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Developing a relationship between user satisfaction, physical environment, and behaviour – A case of pedestrian infrastructure

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Abstract

Does infrastructure shape human behavior, or does human behavior shape infrastructure? Users' perception about infrastructure, both current condition and future needs, is essential in devising policy decisions. In the transport sector, one of the reasons of several large infrastructure projects being either delayed or not living up to expectations once they are built, is because the users are not taken into confidence sufficiently. At the same time, it is uncertain to what extent user perception leads to actual behavior change – how many people that say today will walk more if walking environment is improved, will actual do so when the facility is built? The current research measures the users' satisfaction of present walking environment using a revealed preference survey on factors that include quality of infrastructure, comfort, safety, design, and others, in two different urban settings of a large metropolis – one a newly planned suburb and the other and older and well established area. Results of an ordinal logistic regression model shows that the factors which are likely to significantly influence the overall user satisfaction of pedestrian facilities are buffer, ease of walking, zebra crossings, footpath continuity, night time safety and location. Subsequently, stated preference data was collected and the results of a negative binomial regression model shows that improving footpath continuity has the greatest impact in the likelihood of bringing about a change in user behavior when compared to not only other individual improvements, but also the combined improvement in buffer and ease of walking.

Keywords: Non-Motorized Transport, Pedestrian Behaviour, User Satisfaction, Ordinal Logistic Regression, Negative Binomial Regression

1. Pedestrians and transport infrastructure

India has a heterogeneous mix of urban transportation modes, which includes non-motorized modes of travel. Estimates indicate 40% – 60% of the current population uses non-motorized modes such as walking, bicycling &

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cycle rickshaws for their localized urban trips. Further, 30% of the total trips are walk trips (Institute of Urban Transport in India, 2014). Although these numbers are encouraging and are even higher than many developed countries, walking trends seem to be declining (Rahul and Verma, 2013) in the Indian cities; where priority is towards enhancing the motorized travel experience by building cost-intensive flyovers, bridges and subway transits (Tiwari and Jain, 2013). Increasing income levels have also increased the vehicular ownership (Pucher and Buehler, 2010) per household. The average yearly growth in urban vehicular population is an alarming 10.07% which was higher than the average yearly urban population growth of 3.2% in the period 2001 to 2015 (Ministry of Statistics and Programme Implementation, 2017). Rise in vehicular ownership induces the increase in Vehicle Kilometres Traveled (VKT) and facilitates urban sprawl (Richardson and Gordon, 1999) because of which a majority of the Indians are shifting away from non-motorized modes and walking in particular. Thus there is a need to recognize factors, understand the users' satisfaction level of these factors and make informed improvements to attract more people towards walking.

As communities and neighborhoods in developed nations reclaim their streets from excessive vehicular traffic, India's inherent strength, that of a multimodal urban transport environment, is being eroded due to negligence towards public and non-motorized transport, despite their large modal share. Be it the service quality of public transport, or the provision of pedestrian infrastructure, many large Indian cities do not effectively address the issue. Road designs can no longer be meant only for seamless vehicular movement, but must satisfy the needs of a variety of users. Context-Sensitive Solutions (CSS) and design flexibility are tools that help transport agencies in creating more livable communities. Central to these techniques and strategies is the necessity to understand user needs, and incorporate them in the planning and design process of urban streets.

1.1. Transport and user perception

In the context of urban transportation, the most common instance of collecting user perception is the customer satisfaction survey conducted by public transport agencies. Literature shows that public transport users are generally the least satisfied compared to users of other modes (Gatersleben and Uzzell, 2007; Páez and Whalen, 2010). Primary reasons of this low satisfaction includes transfer and waiting time, or combinations of several modes (St-Louis et al., 2014). Specific to India, it has been seen that comfort and safety has the greatest impact on overall satisfaction of public bus transport, followed by the adequacy of capacity of public bus transport services, orderly and clean environment inside buses, elegant design of buses and bus stops, and accessibility to public bus transport services in the city (Singh, 2016). Literature also shows that such user feedback has resulted in policy recommendations; e.g. emphasizing public transport for the urban poor and the old, and that are particularly sensitive to female trip-making needs (Gebeyehu and Takano, 2008).

In recent years, in addition to assessing user satisfaction of public transport users, several countries across the world have begun to measure satisfaction of non-motorized users. Studies in Canada and Sweden suggest that active transportation commuters tend to be the most satisfied, with cyclists displaying the highest satisfaction scores, and pedestrians usually rank second (Olsson et al., 2013; Páez and Whalen, 2010). In Sydney, Australia, people who walked or cycled to work or study in inner the inner city core reported higher levels of enjoyment from their commute compared with those who drove (Rissel et al., 2016). Studies conducted in Scotland have shown that transport satisfaction between 1997 and 2010 have increased greatly for active transport trips, public transport trips, and multimodal trips, when compared to trips made only by car (Olsen et al., 2017). Research has shown that user perception factors such as absence of comfort, convenience, safety, and shade (Zainol et al., 2014), and design factors such as the presence of driveways, bus stops, and the number of vehicle lanes (Choi et al., 2016), reduce the level of pedestrians' satisfaction. Alternately, human-centered designs can improve pedestrians' satisfaction level and perception of community walkability.

In Indian cities, despite a high percent of trips being undertaken on foot, large proportions of sidewalks are either encroached upon, discontinuous, unsafe, or are unusable due to poor upkeep. As such, studies on measuring satisfaction of non-motorized users and facilities need to be conducted is order to establish a baseline of current infrastructure condition and user perception. This will then help in framing policies to choose and prioritize infrastructure projects.

1.2. Transport infrastructure and travel behavior

The subsequent question to be asked is, if infrastructural improvements are carried out, and user satisfaction is enhanced, will it lead to a change in travel behavior? Several before-and-after studies have noticed significant differences in users' willingness to change and their actual change (Kong et al., 2014). Strategies to reduce car use essentially deals with changing user behavior by influencing a user's choice of mode, i.e. making alternate modes of transport more attractive than the automobile (Guitink et al., 1994). Recent studies that have researched the impact of information and communication technologies (ICT) on travel behavior indicate that ICT leads to reorganization of activities in time and space, which then leads to a change in travel behavior (Lenz and Nobis, 2007). Chatterton and Wilson (2014) proposed a 'Four Dimensions of Behaviour' (4DB) framework which could assist practitioners on the design of effective 'behaviour change' interventions. Overall it can be said that bringing about a behavioral change takes time, and established travel habits are difficult to break (Gärling and Axhausen, 2003; Møller and Thøgersen, 2008). Thus, careful consideration should be given while planning for a new area and also one has to temper his/her expectations of user behavior change as a result of improved infrastructure.

Pedestrian infrastructure improvements are almost often overlaid on a street network, which was designed for motorists. Such "after the fact" and isolated improvements, for example, provision of foot-over-bridges or underpasses and short stretches of sidewalks, along a predominantly motorized route, does not bring about a change in user behavior and thus suffers from low usage. Thus it is necessary to identify the type(s) of improvement and the amount of behavior it can likely bring about, in order to manage the expectations of the decision makers.

2. Methodology

Most of the studies usually either study user behavior of existing infrastructure, or measure the likelihood of usage of an infrastructure to be provided the future. In this study, we have developed an integrated two-step methodology where in the first phase revealed preference data was collected to model the satisfaction of pedestrians, and improvements that impact user satisfaction were identified; and subsequently in the second phase, a stated preference survey was conducted to estimate change in behavior of pedestrians as a results of the improvements identified in the first phase. The surveys were conducted in two neighborhoods of Kolkata, one that is a newly developing planned area (referred to as "Area A" henceforth), whereas the other is a relatively old and established area that has grown organically (referred to as "Area B" henceforth) without planning interventions. The flow of tasks is depicted in Figure 1.

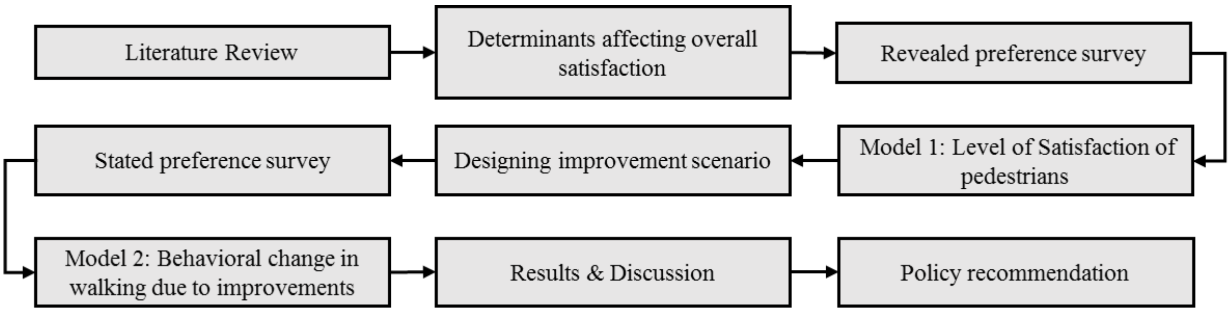

Fig. 1. Flow chart of methodology.

Figure 2 shows two pictures, which are representative of the pedestrian environment of Area A and Area B respectively. Area A is predominantly a residential area with sparse high-end office buildings in vicinity, whereas Area B has a prominent educational institute, residential buildings, and several small and medium size businesses (local/street market). Both areas have a bus terminal.

a b

Fig. 2. (a) Study area A; (b) Study area B

2.1. Physical factors affecting overall satisfaction of individual pedestrians

Important factors were selected after conducting a literature review of related studies. Table 1 shows the list of factors considered for the study.

Table 1. Physical factors affecting satisfaction level of users

Sl. No.	Pedestrian Factors	Description	Sources
1	Footpath quality	Texture, material, and condition of footpath surface	(Gallin, 2001; Jensen, 2007; Sisiopiku et al., 2007)
2	Continuity of footpath	Availability of footpath throughout the journey	(Dixon, 1996; Gallin, 2001; Sarkar, 1994)
3	Shading/Tree cover	Presence of natural or man-made shading along footpath	(Dixon, 1996; Gallin, 2001; Jaskiewicz, 2000; Jensen, 2007)
4	Signage	Presence of directional street signs for wayfinding	(Jaskiewicz, 2000; Lopez, 2006)
5	Air quality	Exposure to poor air quality while walking	(Jaskiewicz, 2000; Sarkar, 1994)
6	Street lighting	Availability and functioning of street lights along footpath	(Sarkar, 1994; Sisiopiku et al., 2007)
7	Buffer	Presence of barrier between footpath and adjoining road	(Dixon, 1996; Jaskiewicz, 2000; Jensen, 2007; Landis et al., 2001; Tan et al., 2007)
8	Speed of traffic	Speed of vehicles on adjoining road	(Dowling et al., 2009; Gallin, 2001; Landis et al., 2001)
9	Ease of walking	Presence of obstructions along footpath	(Gallin, 2001; Jaskiewicz, 2000)

Sl. No.	Pedestrian Factors	Description	Sources
10	Pedestrian space along footpath	Presence of other pedestrians along footpath	(Fruin, 1971; Gallin, 2001; Muraleetharan and Hagiwara, 2007; Polus et al., 1983; Sisiopiku et al., 2007; Tanaboriboon and Guyano, 1989)
11	Grade of footpath	Presence of uphill or downhill segments along footpath	(Bandara, 1994; Gallin, 2001; Jaskiewicz, 2000)
12	Intersections	Presence zebra crossings at signalized intersections	(Gallin, 2001; Landis et al., 2001; Muraleetharan and Hagiwara, 2007; Sisiopiku et al., 2007)
13	Daytime safety	Sense of security felt during daytime	(Khisty, 1994; Sarkar, 1994; Sisiopiku et al., 2007)
14	Night time safety	Sense of security felt during night time	(Khisty, 1994; Sarkar, 1994; Sisiopiku et al., 2007)

2.1. Design of survey instrument

2.1.1. Revealed Preference (RP) survey: Perceived level of satisfaction due to factors

A total of approximately 400 users were surveyed at both the locations combined. Current pedestrian behavior data was collected – such as, frequency of pedestrian trips and distance/travel time to various trip purposes. The respondents are also asked to rate (on a Likert Scale of one to five) different parameters (factors selected as discussed in section 3.1) affecting their satisfaction of existing pedestrian facilities such as existing footpath quality, continuity, shading/tree cover, air quality, street lighting, buffer from adjoining streets (e.g. railing, trees, on-street parking), speed of vehicular traffic on adjacent street, ease of walking (e.g. obstructions due to street vendors, parking on pedestrian pathway), etc. In addition to the satisfaction data of individual parameters, an overall satisfaction level (on a scale of one to five) was also recorded.

2.1.2. Stated Preference (SP) survey: Indicated change in behaviour due to improvements

The SP survey was done after the data from the RP survey was analyzed using ordered logistic regression. Approximately 1500 instances of behavior change possibilities were recorded at the same locations in Areas A & B. Pictorial questionnaires of nine future improvement scenarios were shown to pedestrians and their walking frequencies were recorded before and after the hypothetical improvements. This walking frequencies were categorised based on the four major trip purposes, namely—(a) work/education; (b) shopping; (c) recreation; and (d) exercise. A more detailed description of both datasets are presented in section 3.

2.2. Modelling Techniques

Collected RP and the SP data were modelled using appropriate statistical techniques. As per figure 1, the first attempt (hereafter called model 1) was to model the peoples' perception of satisfaction from the built environment, whereas, the second attempt (hereafter called model 2) was to model the change in the walking behaviour of the users due to hypothetical improvements in the walking environment. Here, the "walking behaviour change" is used to signify the change in the weekly frequency of walking per person categorised as per trip purposes mentioned earlier.

2.2.1. Model 1: Ordered logistic regression (OLR) & Odd's Ratio (OR) Analysis

Ordered logit model, also called 'proportional-odds model' (or cumulative logistic regression) is prevalently used in cases of ordinal data. It is an extension of the logistic regression, where the dependent variable (Y) is dichotomous in nature. However, for OLR, multi-category responses could be taken into account, thereby making it suitable for assessing the ordered responses of satisfaction. OLR is a well-established technique in both domains of users' satisfaction modelling (Eygu and Gulluce, 2017) and transportation studies (Çelik and Senger, 2016; Eboli and Mazzulla, 2009; Huntsinger et al., 2013).

OLR uses cumulative probabilities up to a threshold, thereby making the whole range of ordinal ranked categories into binary at that threshold. Considering, the dependent variable, Y = 1, 2, 3…j, where, responses being ordinal in nature and $\{\pi_1, \pi_2..., \pi_j\}$ be the probabilities associated with it. A cumulative probability of a response less than or equal to j is written as shown in equation 1 (Kleinbaum and Klein, 2010).

$$P(Y < j) = \pi_1 + \pi_2 + \cdots + \pi_j \quad (1)$$

Using equation 1 OLR can be defined in terms of log odds as shown in equation 2. This equation describes the log-odds of two cumulative probabilities –one is less than and the other is greater than type. This shows how likely a response will be below or equal to category j versus above category j.

$$\log\frac{P(Y \le j)}{P(Y > j)} = \log\frac{P(Y \le j)}{1 - P(Y \le j)} = \log\frac{\pi_1 + \pi_2 + \cdots + \pi_j}{\pi_{j+1} + \pi_{j+2} + \cdots + \pi_J} = L_j \quad (2)$$

The sequence of the logged odds is incorporated with a linear form of the independent factors and the general form of the OLR model is given by equation 3.

$$L_j = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \quad (3)$$

Where, L_j= Logged-odds, X_j=factors associated with the model; P= number of factors; and, J=total number of ordered response. The parameters are interpreted as follows–

- Intercept β_0 defines the log-odds of being below the category j when $X_1 = X_2 = \cdot \cdot \cdot = 0$
- Parameter β_j describes how X_j affects L_j such that—β_j is the increase in log-odds of falling into or below any category associated with a one-unit increase in X_j, holding all the other independent factors constant. Therefore, a positive slope indicates a tendency for the response level to decrease as the variable decreases and vice-versa.

In a dichotomous situation, the OR is a ratio between the odds of success to failure of an event. Odd's ratio (Kleinbaum and Klein, 2010) is a statistical quantity used in logistic regression models to represent the change in odds for one-unit increase in one of the independent variable when all other variables are constant. The reference (base) combination needs to be ascertained for apprehending this change. This information is crucial in realizing the independent factors which might have a profound role on the dependent variable.

This study uses the estimated logistic regression model to identify significant and important factors which is instrumental in influencing users' satisfaction level. Following this, the odds' ratio analysis was conducted to construct the various improvement scenarios. These improvement scenarios were the basis for designing the SP survey on which model 2 was estimated.

2.2.2. Model 2: Negative Binomial Regression (NBR)

Dependent variables which measures count has a discrete probability distribution and may be modelled with the family of Generalized Linear Models (GLMs). An important probability distribution in the family of GLMs are Poisson distribution, but this distribution is not used when over-dispersion is observed in the dataset. Therefore, to counteract this effect, negative binomial (Desjardins, 2016; Erdman et al., 2008) is used along with a dispersion parameter. The general form of the negative binomial probability distribution is shown in equation 4.

$$P(Y_i = y_i | X_i) = \frac{\theta^\theta \mu_i^{y_i} \Gamma(\theta + y_i)}{\Gamma(1 + y_i)\Gamma(\theta)(\mu_i + \theta)^{y_i+\theta}} \quad (4)$$

Where, expected value of the Poisson distribution (mean), $\mu_i = e^{X_i \beta_i}$; X_i=independent factors; θ=inverse of the dispersion parameter= 1/α; Γ the gamma distribution; and Y_i= dependent count data. For the purpose of regression, when the dataset, if found to be over-dispersed, is corrected using the dispersion parameter and therefore viewed as a Poisson distribution. The general regression equation is shown in equation 5, on which, simple manipulation was done to achieve linearity to use for regression (equation 6).

$$e^y = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \quad (5)$$

$$Y = \ln(\beta_0 + \sum_{j=1}^{P} \beta_j X_j) \quad (6)$$

NBR is a well-known technique applied to the field of crash modelling in transport studies (Chang, 2005; Poch and Mannering, 1996) however fewer studies were found which modelled the frequency of walking with the improvements in built environment using NBR. The interpretations for the parameter estimates are the same for any regression technique (as had been discussed in section 2.2.1), however the logarithmic nature of the regression model needs to be taken into account. Analogous to the odd's ratio in logistic regression, NBR uses Incidence Rate Ratio (IRR) to quantify the direction and the strength of relationship between the dependent and the independent variables.

2.3. Tests for heterogeneity of users' responses

Test for heterogeneity of responses among various sub-groups of the total sample, was carried out to check whether responses were similar or dissimilar. The sub-samples used in the study was based on demographics and trip-related information and the sub-sample testing were conducted separately for the RP and SP dataset. These tests give necessary insight regarding the sub-samples and help decision makers to frame policies specific to their needs. Non-parametric statistical tests are suitable assessment technique where the assessment variables are ordinal or count data in nature. Responses were checked using the Man-Whitney U test (Mann and Whitney, 1947) and the Kruskal-Wallis H test (Kruskal and Wallis, 1952). Man-Whitney test is performed on two independent groups, whereas the Kruskal-Wallis test is performed on two or more independent groups of the sample population.

Both tests are popular and has been used widely in transportation studies (Majumdar et al., 2015; Sadhukhan et al., 2015; Thomaz et al., 2016). The test statistic H for Kruskal-Wallis is shown in equation 7 and the test statistic U for the Mann-Whitney is shown in equation 8.

$$H = \frac{12}{n(n+1)} \sum \frac{R_j^2}{n_j} - 3(\mathrm{n} + 1) \quad (7)$$

where, R_j = rank sum for sample j; n = total number of samples; n_j = number of respondents in sample j

$$U = n_1 n_2 + n_2 \frac{(n_2+1)}{2} - \sum_{i=n_1+1}^{n_2} R_i \quad (8)$$

where, n_1, n_2 = samples which are pooled; R_i = ranks

3. Descriptive findings from collected responses

3.1. RP data findings

Data gathered from the survey was used to determine (a) travel characteristics of pedestrians in the study areas; and (b) satisfaction of pedestrians with the walking environment.

3.1.1. Pedestrian travel characteristics

The average walking distance was found to be 1.4 km, or an average of 18 minutes of walking activity. The number of people walking decreased as distance increased, with 75% of the people walking up to a distance of 1.5 km. When it came to frequency of walking, it was found that a majority of the respondents walked daily (35%), but at the same time, there were many infrequent pedestrians as well, who walked only once a week (32%). It was also noticed that for a majority of the people the purpose of a pedestrian trip is shopping (36%), which was followed by health/fitness (34%). Only about 16% walked for work/education, and 14% for recreation/leisure. Finally, it was also noted that the percent of people walking to work decreases as income increases, and percent of people walking for health/fitness is higher among higher income groups.

Figure 3 below show the variation in pedestrian trips by purpose and frequency. It can be seen that people on an average walk more frequently and for longer time for health/fitness, followed by shopping. However, the average time spent walking for shopping is significantly less than that for health/fitness.

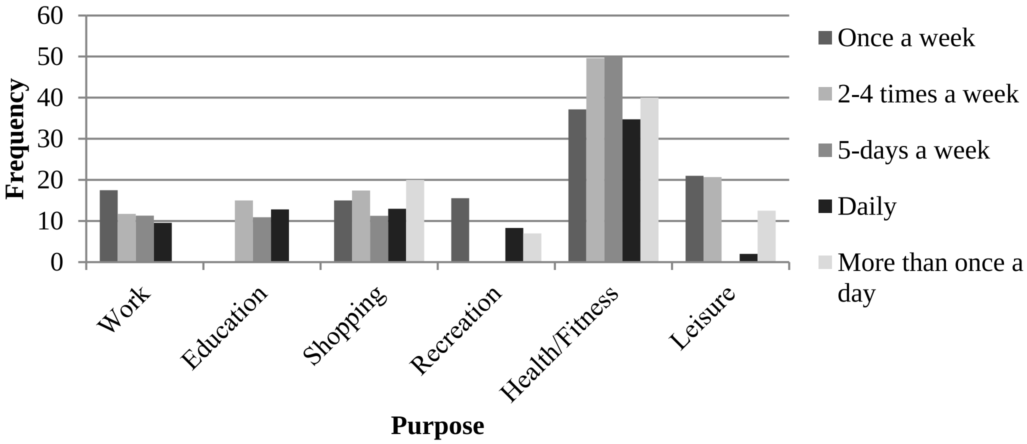

Fig. 3. Variation in pedestrian trips by purpose and frequency

3.1.2. Satisfaction Level of Individual Pedestrian

Table 2 below show the satisfaction ratings, on a scale of 1 – 5, that majority of the pedestrians perceived for each of the factors at both the study locations. It can be observed that a majority of the pedestrians gave an "average" satisfaction rating to 9 out of the 14 factors in Area A, despite it being a new and planned area of Kolkata. However, none of the factors received a "poor" or "very poor" rating, with the rest of the 5 out of 14 factors receiving a "good" rating. When asked about the overall pedestrian environment, majority of the respondents (56%) provided a rating of "average", whereas about 25% provided a rating of "good" or "excellent", and nearly 18% had a satisfaction of "poor". The findings for Area A were surprising as it was expected that a newly developing and well planned area would have a pedestrian environment which the users would be highly satisfied with.

In case of Area B, a majority of the pedestrians gave an "average" satisfaction rating to 8 out of the 14 factors, almost similar to that of Area A. However, when it came to the "poor" or "very poor" ratings, a majority of the respondents believed that 4 out of the 14 deserved to be in that category. Only 2 out of the 14 factors received a satisfaction rating of "good" from majority of the respondents. When asked about the overall pedestrian environment, majority of the respondents (55%) provided a rating of "average", whereas about 30% provided a rating of "poor" or "very poor", and only 15% had a satisfaction rating of "good". The findings in Area B are reflective of any older neighborhood in India, which grew organically, and hence may not have the requisite amount and quality of pedestrian facilities.

Table 2. Pedestrians majority satisfaction levels (user responses)(Transportation Research Board, 1994)

Pedestrian Environment Factors	**Satisfaction Rating (Mode value)**	**Satisfaction Rating (Mode value)**
	Area A	**Area B**
Footpath quality	4	3
Continuity of footpath	3	3
Shading/ Tree cover	3	2
Signage	3	2
Air quality	3	1 & 2
Street lighting	4	4
Buffer	3	3
Speed of traffic (on adjacent street)	3	3
Ease of walking (obstructions along facility)	3	3
Pedestrian space along facility (crowding)	3	3
Grade of footpath	3	3
Zebra Crossing/ Intersections	4	3
Daytime safety	4	4
Nighttime safety	4	2
OVERALL	3	3

Figure 4 show the breakup of individual satisfaction ratings for the 14 factors in Areas A & B respectively. It can be seen that there are higher dis-satisfaction rates, i.e. respondents providing a rating of “poor”, for shading/ tree cover, footpath continuity and speed of traffic in Area A. People are mostly satisfied, i.e. provided a rating of “good”, with street lighting, zebra crossings, daytime & nighttime safety. In Area B, more than a quarter (25%) of the surveyed people are dis-satisfied in many aspects of the pedestrian facilities such as footpath quality, continuity, shading, signage, air quality, ease of walking, and pedestrian space along facility (crowdedness). People are most dis-satisfied with the air quality that they experience while walking in the area, with almost 32% of them giving it a rating of “very poor”.

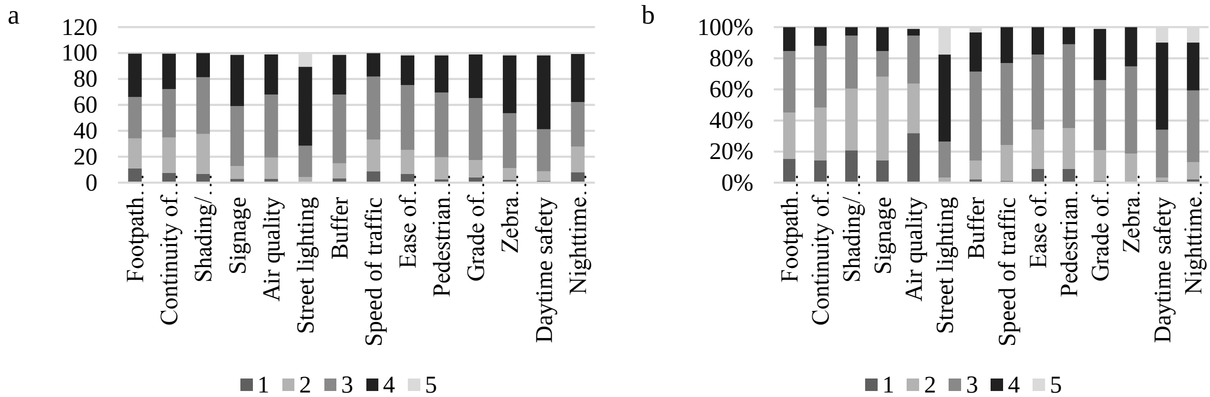

Fig. 4. Distribution of users’ (percentage) with satisfactions levels for (a) Area A; and (b) Area B pedestrian facilities

3.1.3. Heterogeneity of user satisfaction among groups

3.2. SP data findings

The respondents were asked to state their weekly walking frequencies (as per the four trip purpose), before (existing) and after the implementation of nine hypothetical improvements using pictorial representations. Nine improvement were utilised for the evaluation of the walking behavior change. These nine improvements were— (1) widening of buffer; (2) ease in walking by removal of encroachments; (3) pedestrian crossing improvement; (4) night time safety; (5) continuity of sidewalks; (6) combination of (1) and (2); (7) combination of (1) & (5); (8) combination of (2) & (5); and, (9) combination of (1), (2), (3) & (4). The rationale behind selection of these nine specific improvements have been dealt in section 6. Data gathered from the survey was used to determine (a) existing and stated future walking frequencies categorised as per trip purposes in the study areas; and (b) significant differences in the satisfaction between various groups.

3.2.1. Existing and stated future walking frequencies categorised as per trip purposes in the study areas

Figure 5 shows the trend of change in walking behaviour based on trip purposes. It is seen that respondents in site A are more responsive to improvements than site B. The maximum weekly frequency change (difference between the existing and the stated future walking frequency) was observed to be 6 whereas this number is 5 for respondents of Site B. Also all the weekly walking frequency changes in the maximum level of 5 at site B is due to only exercise trips. A major portion of the work/education and shopping trips in site B have stated to not change their walking frequencies under any improvement whereas for Site A, the same is attributed to trip with recreation and exercise purposes.

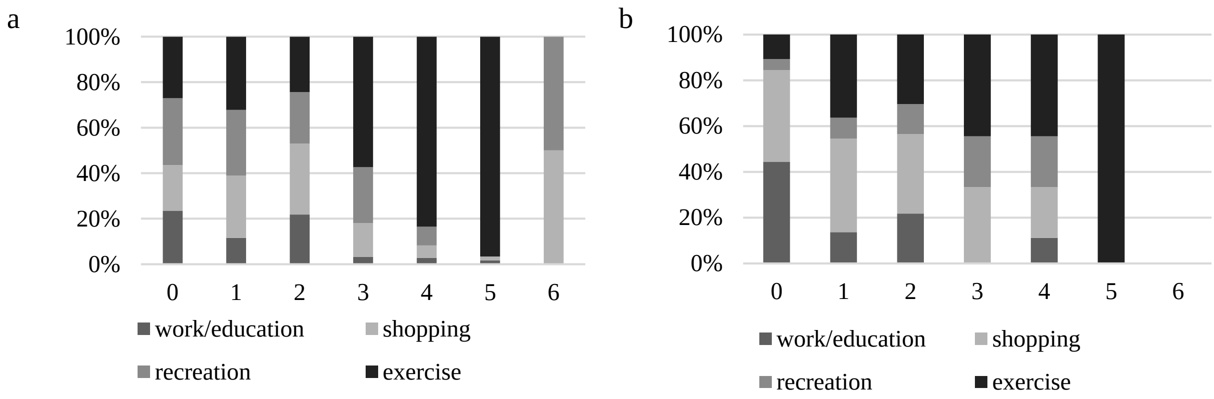

Fig. 5. Variation in weekly walking frequency change for (a) Site A; and (b) Site B categorised as per trip purpose

It is also interesting to note that the overall walking behavior change due to these improvements follow a declining trend (figure 6). More respondents have stated a “no change” in their walking behaviour under the nine improvements; the mean of weekly walking frequency change was found to be 1.34 whereas the variance was 2.104. Such a situation allows us to consider the negative binomial regression to model this occurrence.

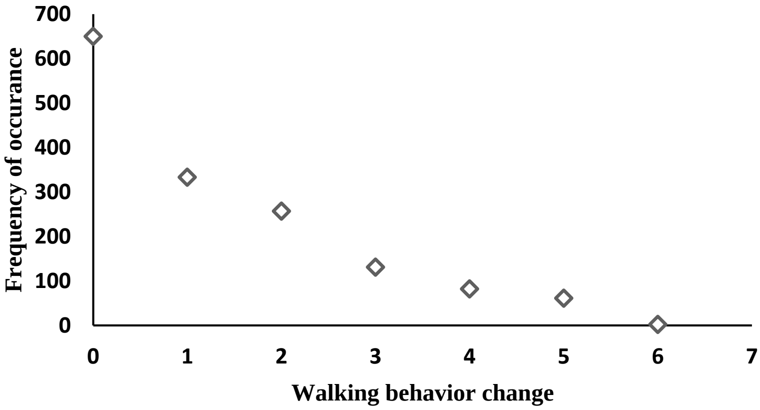

Fig. 6. Variation in walking behaviour change for (a) Site A; and (b) Site B

3.2.2. Heterogeneity of stated walking behaviour change

Heterogeneity tests for the stated walking behavior change is performed under the null hypothesis (H_0) that the median walk frequency change per week is not same across the sub-groups of the collected samples, whereas the alternate hypothesis (H_1) is taken to be as no difference in the median walking frequency change per week across all the sub-groups. The collected sample of responses are divided into sub-groups based on the location type (Site A or B), five income levels (1= < INR 10000, 2= INR 10000-20000, 3= INR 20000-30000, 4= INR 30000-40000,5= > INR 40000), four trip purposes (1= work/education, 2= shopping, 3= recreation, and 4=exercise) and nine improvement types (as mentioned earlier in section 3.2, numbered 1 to 9). The test statistic used for such test are Mann-Whitney U for two independent sub-groups and Kruskal- Wallis H for more than two independent sub-groups. If sub-groups (more than two in number) showed evidences of heterogeneity using the Kruskal- Wallis H test, then it was followed up with the Mann-Whitney U test to ascertain specifically— which set of sub-groups showed heterogeneity as presented as an excerpt in table 5. The asymptotic significance (p-value) at 95% confidence interval (CI) helps to understand if the H_0 is accepted or rejected. It is concluded that a majority of the sub-groups, (e.g., improvement= 1 vs. 5) are heterogeneous whereas a few sub-groups did not show such feature (e.g., improvement= 1 vs 2).

Table 5. Sub-groups which showed evidences of heterogeneity and their corresponding p-values (excerpt)

Sub-groups	Test	Results
Location: A vs B	Mann-Whitney U	P=0.011<0.05, significant difference exists
Income (1 to 5)	Kruskal-Wallis H	P=0.004<0.05, significant difference exists
Income (1 vs. 3)	Mann-Whitney U	P=0.003<0.05, significant difference exists
Income (3 vs. 5)	Mann-Whitney U	P=0.001<0.05, significant difference exists
Income (3 vs. 4)	Mann-Whitney U	P=0.001<0.05, significant difference exists
Income (2 vs. 3)	Mann-Whitney U	P= 0.049<0.05, significant difference exists
Purpose (1 to 4)	Kruskal-Wallis H	P=0.00<0.05, significant difference exists
Purpose (1 vs. 2)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Purpose (1 vs. 3)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Purpose (1 vs. 4)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Purpose (2 vs. 4)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Purpose (3 vs. 4)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Improvement (1 to 9)	Kruskal-Wallis H	P=0.00<0.05, significant difference exists
Improvement (1 vs. 3)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Improvement (1 vs. 4)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Improvement (1 vs. 5)	Mann-Whitney U	P=0.00<0.05, significant difference exists

Sub-groups	Test	Results
Improvement (1 vs. 6)	Mann-Whitney U	P=0.00<0.05, significant difference exists
Improvement (1 vs. 7)	Mann-Whitney U	P=0.00<0.05, significant difference exists

4. Determining factors effecting overall pedestrian satisfaction

4.1. OLR– Calibration

The ordered-logit model was calibrated using the 80% of the total sample size (data) collected from both the locations. The model is later validated using the rest of the 20% data collected during survey. Table 6 shows the variables significantly affecting users' overall satisfaction of the existing pedestrian environment. They include 'Buffer', 'Ease of walking', 'Zebra crossing', 'Night-time safety' and 'Continuity of footpath', which are all statistically significant at 95% confidence interval. 'Location', which was binary coded as 1 for Area A and 0 for Area B, was also statistical significant with a negative sign implying both, that location plays a role in user satisfaction of pedestrian facilities, and the overall satisfaction is significantly lesser in Area B when compared to Area A.

The model also depicts that 'Ease of walking' has the highest impact on overall satisfaction, followed by 'Night-time safety' and 'Zebra crossings'. This gives an insight to decision makers when it comes to prioritizing pedestrian improvement projects. It is more likely that user satisfaction will be improved if obstructions are removed from the footpaths rather than if the quality of footpath surface is improved, as the 'footpath quality' variable was not found to be significant. In addition, the model also tells us that making the same improvement in two different locations may not yield same results of improving user satisfaction.

Table 6. Final ordinal logit regression results for pedestrian facilities

	Estimate	Std. Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
[Satisfaction level while walking = 1.00]	1.786	1.006	.076	-.186	3.759
[Satisfaction level while walking = 2.00]	5.491	.811	.000	3.902	7.080
[Satisfaction level while walking = 3.00]	9.094	.946	.000	7.239	10.949
[Satisfaction level while walking = 4.00]	13.057	1.150	.000	10.804	15.311
Buffer	.310	.182	.021	-.046	.667
Ease of walking	.778	.177	.000	.433	1.124
Zebra Crossing	.506	.182	.000	.379	1.091
Night-time safety	.509	.140	.000	.217	.765
Continuity of footpath	.299	.158	.044	-.073	.547
Location	-.701	.288	.018	-1.281	.122

The log-likelihood values model fitting information shown in Table 7 indicates that the final model with all the predictor variables does better than the intercept only model with no intercept variables which is a clearly underlines the fact that the above listed variables (Table 6) helps in predicting the overall satisfaction levels in a better manner The Goodness-of-Fit statistic of the model is shown in Table 8 and R^2 value comes to be approximately 0.23.

Table 7. Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	412.983			
Final	298.060	114.923	5	.000

Table 8. Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	1296.980	380	.000
Deviance	220.084	380	1.000

4.2. Model validation

The overall levels of satisfaction models are validated using the 20% of the unused sample (data). The predicted overall satisfaction levels from the model were compared with the actual satisfaction levels noted during the survey and the overall satisfaction levels were predicted with an accuracy of 61% for pedestrian facilities. Different models with different sets of randomly selected 80% of total dataset are iterated and validated where the accuracy ranged between 59 % and 68 %.

5. Pedestrian improvements and enhancing user satisfaction

The improvement in the overall satisfaction levels with improvement in the individual as well as combination of pedestrian factors are predicted based on the model. The tables below show the improvement in the overall satisfaction levels of the pedestrian facilities when there is an increase in the satisfaction levels of the various affecting parameters.

5.1. Improving Level of Satisfaction – Pedestrian environment in Area A

The model predicts (refer table 9) that any improvement to the buffer that causes one-unit increase in the user satisfaction, i.e. from the current level of 3 to 4, can bring about a one-unit improvement in the overall user satisfaction, in this case also from level 3 to 4, given all other factors are held constant. However, the same is not true in the case of footpath continuity, i.e. any improvement made to improve the continuity of footpath that causes one-unit increase in the user satisfaction, is not likely to bring about an improvement in the overall user satisfaction.

Another finding of the analysis is that, there may be common improvements, which when performed, is likely to improve the satisfaction of multiple factors, and subsequently improving the overall level of satisfaction of the users. For example, by clearing the vehicles that are parked along footpaths and providing them parallel parking along the curbside could not only improve ease of walking, but also provide better buffer to the pedestrians. Thus, this one improvement, may bring about a one-unit change in the satisfactions levels of two factors, and is subsequently likely to bring a one-unit change in the overall level of satisfaction for pedestrians.

Lastly, it may be noted that an increase in one-unit of satisfaction from level 3 to level 4 is likely to be easier when compared to a one-unit increase from level 4 to level 5. As this is an ordinal scale, the difference between the levels are not constant. Thus, although improvements to zebra crossings that bring about a one-unit change (from a level 4 to a level 5), will bring a one-unit change in the overall satisfaction, but this change is likely to be harder to achieve when in comparison to a one-unit change in buffer or ease of walking, where the improvement in satisfaction is from level 3 to level 4.

Table 9. Area A: Pedestrian facility overall satisfaction predicted improvement.

Combination Id	Buffer	Ease of walking	Zebra crossing	Night time safety	Footpath continuity	Predicted
Base case	**3**	**3**	**4**	**4**	**3**	**3**
1	**4**	3	4	4	3	**4**
2	3	**4**	4	4	3	**4**
3	3	3	**5**	4	3	**4**
4	3	3	4	**5**	3	**4**
5	3	3	4	4	**4**	3
6	**4**	**4**	4	**4**	3	**4**
7	**4**	3	**5**	4	3	**4**
8	**4**	3	4	**5**	3	**4**
9	**4**	3	4	4	**4**	**4**
10	3	**4**	**5**	4	3	**4**
11	3	**4**	4	**5**	3	**4**
12	3	**4**	4	4	**4**	**4**
13	3	3	**5**	**5**	3	**4**
14	3	3	**5**	4	**4**	**4**
15	3	3	4	**5**	**4**	**4**

5.2. Improving Level of Satisfaction – Pedestrian environment in Area B

Table 10 depicts a similar analysis performed for Area B, which is an older and established area in comparison to Area A. In this case, the model predicts that there is only one scenario where the overall user satisfaction can be increased. Only an improvement that can bring about a one-unit change in user satisfaction for all four factors of 'buffer', 'ease of walking', 'zebra crossing', and 'nighttime safety', is likely to result in a one-unit improvement in the overall level of satisfaction of the pedestrian. This is an interesting result, which may point towards the fact that it is difficult to change the perception of users in an old and established area, as opposed to a new area. Also, it is often noticed that improvements are difficult to be carried out in established areas primarily due to lack of space, and even if improvements are made, they are often not the optimal solution, which ultimately does not lead to the satisfaction of its users.

Table 10. Area B: Pedestrian facility overall satisfaction predicted improvement.

Combination Id	Buffer	Ease of walking	Zebra crossing	Night time safety	Footpath continuity	Predicted
Base Case	**3**	**3**	**3**	**3**	**3**	**3**
1	**4**	3	3	3	3	3
2	3	**4**	3	3	3	3
3	3	3	**4**	3	3	3
4	3	3	3	**4**	3	3
5	3	3	3	3	**4**	3
6	**4**	**4**	3	3	3	3
7	**4**	3	**4**	3	3	3
8	**4**	3	3	**4**	3	3

Combination Id	Buffer	Ease of walking	Zebra crossing	Night time safety	Footpath continuity	Predicted
9	**4**	3	3	3	**4**	3
10	3	**4**	**4**	3	3	3
11	3	**4**	3	**4**	3	3
12	3	**4**	3	3	**4**	3
13	3	3	**4**	4	3	3
14	3	3	**4**	3	**4**	3
15	3	3	3	**4**	**4**	3
16	**4**	**4**	**4**	3	3	3
17	**4**	**4**	3	**4**	3	3
18	**4**	**4**	3	3	**4**	3
19	**4**	3	**4**	**4**	3	3
20	**4**	3	**4**	3	**4**	3
21	**4**	3	3	**4**	**4**	3
22	3	**4**	**4**	**4**	3	3
23	3	**4**	3	**4**	**4**	3
24	3	3	**4**	**4**	**4**	3
25	**4**	**4**	**4**	**4**	3	**4**
26	**4**	**4**	**4**	3	**4**	3
27	**4**	**4**	3	**4**	**4**	3
28	**4**	3	**4**	**4**	**4**	3
29	3	**4**	**4**	**4**	**4**	3

6. Walking behavior change due to hypothetical improvements

The SP dataset procured from site A and B is based on the nine improvements as discussed in section 3. The dataset itself was divided into two parts—70% of which was used for training the model whereas the remaining 30% was used for verification purposes. 70% of the data from the complete data set was selected randomly and the NBR was conducted using the statistical package SPSS; such a trial was conducted ten times to achieve statistical stability in interpretation.

6.1. NBR– Calibration

The NBR model consisted of independent variables like income, type of trip purpose, type of improvement and location (i.e. Site A or B), whereas the dependent variable was the walking behaviour change (i.e. difference between stated walking frequencies before and after the improvement). All the ten trials of the models found certain demographic variables (such as, age, gender and total vehicles owned) to be insignificant in the model estimation. Thus these variables were removed and the ten trials of the models were re-estimated. All the independent variables were categorical in nature and thus had to be represented by dummy indicator as per standard procedures (Heathington and Isibor, 1972; Hu, 2010).

Estimations of the individual parameter values for each independent variable were found to be consistent from the ten trials and the model with the lowest Akaike's Information Criterion (AIC) (Akaike, 1974; Shang and Cavanaugh, 2008) was selected (figure 7). It was found that the ninth trial had the lowest AIC, and thus its estimates were utilised for interpretation.

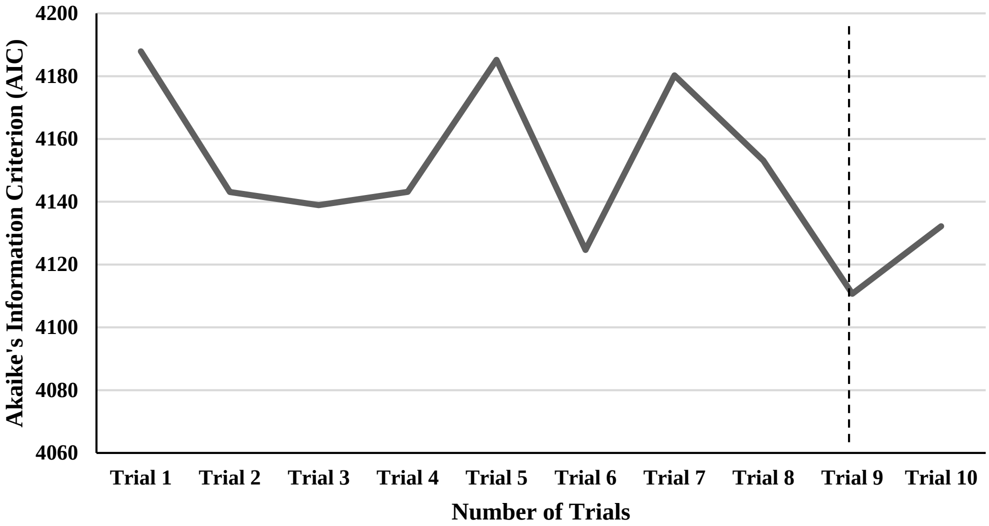

Fig. 7. AIC variation for the ten trials of NBR

The Wald Chi Square test is used for the evaluation of parameter significance as shown in table 11, it was seen that all the independent variables were statistically significant at 95% CI. The deviance is twice the difference between the maximum achievable log-likelihood and the log-likelihood of the fitted model (Hintze, 2007). The ratio deviance to the degrees of freedom was found to be 0.822 (should be about one) which indicates that the model fits the data well (UCLA: Statistical Consulting Group., 2017).

Table 11. Test of Model effects

Independent Variables	Wald Chi-Square	Degrees of freedom	Significance
(Intercept)	65.955	1	.000
Income	18.127	4	.012
Purpose	378.466	3	0.000
Improvement	38.087	8	.000
Location	79.251	1	0.000

The parameter estimates, of the final model is presented in table 12. It is to be noted that the reference dummy indicator for the five "Income" level is "Income=1" which is the salary range of less than 10,000 (in INR); for the four "Purpose" level, "Purpose=1" which is the work/education trips; and for the nine "improvement" levels, "Improvement=1" which is the buffer improvement level. "Location" is a dichotomous variable with 0 representing Site A and 1 representing Site B. As could be seen from table 7, the best improvement level is the "Improvement=9" which is the combination of four improvements of—buffer, ease in walking, pedestrian crossing and night-time safety. The parameter estimates indicate that this improvement is instrumental in bringing out behaviour change 0.782 more than the reference case. In fact, all the improvements designed in combination ("Improvement=6 to 9") of individual improvements ("Improvement=1 to 5") have a higher propensity for impacting behavior change, except for "Improvement =5" (continuity of sidewalks) and "Improvement=4" (night-time safety improvements). These indicators are comparable to “Improvement =6” (buffer + ease of walking) and “Improvement=7” (buffer + continuity). This indicates higher impact in walking behaviour for an easier implementation for such improvements. It is also to be noted that the IRR of the trip purposes are extremely high, which shows that walking behaviour change is extremely dependent on the purpose of the trip and the behavior change may be more significant for recreational and outdoor exercise trips compared to work/education trips. In case of income, similar inferences could be drawn using the parameter estimates, higher income groups (“Income=5” and “Income=4”) have a lower propensity to shift than lower income groups (“Income=1” and “Income=2”) however the corresponding IRR values suggests such a trend is not very powerful in comparison to other independent variables. The model also shows that behavioral impact in walking will be evident for “location”, it is approximately 0.39 times more for Site A in comparison to site B.

Table 12. Estimates of the NBR model

Parameter	Parameter estimates (B)	Std. Error	IRR= Exp(B)
(Intercept)	-1.257	.1063	.284
Income=5	-.098	.0929	.906
Income=4	-.139	.0960	.870
Income=3	.250	.0848	1.284
Income=2	.043	.0914	1.044
Income=1	0		1
Purpose=4	1.893	.0990	6.638
Purpose=3	1.548	.1141	4.704
Purpose=2	1.642	.1088	5.165
Purpose=1	0		1
Improvement=9	.782	.1184	1.704
Improvement=8	.482	.1204	1.416
Improvement=7	.437	.1203	1.401
Improvement=6	.297	.1226	1.537
Improvement=5	.425	.1167	1.529
Improvement=4	.410	.1220	1.507
Improvement=3	.117	.1539	1.125
Improvement=2	.033	.1007	1.033
Improvement=1	0		1
Location	-.386	.0810	.486
Dispersion parameter	.43		

6.2. Model accuracy

The model verification is done on the observed and the calculated values of the same dataset (i.e. 70% of the complete data), whereas the model is validated from the remaining 30% of the dataset. The model is checked for all types of error i.e. type III error, when the predicted values (>0 frequency change) are in “false positive” agreement with observed values (no frequency change) and type IV error, when the predicted values (no frequency change) are in “true negative” agreement with observed values (>0 frequency change). The model accuracy is summarized in table 13, it could be concluded that the model is a good fit to the training dataset and is moderately accurate on its predictive power.

Table 13. Summary of NBR model accuracy

	Observed=Predicted (true positive)	"false positive" (type –IV error)	"true negative" (type –IV error)
Training Dataset: 70% of data points	72.52%	2.99%	24.48%
Testing Dataset: 30% of data points	63.27%	12.15%	24.58%

7. Conclusions & Discussion

This study developed an integrated methodology to assess the level of satisfaction of pedestrians and subsequently determine whether the factors that lead to improvement in user satisfaction does actually bring about a change in user behavior, i.e. change in walking frequency. Surveys were conducted in two locations, on two different occasions, of a large urban metropolis, one being a newly planned area, whereas the other being an area that is well established and grown organically. The major conclusions drawn from the research are:

- Infrastructural elements have a significant impact on pedestrians' satisfaction: The study identifies five infrastructural elements that have a significant bearing on the overall level of satisfaction of pedestrians. They are – a barrier between footpath and road; presence of a continuous footpath from origin to destination; presence of zebra crossings at intersections; presence and functioning of streetlights along footpath to enhance safety at night; and lack of obstructions along footpath to enhance ease of walking.
- 'Average' to 'poor' satisfaction levels of pedestrians: Majority of pedestrians in both Areas A & B, had an overall satisfaction level of 3 ('Average'). However, there is a significant difference in the user satisfaction of various individual factors of the pedestrian environment between the two locations. In the newer location, Area A, 9 out of the 14 factors received a satisfaction rating of 3 ('average'), whereas in the older location, Area B, 12 out of the 14 factors received a satisfaction rating of either 2 ('poor') or 3 ('average').
- Overall pedestrian satisfaction depends upon type of improvement: Not all of the five infrastructural improvements are equally likely to result in an improvement in overall satisfaction of users. The study shows that an improvement that will result in user satisfaction of ease of walking is likely to bring about the greatest improvement in the overall satisfaction of the pedestrians, when compared to an improvement that will result in the user satisfaction for the 'buffer' factor.
- User satisfaction depends upon location: The study suggests that providing same improvements in different locations may not result in same change in user satisfaction. In Area B, only in one scenario, where an improvement brings about a change in user satisfaction of 4 of the 5 factors together, is there a likely change in the overall satisfaction of the pedestrian. Alternately, in Area A, there are several scenarios where the overall user satisfaction is likely to improve as a result of an improvement. For our case, this could be attributed to Area B being an old and well established area, where implementing improvements is not easy, and also changing established travel behavior may be difficult when compared to a newer area, i.e. Area A.
- Change in user behavior depends upon type of improvement, trip purpose and income: The study reveals that the likelihood of change in walking frequency will be greater if an improvement in footpath continuity is carried out versus if an improvement in buffer or ease of walking is carried out. The highest probability of change in behavior is noticed for the scenario when all four factors are improved simultaneously. Secondly, purpose of trip was also found to play a role in the likelihood of change in walking frequency, where a person is more likely to increase his/her walking frequency if it is for the 'exercise' purpose when compared to a 'work/education' trip purpose.
- User satisfaction may not always lead to behavior change: Improvement in user satisfaction with footpath continuity had the least impact on the likelihood of overall user satisfaction, whereas, an improvement in footpath continuity has the greatest impact on the likelihood of change in walking frequency. On the other hand, the study finds consistency in likelihood of increase in user satisfaction and likelihood of change in walking

frequency when it comes to the combination of improvements of (i) continuity of footpath and buffer; and (ii) continuity of footpath and ease of walking. This one should not implement an improvement merely because it is likely to improve user satisfaction and expect a change in behavior.

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