A Hybrid Grey Relation-Based Importance Satisfaction Analysis for Prioritizing Pedestrian Crossing Facilities: A Case of Roorkee

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Abstract: The present study demonstrates a perception-based hybrid model (GRA-ISA) of Grey Relational Analysis (GRA) and Importance Satisfaction Analysis (ISA) methodology to identify critical crossing facility attributes requiring immediate attention for their priority improvement. The perceived importance and satisfaction rating data towards a set of 12 attributes involving 554 complete samples were recorded on a 1-to-5-point Likert-type ordinal scale using a face-to-face questionnaire survey in an educational city, Roorkee in India. Further, the attributes were grouped into four importance-satisfaction (I-S) quadrants based on mean relative importance and satisfaction scores using the GRA-ISA methodology. Consequently, the study identified *'zebra crossing' (ZCR), 'traffic signal' (TSL), 'facilities for differently abled and elderly' (FDE)*, and *'signboards and markings' (SBM),* as critical attributes requiring priority improvement with high importance scores but perceived with low satisfaction scores. The study would help policymakers and urban local bodies make rational decisions to improve existing crossing facilities strategically.

Keywords: Crossing Facilities, User's Perception, Educational City, GRA, ISA

1. INTRODUCTION

Walking is considered a healthy and sustainable mode of transport as it helps to recharge the body and impart a sense of happiness. It also assists to reduce the use of motorized vehicles and the associated social and environmental costs (Bellizzi et al., 2019). However, the exponential increase in the overall population and the available job opportunities in cities has increased the rate of urbanization. Also, it is expected that 70 % population will be living in urban areas by 2050, and the growth will mostly be seen in developing countries. India has also witnessed rapid urbanization, with its increase in population nearly to 35% in 2020 (The World Bank, 2021). Thus, rapid urbanization coupled with high growth in the share of private vehicles with a lack of adequate transport facilities has resulted in injuries and life losses (MoRTH, 2020). Recently, a report published by the Union Transport Ministry, Government of India, showed that 62 pedestrians lose their lives daily (India TV News Desk, 2022), which refers to the pathetic situation of pedestrians' mobility in India. Though, this is not the case for India only; most developing countries have lacked to give attention to provide adequate infrastructure facilities for pedestrians. This is the reason that the priorities of pedestrians have been undervalued for a long compared to vehicles (Bivina & Parida, 2019). Walking is still regarded as a universal mode of transportation, especially for the start and the end of a trip (CSIR - Central Road Research Institute, 2017); therefore, the provision of adequate pedestrian infrastructure, such as sidewalks and crossing facilities is, required to promote walkability in

an urban area (Kadali & Vedagiri, 2015). Since pedestrian crossing activities may involve the risk of pedestrian-vehicle conflicts, the provision of crossing facilities is necessary. The crossing facilities can be of two types, i.e., at-grade and grade-separated. At-grade crossing facilities may include zebra crossing at mid-block/intersection and pedestrian signals, as shown in Figures 1(a) and 1(b). At the same time, grade-separated crossing facilities may include a foot-over bridge and underpass, as shown in Figures 1(c) and 1(d).

Figure 1. (a) zebra crossing, (b) pedestrian signal, (c) foot over bridge, (d) underpass

However, inadequate pedestrian crossing facilities, especially in cities of developing countries, have led to frequent conflicts between pedestrians and vehicles (Kadali & Vedagiri, 2018). Consequently, pedestrians feel unsafe choosing to walk as their mode of transport, especially for shorter trips. Although, the Government of India has emphasized providing pedestrian infrastructure facilities, including crossing facilities, to promote walking as a healthy and sustainable mode of transport (Ministry of Urban Development (MoUD) Government of India, 2014).

Moreover, it may also be mentioned that the perception of pedestrians plays a crucial role in their decision to walk based on the existing pedestrian facilities in an urban area. Recent literature suggests the power of pedestrians' perception towards selecting any pedestrian facilities such as the sidewalk, crossing facilities, etc. (Bivina et al., 2020; Majumdar et al., 2021; Sultan et al., 2021). Therefore, it becomes essential for policymakers and planners to understand crossing facilities based on their perceptions of pedestrians' priorities. It would eventually help to assess the existing crosswalk facilities and recommend necessary improvement strategies. To achieve this, the attributes influencing crossing facilities need to be investigated in terms of their importance and satisfaction as perceived by pedestrians. However, previous studies lack to prioritize pedestrian crossing facilities in view of pedestrians' needs, especially in cities of developing countries such as India. Thus, to address these gaps, the study aimed to prioritize the crossing facility attributes based on their importance and satisfaction as perceived by pedestrians. Therefore, the key objectives of the present study are as follows:

- To determine the perceived relative importance and satisfaction scores of crossing facility attributes
- To identify the critical crossing facility attributes which require immediate attention for their priority improvement

The present study was conducted in reference to Roorkee city in India. Being an education hub, the city (with 0.12 million population) attracts many students and scholars from India and around the world. The city often observes frequent pedestrian crossing activities at various intersections and mid-blocks. Based on a reconnaissance survey, it was observed that the city lacks adequate pedestrian crossing facilities, which motivated authors to consider this city as a case area to understand pedestrians' priorities. Accordingly, a face-to-face questionnaire survey was conducted using digital and paper-pen-based modes to collect importance and satisfaction rating data towards crossing facility attributes under study as perceived by pedestrians on a 5-point Likert-type ordinal scale (Likert, 1932). Further, the database was analyzed using a novel hybrid model (GRA-ISA) of Grey Relational Analysis (GRA) and Importance Satisfaction Analysis (ISA) to identify the critical crossing facility attributes requiring immediate attention for their priority improvement.

The paper is organized as follows: The next section discusses a brief review of the literature for the identification of attributes influencing the perceived level of service and quality of service of pedestrian facilities. In section 3, the theoretical background of the prioritization methods of attributes has been described. This section also discusses the novel hybrid model of GRA-ISA applied to the present study. Section 4 describes the survey and database. In section 5, the results after analyzing the collected database have been discussed. Section 6 presents the conclusions and future scope of the study.

2. LITERATURE REVIEW

As discussed earlier, the perception of pedestrians becomes essential to consider while improving and designing pedestrian infrastructure facilities. In this regard, some studies have tried to study and understand users' perceptions of pedestrian crossing facilities (Asadi-Shekari et al., 2019a; Georgiou et al., 2021; Majumdar et al., 2021). Few researchers have considered the perception of users to understand how they perceive sidewalks (Bivina et al., 2020; Majumdar et al., 2021; Ujjwal & Bandyopadhyaya, 2021; Vallejo-Borda et al., 2020). The power of users' perception has also been found quite influential towards other modes of transport, such as prioritization of transfer facility attributes for the commuters of the metro (Sadhukhan et al., 2015), perception towards infrastructure facility design for bicycles (Barrero & Rodriguez-Valencia, 2020), perception of public transport users to prioritize their needs (Bajčetić et al., 2018), perception of users towards the evaluation of service quality of public transport (Mandhani et al., 2020). This section discusses the recent key studies on assessing the quality of service and level of service of pedestrian infrastructure facilities. It would help to select the attributes influencing crossing facilities.

2.1 Attributes Influencing Perceived Quality of Service and Level of Service towards Pedestrian Infrastructure Facilities

Recent studies have evaluated the perceived level of service and quality of service for pedestrian infrastructure such as sidewalks and crossing facilities in view of pedestrians' perceptions. Accordingly, the attributes influencing the perceived level of service and quality of service towards pedestrian infrastructure facilities have been identified. Vallejo-Borda et al. (2020)

evaluated the quality of service (QoS) for urban sidewalks using structural equation modeling (SEM) in Colombia. They found the direct effect of sidewalk characteristics and surroundings on QoS, such as width, signage, lighting, and cleanliness. Majumdar et al. (2021) used the importance satisfaction analysis (ISA) and the technique for order preference by similarity to ideal solution (TOPSIS) to prioritize sidewalk attributes and crosswalk attributes in Hyderabad (India). The study found that the crosswalk attributes, such as zebra crossing, pedestrian island, pedestrians' conflicts with traffic, etc., require immediate attention for priority improvement. Bivina and Parida (2020) used the analytic hierarchy process (AHP) to prioritize the needs of pedestrians in the case of an Indian city. The study found that pedestrians prioritize safety and security over comfort and mobility. Li et al. (2021) evaluated QoS for pedestrian road systems in China. They used an analytic hierarchy for determining the weights of indicators and found road smoothness with the highest weightage, followed by crossing facilities. Ahmed et al. (2021) considered crosswalks and mid-block crossings to evaluate Malaysia's pedestrian crossing level of service (PCLOS). They found zebra crossing as the most critical and drainage as the least critical attribute for crossing facilities. Few studies investigated the effect of land use on the pedestrian level of service (PLOS) at unprotected midblock crosswalks. In this regard, Kadali and Vedagiri (2015) developed an ordered probability model and found industrial and business locations with higher PLOS than residential and mixed land use in Mumbai city, India. The study conducted by Anapakula and Eranki (2021) developed an index to quantify the pedestrian environment in Bengaluru, India. The most important attribute was 'zebra crossing' from an expert's perspective and 'traffic signal' from the pedestrians' perspective. Labdaoui et al. (2021) developed an index to identify attributes influencing comfortable walking in Algeria. They found that landscaping, trees, mid-block crossings, pedestrian signals, etc., are influential attributes for comfortable walking. The study conducted by Sultan et al. (2021) considered a contagious attribute, namely 'effective sidewalk width' based on WHO (World Health Organization) guidelines. They found that it helps implement social distancing and appropriate safety measures during pandemic times by promoting the concept of walkability.

The review of past studies suggests that the set of attributes identified based on studies carried out in developed countries may not be appropriate in the context of developing countries such as India due to the variation in socio-economic characteristics and the type of pedestrian crossing facilities compared to the other developed countries. Therefore, there is a need to identify a new set of crossing facility attributes based on the Indian context. Further, the review of existing literature suggests that previous studies lack investigation for priority intervention of crossing facilities based on users' perception, especially in the Indian context. Also, most Indian cities (Roorkee in specific) lack adequate crossing facilities. Therefore, the present study identify the critical crossing facility attributes requiring immediate attention for their priority improvement. The following section discusses the rationale behind selecting the novel hybrid model for identifying critical crossing facility attributes for priority intervention.

3. METHODS

Existing literature has considered various methods for the prioritization of attributes. The multi-attribute decision-making (MADM) methods such as the grey relational analysis (GRA), relative to an identified distribution integral transformation (RIDIT), the technique for order preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), and elimination and choice expressing reality (ELECTRE) have been widely used in earlier studies in various fields. The present study used the GRA method to prioritize the crossing facilities by calculating the relative importance and satisfaction scores associated with the crossing facility

attributes under study. The GRA is an approach taken from the grey system theory developed by Deng (1982). This method has been used widely in different fields (J. L. Deng, 1982). GRA is used for the analysis of discrete data series. This method has been found suitable for making decisions with data having limited information, uncertainty, and small sample size. GRA has been used in existing literature, such as for solving facility layout problems (Kuo, 2008), prioritizing the transfer facility attributes for metro stations based on commuters' perceptions (Sadhukhan et al., 2015), and for measurement of the company's performance (Sarraf & Hashemi, 2020), etc. GRA has been found appropriate for analyzing data surveyed on the Likert-type ordinal scale (Wu, 2007). However, GRA can only assess the relative importance and relative satisfaction scores of various crossing facility attributes. Therefore, to identify the area for priority improvement of crossing facilities based on pedestrians' perceptions, a novel hybrid model, GRA-based importance satisfaction analysis (ISA), is used for the present study. Previously, ISA has been widely used in various fields of literature, which include the medical field (Ho et al., 2014), the field of tourism (J. Deng & Pierskalla, 2018), and the field of transportation relating to pedestrian infrastructure (Majumdar et al., 2021). ISA helps to identify the area of improvement in any existing service to formulate effective strategies for improvement. The primary purpose of ISA in this study is to assess how pedestrians perceive the satisfaction of the crossing facility attributes based on their perceived importance to identify the area of concern. The following subsection describes the GRA method followed by the hybrid GRA-ISA model.

3.1 Grey Relational Analysis (GRA)

The steps followed for GRA are shown below (Wang, 2019) (Sadhukhan et al., 2015).

Step 1: Develop a data series matrix x_i based on 554 complete perception response data of pedestrians towards 12 crossing facility attributes on a 1 to 5-point Likert-type ordinal scale.

$$x_i = (c_{i1}, c_{i2}, \dots, c_{im}) \text{ where } i = 1, \dots, k \tag{1}$$

Where m denotes the number of respondents,. The recorded data element is represented by c_{im}. The crossing facility attribute has k in number denoted by i.

Step 2: Develop a comparison data series matrix x_i' by normalizing each data element c_{im} of data series matrix x_i . The normalization formula used is

$$d_i = {[c_i - c_{i(min)}]}\Big/{[c_{i(max)} - c_{i(min)}]} \quad \forall\, m \tag{2}$$

Now, the comparison data series matrix x_i' can be given by

$$x_i' = (d_{i1}, d_{i2}, \dots, d_{im}) \text{ where } i = 1, \dots, k \tag{3}$$

k number of comparison data series matrix will be formed for k number of crossing facility attributes.

Step 3: Develop reference data series x_0 consisting of the most favored responses of m respondents for each crossing facility attribute i

$$x_0 = (d_{01}, d_{02}, \dots, d_{0m}) \text{ where } i = 1, \dots, k \tag{4}$$

Step 4: Formulating the difference data series matrix Δ_i for crossing facility attribute, obtained through calculating the difference of each element in comparison data series from reference data series, which can be given as follows

$$\Delta_i = (|d_{01} - d_{i1}|, |d_{02} - d_{i2}|, \ldots, |d_{0m} - d_{im}|) \quad (5)$$

Step 5: Evaluating the global maximum value (Δ_{max}) and global minimum value (Δ_{min}) in the matrix Δ_i as follows

$$\Delta_{max} = \max_{\forall i}(max\, \Delta_i) \qquad \Delta_{min} = \min_{\forall i}(min\, \Delta_i) \quad (6)$$

Step 6: Evaluating the grey relation coefficient, $\theta_i(j)$ based on each data element of Δ_i using the following equation.

$$\theta_i(j) = \{\Delta_{min} + \omega\Delta_{max}\} \Big/ \{\Delta_i(j) + \omega\Delta_{max}\} \quad (7)$$

where $\Delta_i(j)$ is jth value obtained in the difference data series Δ_i. The coefficient value ω is taken as 0.5 (varies between 0 and 1).

Step 7: Calculating the grey relation grade (τ_i) for each crossing facility attribute based on each difference data series.

$$\tau_i = {}^{1}\!/_{m} \sum_{n=1}^{m} \theta_i(n) \quad (8)$$

τ_i denotes the grey relational grade for ith crossing facility attribute. It is assumed that data elements in the data series have equal weights. Further, the grey relational grade of each attribute is normalized to the same scale range from 0 to 1. Here, the normalized grey relational grades for crossing facility attributes are termed the relative scores. Therefore, the relative score in the case of perceived importance is represented as 'RIS_τ' (relative importance score), while the relative score in the case of perceived satisfaction is represented as 'RSS_τ' (relative satisfaction score).

3.2 Hybrid GRA-ISA Model

The present study aimed to identify the critical crossing facility attributes requiring immediate attention for priority improvement using a hybrid GRA-ISA-based approach. Figure 2 shows the graphical representation of the hybrid model GRA-ISA. It may be noted that the importance and satisfaction rating of crossing facility attributes as perceived by pedestrians were collected on a 1-to-5-point Likert-type ordinal scale. Therefore, the mean and standard deviation may not be appropriate for this rating data (Kothari, 2004; Wu, 2007). However, the GRA method can convert the ordinal type rating data into significant score values (weights), which can be used further to calculate the means. Hence, this hybrid model, which integrates GRA with the existing ISA, helps identify the area for priority improvement based on data collected on ordinal data. Accordingly, GRA-based RIS_τ and RSS_τ of crossing facility attributes under study are plotted on a 2-dimensional X-Y plane where X and Y axes represent RIS_τ and RSS_τ, respectively. Subsequently, mean RIS_τ and mean RSS_τ are calculated and plotted as two axes to obtain the four importance-satisfaction (I-S) quadrants, i.e., four regions in the ISA graph. The four quadrants of the ISA graph are described below (refer Figure 2). The present study has used geometric means with its benefits to minimize the variation in data.

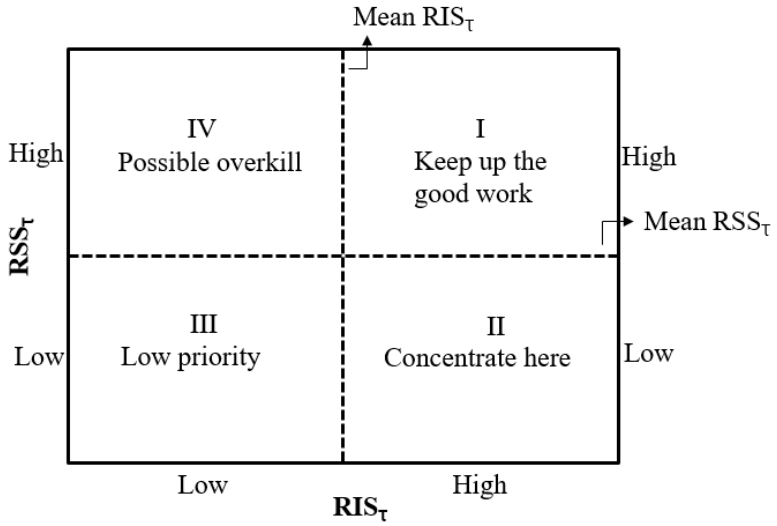

Figure 2. Grey Relational Analysis based Importance Satisfaction Analysis (GRA-ISA)
NOTE: 'RIS$_\tau$' and 'RSS$_\tau$ denote 'relative importance score' and 'relative satisfaction score', respectively.

The four quadrants of the ISA graph are explained as follows.

Quadrant I (*keep up the good work*): The attributes falling into this quadrant show high RIS$_\tau$ and high RSS$_\tau$, which suggests the attributes are performing well, and the job is to continue in this area.

Quadrant II (*concentrate here*): The attributes falling into this quadrant show high RIS$_\tau$ but low RSS$_\tau$, which suggests that improvement strategies need to be concentrated here. These attributes are termed here as critical crossing facility attributes requiring immediate attention for priority improvement.

Quadrant III (*low priority*): The attributes falling into this quadrant show low RIS$_\tau$ and low RSS$_\tau$, which indicates that there is no need to focus on this area.

Quadrant IV (*possible overkill*): The attributes falling into this quadrant show low RIS$_\tau$ but high RSS$_\tau$, which shows these attributes have been given more attention than required, indicating a lack of proper planning by urban local bodies.

4. SURVEY DESIGN AND DATABASE

The objective of the study was to identify the critical crossing facility attributes requiring immediate attention for priority improvement based on their importance and satisfaction as perceived by pedestrians. Accordingly, the survey questionnaire was framed, and the database was prepared based on the collected data from respondents. The following subsection discusses the design of the questionnaire, data collection, and the preparation of the database.

4.1 Design of Survey Questionnaire

Initially, the authors extracted a large set of attributes through an extensive literature review to frame the survey questionnaire. After that, the extracted attributes were given technical terminology based on the authors' understanding. The attributes having the same meaning were merged to have a variety of attributes. Subsequently, the new set of attributes was screened further based on their frequency of occurrence in recent studies related to pedestrian crossing facilities. Also, a detailed reconnaissance survey was carried out across Roorkee city in March 2022 to observe the existing crossing facilities and find any site-specific attribute (if any)

influencing pedestrians' perception of crossing facilities. Pedestrians were interviewed, and their priorities and expectations regarding crossing facilities were noted. Meanwhile, certain specific places were also identified and marked in view of conducting a user perception survey. Finally, based on users' opinions and discussions with experts, 12 crossing facility attributes were finalized, listed below.

1) *Zebra Crossing (ZCR)*: It represents the provision of marked and adequate width (2-4 m wide) of zebra crossing for pedestrians (Bivina and Parida, 2020; IRC 103-2012, 2012; Majumdar et al., 2021; Sultan et al., 2021).
2) *Surface Quality for Crossing (SQC)*: It represents the provision of a good quality surface for the crossing of pedestrians, which should be smooth and even as well as should not be slippery and broken (Bivina & Parida, 2020) (Sultan et al., 2021) (Majumdar et al., 2021).
3) *Foot Over Bridge and Underpass (FBU)*: It represents the provision of grade-separated crossing facilities such as foot over bridge(with a minimum width of 1.8 m) and underpass (with a width of 4.8 m) with the provision of adequate facilities of stairs, escalators, lifts, etc. (Asadi-Shekari et al., 2019b; Georgiou et al., 2021; IRC 103-2012, 2012).
4) *Facilities for differently abled and elderly (FDE)*: It represents the provision of adequate and comfortable facilities such as curb ramps (of slope 1:20), tactile pavers with a width of 2-5 m, etc., for their ease of access (Bivina & Parida, 2020; Georgiou et al., 2021; IRC 103-2012, 2012; Sultan et al., 2021).
5) *Sign Board and Marking (SBM)*: It represents the provision of appropriate signboards and marking for the crossing of pedestrians (Bivina & Parida, 2020) (Sultan et al., 2021) (Georgiou et al., 2021).
6) *Traffic Signal (TSL)*: It represents the provision of traffic signals at intersections and mid-blocks on a road section to control the traffic flow (Majumdar et al., 2021) (Anapakula & Eranki, 2021).
7) *Pedestrian Signal (PSL)*: It represents the provision of a pedestrian signal for pedestrians for their safe crossing at crosswalks (Sultan et al., 2021) (Labdaoui et al., 2021) (Loo, 2021).
8) *Speed Breakers and Rumble Strips (SBR)*: It represents the provision of traffic-calming measures such as speed breakers and rumble strips (Asadi-Shekari et al., 2019b) (Anapakula & Eranki, 2021).
9) *Pedestrian Island (PIL)*: It represents the provision of a marked and defined area with a recommended width of 2 m to hold pedestrians while attempting to cross the road (Majumdar et al., 2021) (Loo, 2021).
10) *Adequate Lighting (ADL)*: It represents the provision of adequate lighting facilities at crosswalks (Majumdar et al., 2021) (Anapakula & Eranki, 2021) (Georgiou et al., 2021).
11) *Security guards and CCTV surveillance (SGC)*: It represents the availability and provision of security guards and CCTV surveillance for the security of pedestrians (Majumdar et al., 2021) (Loo, 2021).
12) *Crossing Safety (CRS)*: It represents the condition for having no conflict between pedestrians and vehicles while crossing through intersections and mid-blocks (Majumdar et al., 2021) (Rodriguez-Valencia et al., 2020).

Accordingly, the survey questionnaire was designed into three parts to carry out the survey. The first part is comprised of the socio-economic and walking characteristics of pedestrians. The second and third parts of the questionnaire consisted of perceived importance and perceived satisfaction by pedestrians towards 12 crossing facility attributes, respectively, on a 5-point Likert-type ordinal scale (Likert, 1932).

4.2 Data Collection and Database

An appropriate digital and paper-pen-based survey instrument was designed in bilingual (Hindi and English) medium to collect the importance and satisfaction rating towards crossing facilities as perceived by pedestrians on a 1 to 5-point Likert-type ordinal scale (Likert, 1932). Where '1' and '5' represent least important and most important, respectively, in case of importance ratings. Whereas '1' and '5' represent least satisfied and most satisfied in the case of satisfaction ratings. Before conducting the final questionnaire survey, a pilot survey was carried out of 85 samples to examine any difficulty faced by respondents in understanding and responding to the stated attributes under study. The authors, with a team of trained surveyors, approached 835 pedestrians randomly to have a variety of samples. However, out of 835 respondents, 554 completed the survey at a response rate of 66.34%. The survey was conducted at the marked locations identified during the reconnaissance survey to illustrate an accurate representation of the city population (Figure 3).

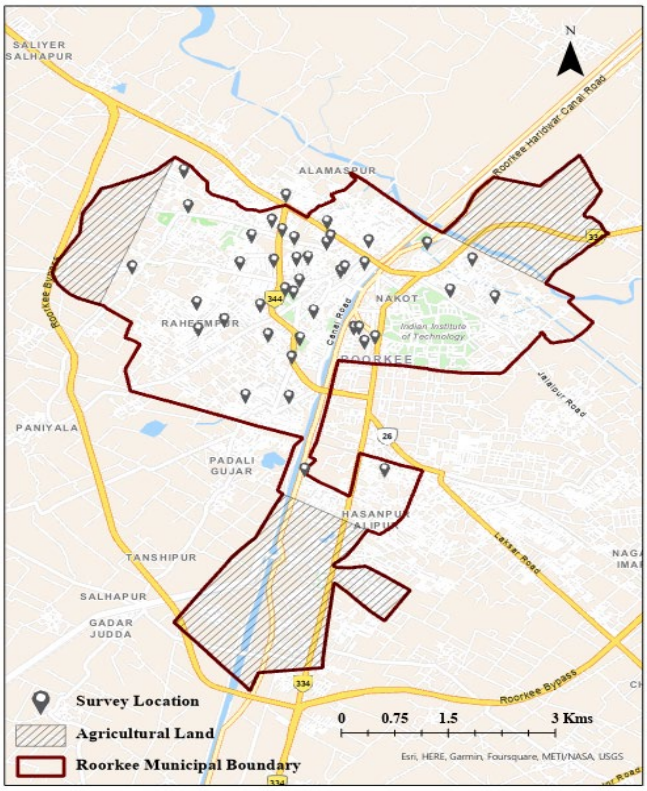

Figure 3. Survey locations of the study area

The collected sample size (554) was found statistically significant in accordance with the minimum required sample size (S), calculated using the following equation (Krejcie & Morgan, 1970).

$$S = \{\chi^2 NP(1-P)\} \Big/ \{d^2(N-1) + \chi^2 P(1-P)\} \quad (9)$$

Where N is the population size of the city, χ^2 is 3.841 at a 5% significance level for 1 degree of freedom obtained from the chi-square table, P is population proportion (taken as 0.05 for calculating maximum sample size), and d is the degree of accuracy taken as 0.05. The value of S was obtained to be 384. The Cronbach's alpha coefficient was determined to check the reliability of the collected perceived importance and satisfaction rating data. The importance

and satisfaction rating data were found significant, with a value of 0.801 and 0.951, respectively. A coefficient value higher than 0.70 is treated as reliable data (Gliem & Gliem, 2003).

The responses of 554 respondents in terms of their socio-economic and walking characteristics are depicted below through pie charts (Figure 4**)**. Of the total surveyed respondents, males and females were 64% and 36%, respectively (Figure 4).

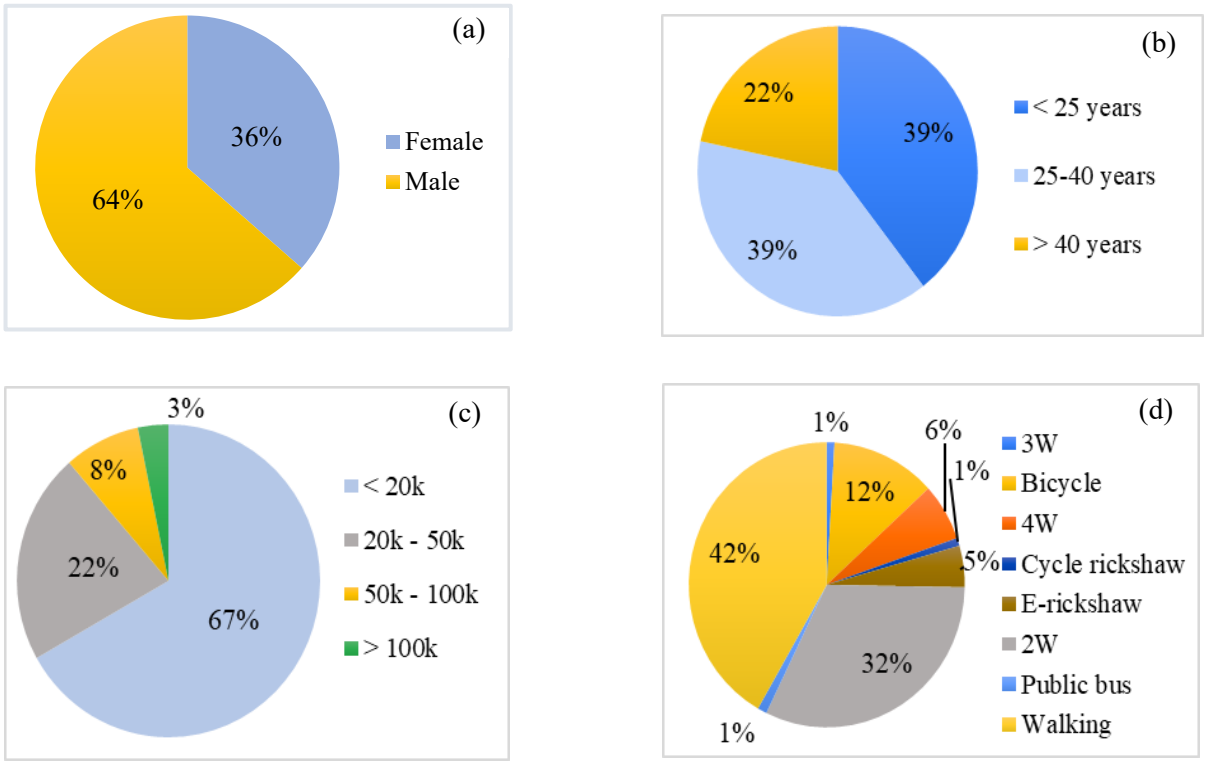

Figure 4. (a) Gender (b) Age group (c) Monthly family income in Indian rupees (1 USD=78.90 Indian Rupees as in June 2022) (d) Most preferred mode of transport

It may be referred from Figure 4(a) that the lower percentage of female respondents suggests they were less likely to participate in work trips than males in the city. Figure 4(b) refers that the share of middle-aged (25-40 years) and young-aged (<25 years) pedestrians were found to be nearly equal (39%). In contrast, higher-aged pedestrians were observed to be 22%. Figure 4(d) indicates that people in the city prefer walking as the most preferred mode of transport among all the modes available.

5. RESULTS AND DISCUSSIONS

It may be observed from Table 1 that pedestrians perceive crossing facility attributes with relatively higher importance (ratings 4 and 5), but they perceive them with low satisfaction (ratings 1 and 2). The possible reason for perceiving higher side importance ratings indicates that pedestrians are more concerned about having adequate crossing facilities. However, the city lacks adequate crosswalk facilities, as shown in figure 5, which may be why pedestrians perceive lower satisfaction ratings (refer Table 1).

Table 1. Importance and satisfaction ratings of crossing facility attributes

Attributes	Importance Ratings					Satisfaction Ratings				
	1	2	3	4	5	1	2	3	4	5

	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
ZCR	1.26	0.90	4.33	29.42	64.08	45.49	30.32	9.57	8.12	6.50
SQC	0.72	0.54	6.14	40.07	52.53	30.14	28.70	19.13	14.26	7.76
FBU	2.53	1.62	7.76	34.66	53.43	45.49	24.55	9.57	8.12	6.50
FDE	0.54	1.08	4.15	36.46	57.76	47.47	29.06	11.19	7.58	4.69
SBM	0.18	0.90	6.14	35.56	57.22	43.14	26.17	15.52	9.57	5.60
TSL	0.54	1.26	7.22	29.60	61.37	44.04	30.14	13.54	8.48	3.79
PSL	1.08	3.25	7.40	38.45	49.82	53.43	22.74	10.83	7.40	5.60
SBR	1.26	1.62	11.37	33.75	51.99	32.49	30.32	17.69	12.27	7.22
PIL	1.81	1.81	9.03	41.52	45.85	51.44	25.81	8.30	8.30	6.14
ADL	0.18	0.90	5.05	27.44	66.43	28.70	25.45	19.31	13.54	13.00
SGC	0.54	1.62	4.15	37.00	56.68	38.27	28.70	13.36	10.11	9.57
CRS	0.36	0.90	5.96	30.32	62.45	30.51	35.38	16.79	10.47	6.86

Note: '1' denotes least important/least satisfied, and '5' denotes most important/most satisfied

Further, the study used GRA to calculate the relative importance score (RIS_τ) and relative satisfaction score (RSS_τ) of crossing facility attributes based on their importance and satisfaction as perceived by pedestrians. This would reveal how differently pedestrians perceive the crossing facility attributes in terms of their importance and satisfaction. It may be seen from Table 2 that relative importance scores are comparatively large in values than relative satisfaction scores, which indicates that the crossing facility attributes understudy were given higher importance but were perceived with lower satisfaction. It may be mentioned from Table 2 that among all 12 crossing facility attributes, 'adequate lighting' (ADL) [RIS_τ = 0.0872, rank=1] received the highest importance from pedestrians, followed by 'zebra crossing' (ZCR) [RIS_τ = 0.0862, rank=2], and 'crossing safety' (CRS) [RIS_τ = 0.0857, rank=3]. The possible reason to give the highest importance to 'adequate lighting' (ADL) may be because pedestrians were observed to make crossing activities during evening hours while going for a daily walk, jogging, visiting shops, vegetable/fruit markets, and other commercial activities. This is why they may need adequate lighting facilities to have safe crossing and ease in making walking activities. Similarly, pedestrians may need marked zebra crossing with alternate black and white strips with adequate width to cross in the city through various intersections and mid-blocks safely. Also, while making the crossing activities in the city, there should not be any conflict between pedestrians and vehicles. As a result, 'crossing safety' (CRS) was given high importance by pedestrians (refer to Table 2). In contrast, the crossing facility attributes such as 'pedestrian island' (PIL) [RIS_τ = 0.0789, rank=12], 'pedestrian signal' (PSL) [RIS_τ = 0.0804, rank=11], 'speed breakers and rumble strips' (SBR) [RIS_τ = 0.0808, rank=10]. were given lower importance by pedestrians (refer Table 2). It may be mentioned that most parts of the city have two-lane roads, i.e., roads of lesser width. Therefore, pedestrians may cross the road completely without stopping in between. As a result, a pedestrian island may not be required for crossing the road. This may be why pedestrians give lower importance to 'pedestrian island' (PIL). It may be noted that most parts of the city lack pedestrian signal facilities. And there is a high possibility that pedestrians may not be familiar with and aware of these facilities. That is why they give lower importance to 'pedestrian signal' (PSL) (refer to Table 2). While in the case of perceived satisfaction towards crossing facilities, 'adequate lighting' (ADL) [RSS_τ = 0.0945, rank=1] was found to be most satisfactory, followed by 'surface quality for crossing' (SQC) [RSS_τ = 0.0890, rank=2], 'security guard and CCTV surveillance' (SGC) [RSS_τ = 0.0867, rank=3] (refer to Table 2). It may be mentioned that the lighting facility in the city was found adequate with the availability of streetlights at regular intervals. That is why 'adequate lighting' (ADL) is perceived with the highest satisfaction. It can be justified based on the existing lighting condition in the city (refer to Figure 6). Similarly, the surface quality at crossing locations was

found to be in good condition. This may be why pedestrians perceive 'surface quality for crossing' (SQC) with higher satisfaction. On the other hand, it was observed that the city has the availability of security guards and CCTV camera at various locations of crossing (refer to Figure 6). This is why pedestrians perceive 'security guard and CCTV surveillance' (SGC) with relatively higher satisfaction. On the contrary, the crossing facility attributes such as 'foot over bridge and underpass' (FBU) [RSS_τ = 0.0786, rank=12], 'facilities for differently abled and elderly' (FDE) [RSS_τ = 0.0786, rank=11], 'pedestrian signal' [RSS_τ = 0.0786, rank=10]. were observed to be low satisfactory as perceived by pedestrians (refer Table 2).

Table 2. Relative importance and satisfaction scores of crossing facility attribute using GRA

Attributes	Perceived Importance			Perceived Satisfaction		
	$(GRG)_I$	RIS_τ	Rank	$(GRG)_S$	RSS_τ	Rank
ZCR	0.865	0.0861897	2	0.439	0.0808471	7
SQC	0.826	0.0823037	8	0.483	0.0889503	2
FBU	0.818	0.0815066	9	0.427	0.0786372	12
FDE	0.846	0.0842965	5	0.427	0.0786372	11
SBM	0.843	0.0839976	6	0.445	0.0819521	6
TSL	0.852	0.0848944	4	0.429	0.0790055	9
PSL	0.807	0.0804105	11	0.428	0.0788214	10
SBR	0.811	0.0808091	10	0.471	0.0867403	4
PIL	0.792	0.0789159	12	0.432	0.079558	8
ADL	0.875	0.0871861	1	0.513	0.0944751	1
SGC	0.841	0.0837983	7	0.471	0.0867403	3
CRS	0.860	0.0856915	3	0.465	0.0856354	5

$(GRG)_I$ and *$(GRG)_S$*: grey relation grades of crossing facility attributes for perceived importance and perceived satisfaction, respectively. RIS_τ: Relative importance score, RSS_τ: Relative satisfaction score

It may be noted that most parts of the city lack the facility of the foot over bridge, underpass, and pedestrian signals. This may be why pedestrians perceive foot over bridge and underpass (FBU), and 'pedestrian signal' (PSL) with lower satisfaction. Similarly, the city lacks adequate facilities for differently abled and elderly people, such as curb ramps, tactile pavers, pedestrian guardrails, etc. This may be the reason for perceiving 'facilities for differently abled and elderly' (FDE) with low satisfaction. It may be mentioned here that the relative importance and relative satisfaction scores calculated and rankings derived based on GRA alone would not be able to identify the critical crossing facility attributes requiring immediate attention for their priority improvement. Therefore, the present study employed the hybrid model of GRA-ISA to identify the critical crossing facility attributes for their priority improvement. To obtain this, firstly, the GRA-based RIS_τ and RSS_τ value of each crossing facility attribute are plotted on a two-dimensional X-Y plane with RIS_τ on X-axis and RSS_τ on Y-axis. Further, the mean RIS_τ and mean RSS_τ were determined as 0.0833 and 0.0832, respectively, using the geometric mean method with its benefits to minimize the variation in collected data. Subsequently, the mean RIS_τ axis and mean RSS_τ axis was drawn to obtain

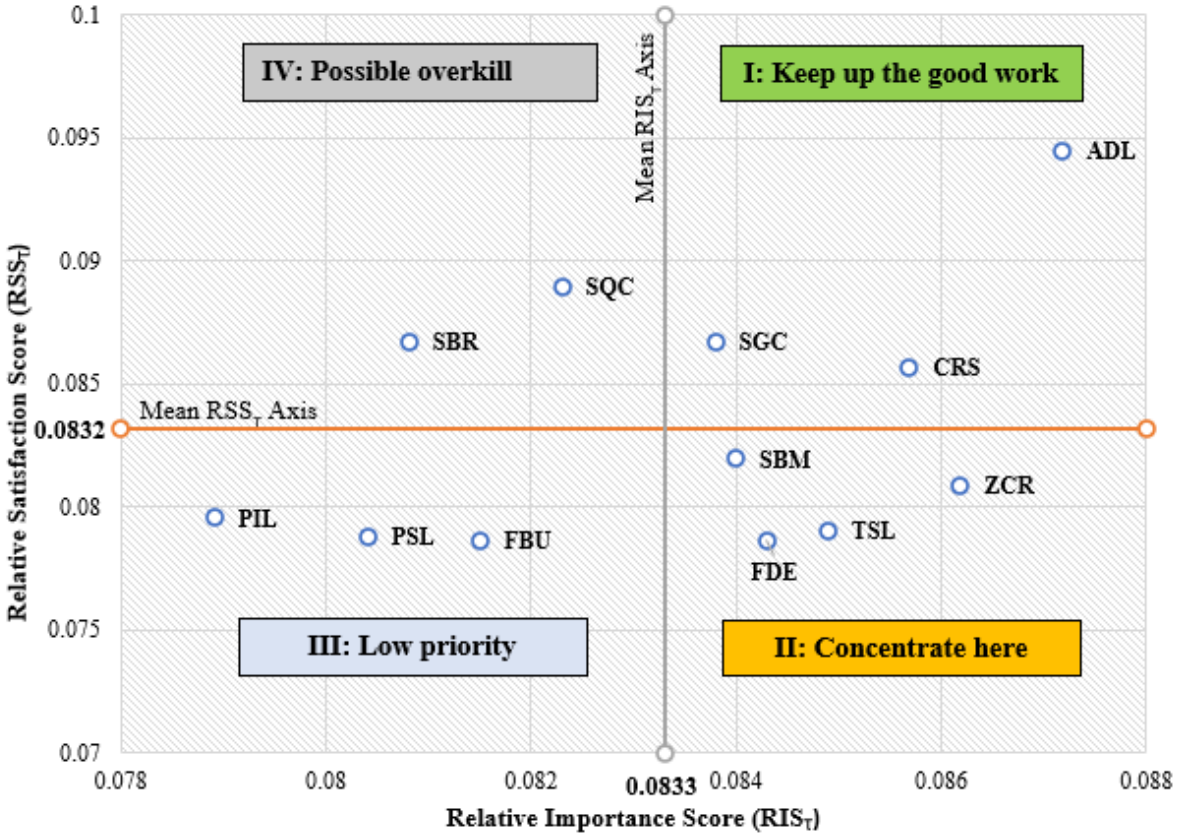

Figure 5. GRA-ISA-based I-S quadrants of crossing facilities

four importance-satisfaction (IS) quadrants, i.e., four regions as shown in Figure 5. It may be mentioned from Figure 5 that the three attributes, namely 'adequate lighting' (ADL), 'security guard and CCTV surveillance' (SGC), and 'crossing safety' (CRS), are found in Quadrant I (*keep up the good work*). This shows that these attributes are perceived with high RIS_T and high RSS_T, which suggests these crossing facility attributes are performing well, and the job is to continue further in this area. The findings can be supported based on the existing condition of these crossing facility attributes shown in Figure 6. While the crossing facility attributes, namely, 'zebra crossing' (ZCR), 'traffic signal' (TSL), 'signboard and marking' (SBM), and 'facility for differently abled and elderly' (FDE), require immediate attention for the priority improvement as these attributes are found to fall into Quadrant II (*concentrate here*) with high perceived RIS_T but perceived with low RSS_T (refer to Figure 5). Therefore, these four attributes under study are the critical attributes identified as high priorities for improvement. These findings were found true and in line with the observation through the reconnaissance survey. Since the existing crossing facilities in the city lacks these facility attributes against their given higher importance by pedestrians (refer to Figure 6). This suggests that the urban local bodies in the city need to look at it and make strategic improvements for the area of concern. It may be observed from Figure 5 that three attributes, namely, 'pedestrian island' (PIL), 'pedestrian signal' (PSL), and 'foot over bridge and underpass' (FBU) are observed to fall into Quadrant III (*low priority*) with low perceived RIS_T and low perceived RSS_T which suggests that there is less attention required in this area. It may be because pedestrians might not be familiar and aware of these facility attributes. As a result,

Figure 6. (a) Absence of zebra crossing and traffic signal in non-working condition, (b) absence of zebra crossing, signboard and marking, (c) absence of zebra crossing, facilities for differently abled and elderly such as curb ramp, tactile pavers, (d) absence of signboard & marking and no provision of facilities of differently abled an elderly, (e) presence of CCTV camera and security guards, (f) presence of street lighting

these facility attributes become irrelevant for pedestrians. Finally, two crossing facility attributes, namely, 'speed breakers and rumble strips' (SBR), and 'surface quality for crossing' (SQC), are observed to fall into Quadrant IV (*possible overkill*). This shows that these attributes are perceived with high RSS_{τ} while perceived RIS_{τ} for the same is much lower than many crossing facility attributes. The finding reveals a lack of proper planning by urban local bodies as they gave more attention than required (refer to Figure 5). Therefore, the city's urban local

bodies must shift their focus from the 'possible overkill' region to the 'concentrate here' region to improve the prioritized or critical attributes with proper management and strategies.

6. CONCLUSION

The present study proposed a hybrid model (GRA-ISA) of Grey Relational Analysis (GRA) and Importance-Satisfaction Analysis (ISA) to identify the critical crossing facility attributes requiring immediate attention for their priority improvement in reference to an educational city Roorkee, India. The study identified some interesting findings regarding pedestrians' priority and expectations towards crossing facilities.

Firstly, the study identified a set of 12 key attributes influencing crossing facilities based on an extensive review of literature, interaction with users onsite, and discussion with experts. The selected attributes under study would help policymakers make decisions while designing crossing facilities in the city.

Further, the study found the Grey Relational Analysis (GRA) as instrumental multi-attribute decision-making (MADM) method to determine the relative importance and satisfaction scores of the crossing facility attributes based on their importance and satisfaction as perceived by pedestrians. The key findings can be summarized as follows:

- The attribute' *adequate lighting' (ADL)* was perceived with the highest importance, followed by *'zebra crossing' (ZCR)*. On the contrary, the attributes such as *'pedestrian island' (PIL)* and *'pedestrian signal' (PSL)* were given lower importance by pedestrians.
- The attribute' *adequate lighting' (ADL)* was found as the most satisfactory, followed by *'surface quality for crossing' (SQC),* whereas *'foot over bridge and underpass' (FBU)* and *'facilities for differently abled and elderly' (FDE)* was perceived with lower satisfaction.

The hybrid GRA-ISA model was identified as an appropriate application tool to identify the critical crossing facility attributes for their priority improvement based on pedestrians' perception rating data collected on a Likert-type ordinal scale. The findings and the recommendations based on GRA-ISA can be summarized as follows:

- Policymakers and urban local bodies are needed to give immediate attention to improve the existing facility of zebra crossing in the city, which is either lacking or not in adequate condition (less visibility of alternately white and black marking).
- Similarly, appropriate signboards and markings are needed at locations currently lacking in the city.
- Further, facilities for the differently abled and elderly such as curb ramps, tactile pavers, pedestrian guardrails, etc., must be provided. At the same time, the existing facility must be improved and maintained regularly to make the city universally accessible.
- The other critical attribute which needs to be focused on immediately by concerned authorities is the provision and proper management of traffic signals at intersections and mid-blocks.

Apart from these interesting findings, the study also has some limitations. The study is limited to Roorkee city. Also, these findings may not be translational to tier-I and metropolitan cities since they have their parameters, such as high mixed traffic flow, pedestrian-vehicle conflicts, pedestrian-pedestrian conflicts, socio-economic characteristics, walking characteristics, etc. However, the study methodology adopted here can be used as an application tool to investigate the priority intervention of crossing facilities in other cities of developing nations in general and Indian cities in particular. The methodology can be employed,

irrespective of the city sizes, based on their parameters to identify the existing voids between users' needs and expectations.

The findings would help planners, policymakers, and urban local bodies in rational decision-making for prioritized strategic improvement and the management of identified critical crossing facility attribute to maintain a pedestrian-friendly infrastructure for safe urban mobility.

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