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Exploring the Underutilization of Pedestrian Sidewalks in South Africa's Urban Residential Areas: A Conjoint Analysis Approach

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Abstract Despite approximately 60% of South Africa's population relying on walking as a primary mode of transport, pedestrian safety remains a critical concern, with one-third of all road fatalities being pedestrians. This alarming statistic underscores the urgent need for governmental interventions to establish safer non-motorised transport systems. However, such developments are often deprioritised in residential areas, leading to pedestrians frequently resorting to using roadways instead of sidewalks. This study investigates the key attributes contributing to the walkability of residential areas, offering insights to inform urban planning design solutions for enhancing pedestrian infrastructure in these regions. Bloemfontein city in South Africa was used as a case study. A Conjoint Analysis technique, a multivariate method for understanding individual preferences, was employed to identify the significance of various sidewalk attributes. The results indicate that the walkable width of a sidewalk, the obstacles number present, the type of surface material, and changes in elevation significantly influence pedestrians' choice to use sidewalks over roadways. By optimising these elements, we can promote sidewalk usage, encouraging a safer transition for pedestrians away from roadways and towards sidewalks.

Keywords Pedestrian Infrastructure, Walkability, Residential Areas, South Africa, Conjoint Analysis, Urban Planning Design, Non-motorised Transport, Sidewalk Attributes, Pedestrian Safety, Transport Policies

1. Introduction

The prominence of pedestrian-friendly environments has seen a growing focus within the domains of urban and transportation planning, as well as medicine, underscored by factors such as sustainability, safety, health, and economic development [1,2]. Walking instead of using motorised transport can reduce emissions and improve health. Beyond these benefits, pedestrian environments significantly influence both micro and macro scales, affecting the movement of residents, and thus, the overall competency of a transport network which restricts access to certain areas [3]. The level of accessibility to open spaces especially a public facility rates the success of the environments [4], while an environment that offers more opportunities to walk provides different benefits (e.g., increased social integration, less air pollution and greater property values) [5]. With its unique challenges in South Africa, the benefits of a walkable environment could surpass those in developed countries.

South Africa has experienced significant changes in land use and urbanisation since the introduction of the new constitution in 1994, driven by consistent migration to cities. This migration has urban sprawl in cities and increased the demand for upgrading a city's infrastructure [6], amplifying the need for pedestrian infrastructure due to a significant rise in urban and suburban pedestrian populations. Sidewalks are central to safe and effective walkable environments, whose importance is evident and well-documented in research related to the increased activities of pedestrianisation [7]. The practical design of sidewalks increases street connectivity, and pedestrian safety. It offers less resistance for pedestrians, which affects pedestrian movement by route selection, time, and selection on mode of travel [8].

Literature suggests that most South Africans depend on walking as a mode of transport. A trend is observable in central business districts (CBD) and residential areas within the city [9]. Despite the inherent dangers, it is common to see pedestrians in residential areas jaywalking or walking directly on the carriageway. Such behaviour can obstruct traffic flow, posing challenges for motorists and increasing the risk of pedestrian-vehicle collisions [10].

Closer examination reveals that even wide sidewalks are often avoided due to obstructions like inappropriate urban furniture, poor maintenance, and low-quality materials. Common issues include overgrown gardens, uneven driveways, and unmaintained surface water inlets.

This study primarily assesses the infrastructure designs influencing pedestrians' decision to opt for a different mode of transport in South African cities, focusing on the city of Bloemfontein as the study area.

2. Materials and Methods

2.1. Using a Conjoint Analysis Technique

This study employs a Conjoint Analysis (CA), a technique initially used as a marketing research tool to comprehend individual preferences [11]. CA operates on the premise that a participant weighs the attributes of a product based on a rating system. With this study, we postulated that the behaviour of pedestrians regarding the use of sidewalks could be interpreted through the lens of sidewalk attributes. We drew from the research of Wicramasinghe and Dissanayake [12], which utilised the CA technique to gauge the attributes compelling pedestrians to avoid using sidewalks objectively. We applied their methodology to residential areas rather than central business districts, aiming to (1) validate the research by Wicramasinghe et al. [12], (2) test the method in a different context, and (3) contribute to how South Africans perceive pedestrians and the growth of walkability.

2.2. Identifying Primary Influential and Independent Sidewalk Attributes

The selection of suitable attributes for evaluation stemmed from an extensive literature review, which highlighted attributes studied internationally and locally. We also did physical surveys on sidewalk attributes identified in the study of Universitas, an urban residential area in the city of Bloemfontein experiencing a high volume of daily pedestrians.

Upon review of various tools and methods to outline the different elements of a sidewalk, attributes such as the width of sidewalks, the presence of sidewalks, surface type, obstructions, and the slope (including vertical separation) were identified. Similarly, Wicramasinghe et al. [12] suggest that sidewalk width, presence of obstacles, opposing pedestrian flow rate, and availability of safety rails primarily influence sidewalk avoidance. [13,14,15,16], were among the first to develop an environmental assessment tool for pedestrians in South Africa. The tool identified critical factors related to obstructions, pavement material, slope, condition, and cuts with driveways. Wicramasinghe et al. [12] recommended that sidewalk attributes within the study area were also considered to evaluate actual needs correctly.

After gathering responses from 319 pedestrians in and around the study area and integrating these findings with the literature, we identified the width of the walkable area, walkway obstacles, the type of surface, and changes in walking elevation as the primary reasons pedestrians avoid sidewalks. Each independent attribute was assigned to three different levels of influence, as illustrated in Table 1.

Table 1. Key Sidewalk Characteristics and Their Corresponding Levels of Impact

Sidewalk Attribute	Different Levels		
	1	2	3
Width of the Walkable Area (m)	> 2	1-2	< 1
Walkway Obstacles (Number)	0	1-5	< 5
Type of Surface	Paved	Gravel	Vegetation
Changes in Elevation of Walkway	0	1 to 3 Changes	> 3 Changes

Prominent sidewalk features within the study area typically include:

- Driveway cuts change due to elevation.
- Width of the sidewalk in the walking area influenced by gardening.
- A variety of surfacing materials (e.g., short vegetation, typically grass, paving blocks, and various gravel materials)
- Different obstructions (e.g., street lighting posts, garden decor, electrical boxes, signboards, trees, and refuse bins) [16].

From 35 measurements taken, the average sidewalk width was found to be 3.7m. Despite the ample width of the sidewalks within the study area, they are often cluttered with inappropriate urban furniture. This reduces the available walking space to varying degrees, from no available space to the full width of the sidewalk.

2.3. Constructing Conjoint Profiles

Supposed profiles were constructed featuring several combinations of these attributes. Generating potential combinations results in 81 ((3) x (3) x (3) x (3) = 81)) profiles. Given that CA relies on a ranking response technique, this could potentially overwhelm respondents and compromise the data quality. To mitigate this issue, we employed the orthogonal fractional design statistical method. This technique reduces product configurations while ensuring all attributes are presented equally and uncorrelated. The orthogonal fractional design was executed using SPSS software (version 23). Consequently, the 81 hypothetical profiles were pared down to nine, as outlined below (Table 2).

Table 2. Orthogonal Fractional Design Profiles

Card	Walkable Width (m)	Obstacles	Walking Surface	Elevation Changes
1	<1	1 – 5	Plants	Non
2	<1	> 5	Paved	1 to 3
3	1-2	0	Plants	1 to 3
4	1-2	> 5	Gravel soil	Non
5	1-2	1 - 5	Paved	>3
6	>2	> 5	Plants	>3
7	>2	0	Paved	Non
8	<1	0	Gravel soil	>3
9	>2	1 - 5	Gravel soil	1 to 3

Each theoretical profile was meticulously transformed into a three-dimensional model using a suitable software rendering tool. We took considerable care to ensure that each profile was uniform to reduce the influence of variables other than the examined features. The pedestrian surveys in Section 2 then included these created profiles, which respondents evaluated from the most favoured (1) to the least preferred (9).

2.4. Compilation of the Results

The questionnaire yielded 284 responses, which were gathered from the participants. The information was then analysed using the SPSS software to conduct the CA. The use of the CA delivers a model to illustrate the relationship between the different attributes with their ranking scores. For this research, we presupposed a distinct link between the ranking score values and the components. According to a discrete model, no assumptions are made on the link between the attributes and the ranks, which argues that the attribute levels are categorical.

The CA yields the comparative importance of each attribute. These essential values show the significance of an attribute compared with others. Determining the relevance of an attribute, the analysis considers the range in the attribute utility values, which signifies the variation that each attribute introduces to the total utility of a product. Figure 1 outlines the process of calculating the percentage importance from the ranges for each attribute. The particular attribute levels used for the evaluation determine how important each attribute is. For instance, a wider range suggests a more significant quality. Measures of importance are relative, ratio-scaled, and study-specific. A 60% importance attribute is therefore twice as important as a 30% importance property.

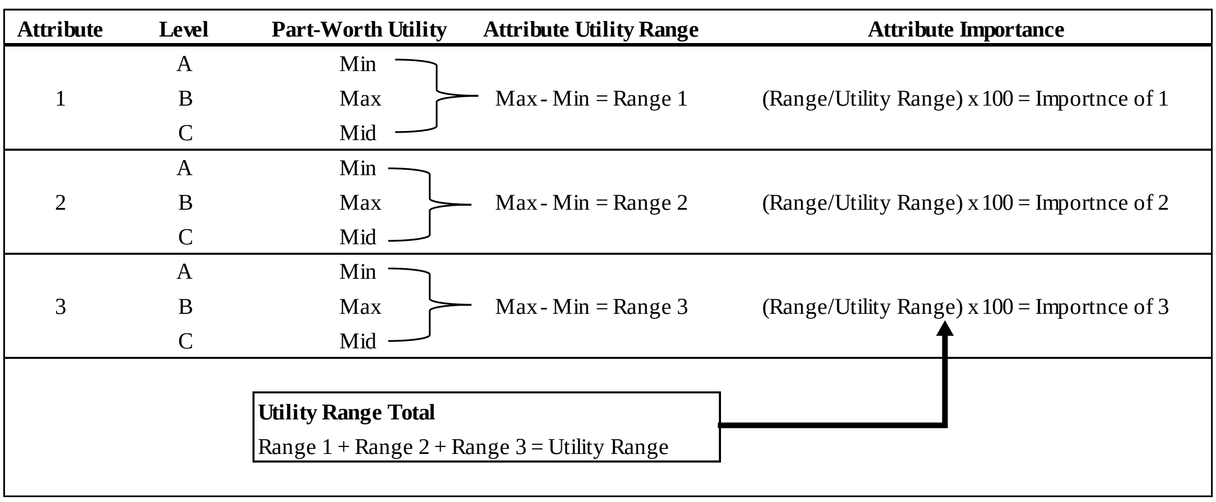

Figure 1. Determination of Attribute Importance [6]

The outcomes of the attribute evaluation are presented in Table 3. As expected, Walkable Width (49.4%) and Walkway Obstacles (36.6%) were identified as having high importance. Intriguingly, the scores for the Surface type (9.6%) and Changes in Elevation (4.4%) attributes were substantially lower in comparison.

Table 3. Results from CA: Assigned Values of Importance

Importance Values	
Walkable Width	49.4%
Walkway Obstacles	36.6%
Type of Surface	9.6%
Changes in Elevation of Walkway	4.4%
Averaged Importance Score	

Regarding sidewalk usage, the most significant attribute was the Width of the Walkable Area, followed by the obstacle number. It is worth noting that the obstacle number is related to the walkable width, given that large obstructions often reduce the available space for walking. One surprising finding was the relative importance of the obstacle number being four times as significant as the surface material. Furthermore, the surface material was found to be twice as crucial as changes in elevation.

Understanding the relevance of each attribute part-worth utility is crucial for interpreting these results, though. The unique characteristics of an attribute that affect a respondent preference can be understood more precisely with the use of part-worth utilities. These numerical values assigned to each level of the attribute show how much influence each level and attribute had on respondents' decisions. Scores are more remarkable for more favoured attributes, while scores are lower for less chosen attributes.

It is important to emphasize that the part-worth utilities presented here are relative in nature. A negative utility value for a specific attribute level does not necessarily indicate that the attribute level is undesirable. In fact, an attribute level with a negative value may still be considered acceptable by all respondents. However, higher positive values indicate a more preferred attribute level, assuming all other factors remain constant. In the CA technique, the part-worths are scaled using an arbitrary additive constant for each attribute, resulting in interval data. As a consequence, the utilities are adjusted to sum up to zero within each attribute. The outcomes of both relative and individual part-worth utilities can be found in Table 4.

Table 4 reveals the significant range of the walkable width, with more than 2m identified as the most desirable attribute and less than 2m as the least desirable, relative to the other attributes. This finding further underscores the importance of this attribute (refer to Table 3). Another point to note is the seemingly logical and relative linear relationship among the levels of the walkable width attribute.

Table 4. Outcomes of Conjoint Analysis: Determined Part-Worth Utilities

Part-Worth Utilities		
Attributes	Attribute change	Estimate Utility
Walkable width	>2m	1.329
	1-2m	-.007
	<1m	-1.322
Obstacles Number	0	1.194
	1 – 5	-.424
	> 5	-.770
Surface	Paved	-.180
	Gravel Soils	.335
	Plants	-.155
Elevation Changes	0	.122
	1 to 3	-.113
	>3	-.009
(Constant)		5.000

The attribute with the second-highest importance is the obstacle number (refer to Table 3). The attribute levels indicate a logical increase in significance, with more than five obstacles being the least important, followed by one to five obstacles, and then no obstacles, which is of the highest importance. Compared to the other attributes and their levels, the absence of obstacles was found to be the second most important attribute level.

The results of the surface material may initially seem counterintuitive, with gravel material ranking higher than paved material. Similarly, vegetation material also scores slightly higher than paved material. The main reason for this can be traced back to the nature of the conjoint-generated profiles. These profiles are designed to represent all attribute levels equally and in an uncorrelated manner, leading to attribute level combinations that compel the respondent to prioritise the most preferred attributes over those of lesser importance. For instance, a respondent might choose conjoint profile card nine with gravel surfacing and a width of more than 2m over profile card two with a paved surface and a walkable width of less than 1m. Given the low importance of surface material compared to walkable width and number of obstacles, surface material appears to be largely overlooked.

Similar to surface material, changes in elevation were identified as the least important attribute. Interestingly, more than three changes in elevation received a higher importance score than one to three changes in elevation. This outcome, too, is due to the combination of attributes in the generated conjoint profiles, as explained under surface material. The part-worth utilities for changes in elevation are so low that they would make little difference in calculating Total Utility Values.

2.5. Study Area

Universitas neighbourhood is a notable case of the identified problem of pedestrians using the roadway instead of sidewalks. From site observations and surveys, it was found that pedestrians sometimes even obstruct regular motorised traffic flow. Despite the presence of sidewalks, these are not pedestrian-friendly. To deepen the understanding of the issue, other residential suburbs in Bloemfontein were evaluated and compared to Universitas. Various factors influencing pedestrians were considered, such as trip-generating destinations, population, size, type of accessibility, and thoroughfare for pedestrians.

Upon evaluating 35 neighbourhoods in Bloemfontein, Universitas was deemed ideal for this study due to its diverse range of trip-generating destinations, its status as the city's largest neighbourhood, and the high number of pedestrians avoiding sidewalks. Furthermore, Universitas adequately represents other neighbourhoods in Bloemfontein.

Universitas, spanning an area of 9.66 square kilometres, is situated on the southwestern side of Bloemfontein. As a major connector of adjacent neighbourhoods and the business district, it serves as a thoroughfare for both motorists and pedestrians. The suburb hosts a diverse range of residential properties, including stand-alone houses, apartments, and townhouses. The University of the Free State, with its 37,000 enrolled students, is located here, contributing to a significant increase in residents over recent years. A considerable number of houses have been converted to student housing to accommodate this growth. In addition to students, Universitas is home to a medium to high income population. Trip-generating destinations include four schools, two retirement villages, five churches, two shopping centres, twelve public parks, and two hospitals, making Universitas rich in pedestrian traffic.

2.6. Calculating Total Utility Value at Selected Sidewalk Locations within the Study Area

The part-worth utility index, derived in the previous section, was employed to calculate the Total Utility Value of selected sidewalk locations using equation (1). According to the Conjoint Analysis theory, the product (in this case, the sidewalk) that yields a higher Total Utility Value compared to other products is deemed more valuable [11].

$$Total\ Utility\ Value\ \ U(Xij) = Constant + \sum_{i=l}^{m} \sum_{j=l}^{kj} U_{ij}Xij \qquad (1)$$

U(Xij) = Total utility of an alternative
m = Number of attributes
ki = Number of levels in ith attribute
uij = Utility associated with jth level of the ith attribute
Xij = Dummy variable that takes on 1 if the jth level of the ith attribute is present or 0 other

Table 5 provides an example of how the Total Utility Value was calculated for location 8. The table lists the attribute levels present at that location and the corresponding part-worth utilities derived from the previous Conjoint Analysis. The Total Utility Value was calculated by summing the part-worth utilities of the individual attribute levels present at location 8.

After determining the attribute levels present at each of the selected locations, the Total Utility Value for all eleven locations was calculated, as shown in Table 6. This table includes the Total Utility Values calculated for each location, allowing for a comparison of the relative value of different sidewalks as perceived by pedestrians.

Table 5. Illustrative Calculation of Total Utility Value for a Specific Location

Attribute	Applicable Attribute Level	Part-Worth Utility	Sum	Conjoint Constant	Total Utility Value
Walkable Width	> 2m	1.33	2.33	+ 5	= 7.33
Number. of Obstacles	None	1.19			
Surface Material	Paved	-0.18			
Elevation Changes	None	-0.01			

Table 6. Attribute Levels and Corresponding Total Utility Values for Selected Locations

Location	Walkable Width (m)		Number of Obstacles		Surface Material		Elevation Changes		Constant	Total Utility Value
1	1-2	-0.01	> 5	-0.77	Veg.	-0.15	1 to 3	-0.11	5	3.96
2	1-2	-0.01	1 – 5	-0.42	Veg.	-0.15	None	-0.01	5	4.40
3	>2	1.33	> 5	-0.77	Gravel	0.33	1 to 3	-0.11	5	5.78
4	>2	1.33	1 – 5	-0.42	Paved	-0.18	1 to 3	-0.11	5	5.61
5	>2	1.33	> 5	-0.77	Veg.	-0.15	1 to 3	-0.11	5	5.29
6	1-2	-0.01	> 5	-0.77	Gravel	0.33	1 to 3	-0.11	5	4.44
7	<1	-1.32	1 - 5	-0.42	30% Gravel 70% Veg.	-0.01	None	-0.01	5	3.24
8	>2	1.33	None	1.19	Paved	-0.18	None	-0.01	5	7.33
9	<1	-1.32	1 – 5	-0.42	Gravel	0.33	None	-0.01	5	3.58
10	>2	1.33	1 – 5	-0.42	40% Paved 60% Gravel	0.13	None	-0.01	5	6.02
11	<1	-1.32	1 – 5	-0.42	Veg.	-0.15	1 to 3	-0.11	5	2.99

2.7. Pedestrian Preference Score Computation

The third segment of the questionnaire was employed to gather data on pedestrian preferences. Respondents were asked to rate the likelihood of utilising a specified location, with a scale ranging from 1 (least likely) to 5 (most likely). This allowed us to compute a pedestrian preference score for each location, after summarising the responses from 287 participants using Equation (2)

$$Pedestrian\ Preference\ Score = \frac{1}{n} \sum_{j=1}^{n} (WCT)_{ij} \quad (2)$$

(WTC)ij = Willingness to use the j^{th} sidewalk by i^{th} respondent

N = Number of respondents

Table 7 shows the calculated pedestrians' preference score for each location. The column PPS Rank ranks the pedestrians' preference score in ascending order from the most preferred sidewalk to the least preferred. The pedestrians' preference score is compared and evaluated against the calculated Total Utility Values of each location and shown in Figure 2.

Table 7. Pedestrians' Preference Score for Each Location

Location	Street Name	PPS	PPS Rank
1	Stofberg Street 1	2.53	9
2	Stofberg Street 2	2.87	5
3	Graniet Street	3.80	4
4	Paul Kruger Avenue	4.01	2
5	Tommy Border Street	2.70	8
6	De Bruyn Street	2.73	7
7	Walter Sisulu	1.92	11
8	Christoffel Du Plessis Street	4.22	1
9	Scholtz Street	2.81	6
10	Weitz Street	3.93	3
11	Magneet Street	2.15	10

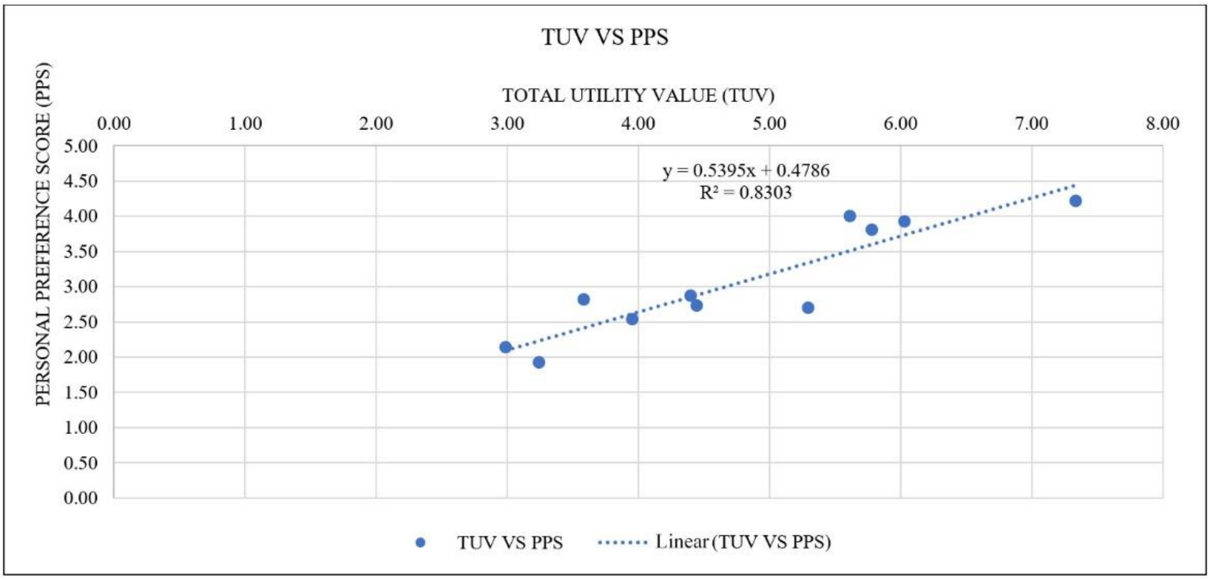

Figure 2. Regression Analysis: Relationship between Total Utility Value and Pedestrians' Preference Score for Each

Ultimately, a correlation and regression analysis were conducted to ascertain if any relationship existed between the Total Utility Value and Pedestrians' Preference Score for each sidewalk location. The computed Total Utility Value and Pedestrians' Preference score were illustrated on a scatterplot graph for each location, as delineated in Figure 2.

A notable positive correlation was discovered between the Total Utility Value and Pedestrians' Preference Score. The Pearson Correlation (r) of the two data sets manifested a robust positive linear pattern with a strength of 0.91. This positive linear pattern suggests that an increase or decrease in the Total Utility Value is likely to correspond with a similar movement in the Pedestrians' Preference Score.

Subsequently, a regression analysis demonstrated that the data aligned well with the linear model, with the Total Utility Value explaining 83% (R-squared) of the variability of the Pedestrians' Preference Score. This finding aligns with the research of Wicramasinghe and Dissanayake [12], indicating that the Total Utility Value can serve as a predictive measure for the likelihood of a pedestrian utilizing a specific sidewalk.

3. Conclusions

The findings from the Conjoint Analysis offer valuable insights into the factors influencing the use and avoidance of sidewalks. In general, the results indicate that pedestrians prefer a walkable area without obstacles. More specifically, a walkable width of more than 2m emerged as the most desirable attribute. Notably, the importance of the surface material and elevation changes were less pronounced compared to the walkable width and number of obstacles.

Obstructions on sidewalks were identified as the primary deterrent for pedestrians, a logical conclusion considering that some obstacles may be physically challenging to maneuver around. Once pedestrians navigate around these obstacles by stepping onto the roadway, they often remain there instead of returning to the sidewalk, demonstrating their preference for obstacle-free routes.

The study also noted that homeowners contribute significantly to sidewalk obstructions, implying that collaborative efforts between city planners and homeowners are necessary to create pedestrian-friendly sidewalks in residential areas. This research underscores the importance of considering pedestrian preferences in urban planning to encourage the use of sidewalks and enhance pedestrian safety.

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