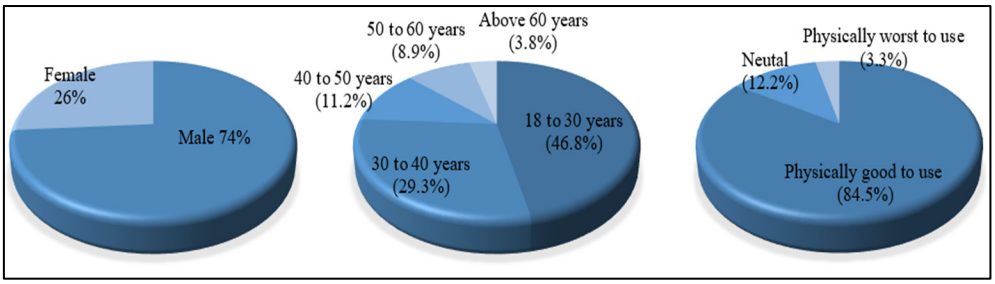

Figure 2: Distribution of gender and health condition of pedestrians

Based on the analysis of the responses provided above, the satisfaction levels regarding both underpasses and overpasses were examined, considering the recent experiences of users. The following tables present the satisfaction levels for each category.

Table 9: Satisfaction level of underpasses

Factors	Dissatisfied	Neutral	Satisfied
Security	37.2%	54.2%	8.7%
Ventilation & lighting	21.4%	66.2%	12.5%
Comfortability	20.4%	67.2%	12.5%
Time to cross	12.5%	55.0%	32.6%
Easy to access	19.3%	66.7%	14.0%
Aesthetic beauty	32.1%	61.3%	6.6%
Hygienic	51.1%	45.3%	3.6%

According to the collected responses, there is notable dissatisfaction with various aspects of the underpass infrastructure. Specifically, a significant proportion of respondents (37.2 %) expressed dissatisfaction with the security measures in place within the underpasses. Conversely, only 8.7% of respondents reported feeling satisfied with the security arrangements. Most respondents remained neutral on this aspect. Furthermore, a similar pattern emerged when considering the ventilation and lighting within the underpasses. Approximately 21.4% of respondents expressed dissatisfaction with the ventilation and lighting conditions, whereas only 12.5% reported feeling satisfied. Once again, a considerable portion of respondents remained neutral in their assessments. Another crucial factor in evaluating underpass infrastructure is the level of comfort experienced by users. Here, 20.4% of respondents expressed dissatisfaction, in contrast to the mere 12.5% who reported feeling satisfied. The majority of respondents remained neutral regarding the comfort of the underpass. The time taken to cross the underpass was another significant consideration. Interestingly, while 19.3% of respondents expressed dissatisfaction with crossing times, a substantial 66.7% remained neutral. This suggests that while dissatisfaction exists, it may not be as pronounced as in other areas of the country. Similarly, the ease of access to the underpasses yielded comparable results, with 19.3% of the respondents expressing dissatisfaction and 66.7% remaining neutral. Regarding the aesthetic appeal of the underpass facilities, the data indicated a notable level of dissatisfaction, with 32.1% of respondents expressing discontent. Additionally, a majority (61.3 %) remained neutral, while only a small fraction (6.6 %) reported feeling satisfied with the aesthetic aspects. However, the most significant dissatisfaction was observed in the realm of hygiene. A substantial 51.1% of respondents expressed dissatisfaction with the hygiene standards of the underpasses, and 45.3% remained neutral. Only a minimal 3.6% reported feeling satisfied with hygiene conditions.

Overall, the data show that hygiene emerges as the most prominent area of dissatisfaction among respondents. This suggests a pressing need for improvements in the underpass infrastructure to better meet the expectations and needs of users. Additionally, while other factors such as security, comfort, and aesthetics warrant attention, they may not elicit as pronounced a level of dissatisfaction as hygiene.

Based on the collected responses, it is evident that there is notable dissatisfaction with various aspects of the overpass infrastructure. When examining the security of overpasses, 35.1% of respondents expressed dissatisfaction, whereas only 7.9% reported feeling satisfied. The majority of respondents remained neutral on this aspect. Regarding the comfort of the underpass, 23.4% of respondents expressed dissatisfaction, in contrast to 10.2% who reported feeling satisfied. Again, most respondents remained neutral regarding their comfort experience in the underpass.

Another important factor considered in the evaluation was the time taken to cross the facility. Interestingly, while 12% of respondents expressed dissatisfaction with crossing times, a significant 31.3% reported satisfaction. This indicates a more positive perception of the time efficiency of overpasses compared with other evaluated factors. Similarly, the ease of access to overpasses yielded varied responses, with 20.6% of respondents expressing dissatisfaction and 14.2% reporting satisfaction. Once again, most respondents remained neutral on this matter. The aesthetic appeal of overpass facilities also emerged as a significant consideration, with 32.8% of respondents expressing dissatisfaction. Additionally, a majority (60.8 %) remained neutral, while only a small fraction (6.4 %) reported feeling satisfied with the aesthetic aspects. However, the most significant dissatisfaction was observed in the realm of hygiene, mirroring the findings related to the underpasses. A substantial 45.5% of respondents expressed dissatisfaction with the hygiene standards of the overpasses, and 50.6% remained neutral. Only a minimal 3.8% reported feeling satisfied with hygiene conditions.

Table 10: Satisfaction level of overpasses

Factors	Dissatisfied	Neutral	Satisfied
Security	35.1%	57.0%	7.9%
Comfortability	23.4%	66.4%	10.2%
Time to cross	12.0%	56.7%	31.3%
Easy to access	20.6%	65.1%	14.2%
Aesthetic beauty	32.8%	60.8%	6.4%
Hygienic	45.5%	50.6%	3.8%

Overall, the data highlighted hygiene as the most prominent area of dissatisfaction among respondents, mirroring the findings related to the underpasses. This underscores the pressing need for improvements in hygiene standards across underpasses and overpasses. Additionally, while aesthetic appeal warrants attention, it may not elicit as pronounced a level of dissatisfaction as hygiene.

Next, the factors that encourage pedestrians to utilise grade-separated crossings were analysed. Six main factors were considered in this analysis: the presence of median barriers, type of pedestrian systems, prevailing vehicle speed on the roadway, width of the road crossing, security measures implemented within the facility, and existence of penalties.

The weighted value for Factor A is calculated using the inverse-rank method. If ranks run from 1 (most important) to 6 (least important), the inverse of each factor's rank

(i.e. 1/rank) is computed. Then, the inverses are normalised so that the weights sum to 1. The weight for Factor i is,

$$w_i = \frac{1/\text{rank}_i}{\sum_{j=1}^{6}(1/\text{rank}_j)} \quad \text{---------- (3)}$$

The table below displays the ranking of these factors based on the results obtained from the survey.

Table 11: Factors that encourage pedestrians to use the grade-separated crossings

Importance	Weight Value (A)	The existence of median barriers	The type of pedestrian system	The existing vehicle speed on the roadway	The crossing width of the road	Security of the pedestrian system	Penalties
1	1	46	22	22	22	108	201
2	0.5	152	27	33	29	111	106
3	0.33	162	31	56	33	117	49
4	0.25	13	67	190	61	25	19
5	0.2	10	126	85	75	26	9
6	0.167	10	120	7	173	6	9
Weight Value for factors (A*Frequency of factors)		182.38	107.72	122.65	106.53	214.56	278.22
Ranking of the factors		3	5	4	6	2	1

According to the analysis, penalties emerged as the most influential factor in encouraging pedestrians to utilise overpasses or underpasses. Following penalties, facility security is of significant importance. Elevated security levels encourage pedestrians to use the facility. The existence of median barriers was ranked next in importance. With median barriers in place, pedestrians are left with limited choices, essentially directing them to use underpasses or overpasses as designated crossing points. Subsequently, the prevailing vehicle speed on a roadway is a crucial determinant. Lower vehicle speeds encourage pedestrians to use the facilities, whereas higher speeds can deter pedestrians from using them. The type of pedestrian system ranked lower in significance, indicating a lesser contribution to encouraging pedestrians to use the facilities. Similarly, the width of the road crossing also fell into this category, suggesting that while these factors may play a role, their impact is comparatively lesser in terms of encouraging pedestrian use of the facilities.

Overall, these findings provide valuable insights into the factors influencing pedestrian behaviour in using grade-separated crossings. By understanding these factors, urban planners and policymakers can make informed decisions to improve pedestrian safety and accessibility in urban environments.

Next, we examined the utilisation of pedestrian facilities based on gender. The analysis revealed that most males preferred using overpasses, followed by at-grade systems as their second choice. In contrast, female respondents demonstrated a more even distribution in their preferences across all types of facilities. This indicates a notable gender-based preference trend, particularly favouring overpasses among male pedestrians, whereas females exhibit a more balanced usage pattern across different facility types.

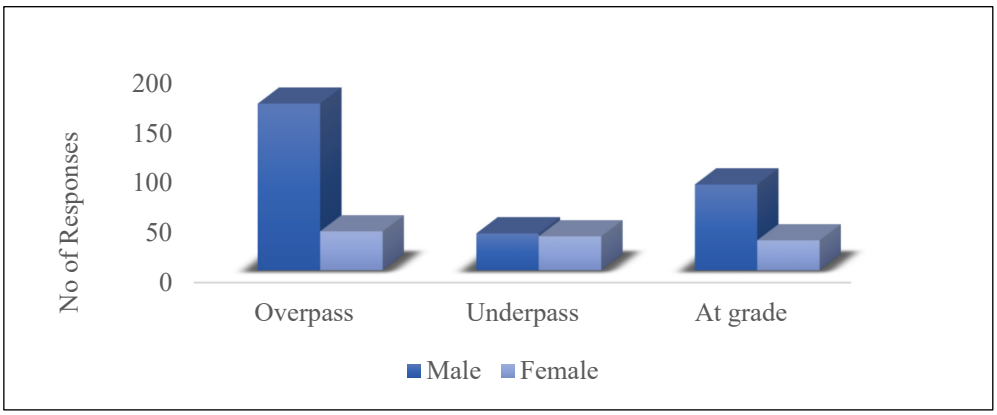

Figure 3: Comparison of pedestrian facility usage by gender

When examining pedestrian facility usage based on health condition, pedestrians in good physical health primarily chose overpasses as their preferred option, followed by at-grade systems and then underpasses. In contrast, pedestrians with neutral or poorer physical health conditions tended to prioritise at-grade systems as their top choice. For both groups (neutral and physically worse health conditions), overpasses were the second most preferred choice, followed by underpasses as the third choice. This analysis underscores how health conditions influence pedestrians' preferences in selecting different types of pedestrian facilities.

When analysing the relationship between age groups and the usage of pedestrian facilities, the graph distinctly illustrates that younger individuals exhibit a stronger preference for overpass use. As individuals age, there is a noticeable shift towards choosing at-grade systems. This trend suggests that younger people are more inclined to use overpasses, whereas older individuals tend to prefer at-grade pedestrian facilities. The graphical representation highlights how age influences the selection of pedestrian infrastructure among various demographic groups.

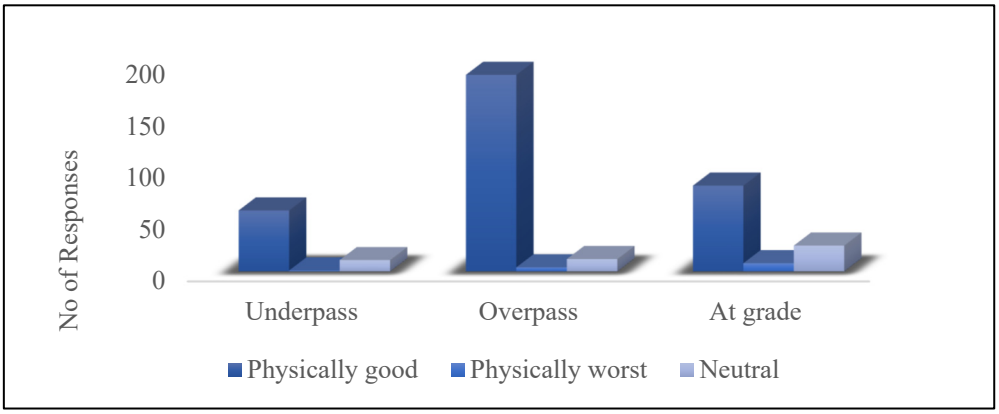

Figure 4: Comparison of pedestrian facility usage by health condition

After analysing pedestrian facility usage based on the gender, age, and health conditions of pedestrians, the next step involved analysing the relationships among these demographic factors. This analysis aimed to investigate how these factors interact and influence preferences and choices related to pedestrian infrastructure.

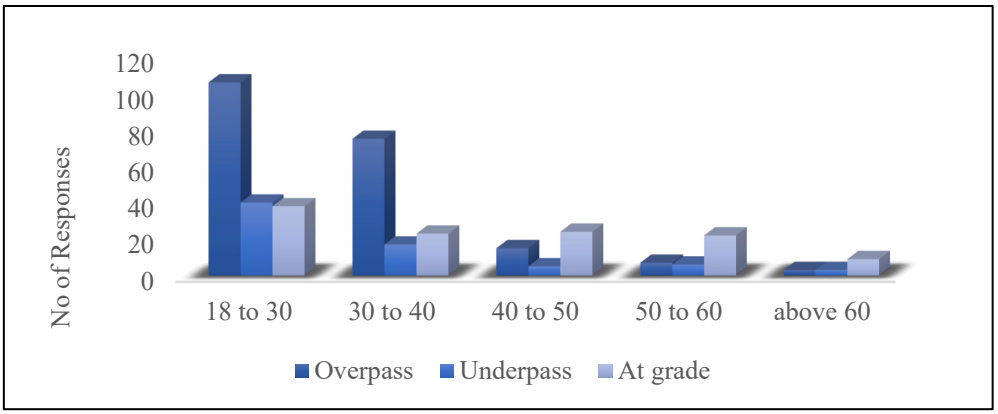

Figure 5: Comparison of pedestrian facility usage by age

Next, the relationship between sex and the decision-making process when choosing a facility was analysed using a chi-square test. Two hypotheses were formulated: the null hypothesis stating that there is no relationship, and the alternative hypothesis suggesting a significant relationship between gender and decision-making. The calculated chi-square value was 22.90, exceeding the tabular chi-square value of 5.99. Consequently, the alternative hypothesis was accepted, indicating a significant relationship between gender and the decision-making process when choosing a facility. Further analysis using Cramer's V test revealed a medium-strength relationship between the two variables.

Subsequently, the relationship between health conditions and decision-making when selecting a facility was examined using a chi-square test. The calculated chi-square value (26.02) surpassed the tabular chi-square value (9.49). The alternative hypothesis was accepted, indicating a significant relationship between health conditions and the decision-making process when choosing a facility. Similarly, Cramér's V test indicated a medium-strength relationship in this context.

The relationship between age and decision-making when selecting a facility was assessed using a chi-square test. Once again, a significant relationship was observed, with the calculated chi-square value of 56.25 exceeding the tabular chi-square value of 15.51. This outcome underscores the significant relationship between age and the decision-making process when choosing a facility.

Table 12: Relationship between demographic factors and decision making when choosing pedestrian facilities

	Relation	Strongness
The relation between gender and decision-making when choosing a facility	Significant	Medium
The relation between health conditions and the decision when choosing a facility	Significant	Medium
The relation between age and decision when choosing a facility	Significant	-

Finally, an overview was conducted to ascertain the most preferred crossing system in Kandy. The results indicated that 52% of respondents considered overpasses as the most preferable crossing system, while 30% of respondents favoured at-grade systems. The remaining 18% of respondents preferred underpasses in Kandy. This distribution is visually represented in the graph below, which clearly illustrates the respondents' preferences regarding crossing systems in the area.

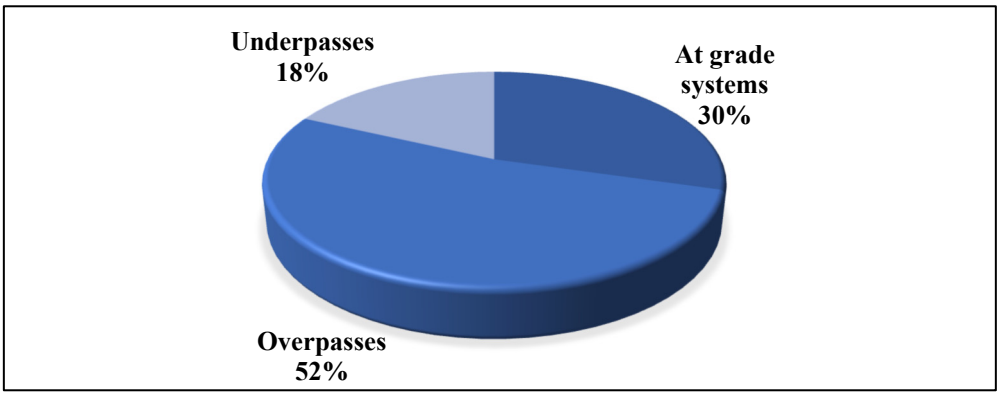

Figure 6: Distribution of public preference for crossing systems

Finally, an overview was conducted to ascertain the most preferred crossing system in Kandy. The results indicated that 52% of respondents considered overpasses as the most preferable crossing system, while 30% of respondents favoured at-grade systems. The remaining 18% of respondents preferred underpasses in Kandy. This distribution is visually represented in the graph below, which clearly illustrates the respondents' preferences regarding crossing systems in the area.

The questionnaire survey yielded several suggestions aimed at enhancing the utilisation of underpasses and overpasses in Kandy. The most frequently cited recommendation was to improve security and hygiene measures within these facilities. Additionally, respondents commonly proposed the introduction of stricter pedestrian rules and enforcement by police officers to promote safer pedestrian behaviours. Another prevalent suggestion was the incorporation of new technologies, such as electric staircases and elevators, to accommodate disabled pedestrians. Respondents also highlighted the need to address safety concerns, particularly the slippery conditions of staircases during rainy weather, and emphasised the importance of improving infrastructure to ensure pedestrian safety. Furthermore, respondents suggested enhancing the functionality of overpasses by installing shelters or roofs to protect them from the elements. These suggestions collectively underscore the importance of addressing security, hygiene, accessibility, and safety concerns to optimise the utilisation of grade-separated facilities in Kandy. Incorporating these recommendations could significantly improve the overall pedestrian experience and promote the effective use of underpasses and overpasses in urban landscapes.

4. CONCLUSION

4.1. Conclusions

The key findings can be discussed across several dimensions. The evaluation of the effectiveness and satisfaction levels of Underpasses and Overpasses across different urban contexts revealed notable insights. The overpasses situated in front of Kandy Girls' High School and near Kandy Courthouse fall within the "Effective" category, while the underpass in front of Peradeniya Hospital also achieves an "Effective" rating. However, the underpass in front of Kandy Market is categorised as "Ineffective."

Furthermore, the analysis of the relationship between sex, age, health conditions, and decision-making when selecting these facilities demonstrated a significant and moderately strong correlation. Additionally, the satisfaction levels associated with underpasses and overpasses vary across several factors. While factors such as security, comfort, crossing time, and accessibility received neutral responses from the

majority, aspects concerning aesthetic appeal and hygiene were predominantly dissatisfying.

Moreover, this study identifies factors that incentivise pedestrians to utilise grade-separated systems. The foremost factor is the imposition of penalties, which emerges as the most influential aspect. Other significant factors include the security of the pedestrian system, presence of centre median barriers, prevailing vehicular speed on the roadway, type of pedestrian system, and width of the road crossing.

Regarding the most preferred pedestrian crossing system for the Kandy area, the findings suggest a preference for overpasses, followed by at-grade systems, with underpasses ranked last.

4.2. Recommendations

Based on the findings and feedback from the questionnaire survey, the following recommendations aim to improve the effectiveness and user satisfaction of pedestrian infrastructure. By addressing key concerns, such as aesthetics, security, accessibility, and awareness, these measures can encourage higher utilisation rates and contribute to safer and more efficient pedestrian systems.

4.2.1. Enhanced aesthetic and hygienic considerations

Pedestrian infrastructure, particularly underpasses, is often criticised for being dark, unclean, and visually unappealing, which discourages usage and leads to jaywalking and increased traffic conflict. Enhancing aesthetics and maintaining cleanliness can create a more inviting and comfortable environment, encouraging regular pedestrian use and instilling a sense of safety and convenience. To achieve this, regular cleaning and maintenance schedules should be established to prevent littering and foul odours, and artistic murals, greenery, and proper lighting can improve visual appeal. Additionally, installing ventilation systems in enclosed spaces can enhance air quality, and community engagement programs can foster local involvement in maintaining these pedestrian areas.

4.2.2. Increased security measures

Security concerns, particularly in underpasses, often deter pedestrians because of poor lighting, loitering, and criminal activity, creating a perception of insecurity. Enhancing security measures is crucial for ensuring pedestrian safety, reducing accidents, and discouraging unsafe road crossings. Effective strategies include installing CCTV cameras and emergency call buttons in underpasses and overpasses, increasing police patrols or security personnel in high-risk areas, and implementing motion-sensor lighting to improve night-time visibility. Additionally, collaboration

with local businesses or vendors can help create a continuous presence, discourage illegal activities, and foster a safer pedestrian environment.

4.2.3. Optimisation of penalty systems and enforcement mechanisms

Many pedestrians opt for at-grade crossings due to convenience, even when safer alternatives are available, and weak enforcement of penalties for jaywalking or improper road use reduces pedestrian infrastructure effectiveness. Strict enforcement is essential to discourage unsafe behaviours and promote the use of designated crossings. Effective measures include fining jaywalkers, conducting random enforcement drives at critical locations, integrating automated pedestrian tracking systems with AI-driven penalty issuance, and offering incentives such as discounted public transport fares for compliant pedestrian behaviour. Strengthening the collaboration between law enforcement and traffic management authorities can further enhance enforcement efforts and improve pedestrian safety.

The video survey revealed behavioural patterns and operational issues that contribute to ineffective facility use, especially at the Kandy Market Underpass. These recommendations focus on improving the actual performance and reducing conflict points.

4.2.4. Align facilities with pedestrian desire lines

The video data showed that pedestrians often avoided the underpass because the entrances did not match their natural walking paths.

- Entrances should be relocated or added closer to the main pedestrian flow.
- Improving the street-level visibility of the underpass.
- Ensure that walking paths lead directly to facility access points.

4.2.5. Improve lighting and visibility

- Observations indicated dim or shadowed areas that discouraged usage.
- Bright, uniform lighting should be added from entrances to exits.
- Eliminate dark corners and create open sightlines to enhance visibility.

4.2.6. Reduce jaywalking and unsafe crossings

- Video recordings revealed high rates of illegal crossings near the market.
- Barriers or median fencing should be installed to guide pedestrians toward the underpass.
- Signage at conflict points should be improved.
- Pedestrian marshals should be added during peak hours if necessary.

Implementing these recommendations can significantly enhance the effectiveness of pedestrian infrastructure by addressing key issues related to safety, accessibility,

aesthetics, and enforcement. A well-maintained and secure pedestrian system encourages safe pedestrian behaviour, reduces traffic congestion, and fosters a pedestrian-friendly urban environment. By combining technological advancements, policy enforcement, and community engagement, urban planners and policymakers can create widely accepted and effectively utilised pedestrian facilities.

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