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Travel Probability Fields – An approach to understand travel behavior: Case study of slum dwellers in Kolkata, India

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Abstract

Transport is an important contributor to the well-being of individuals and communities. Lack of suitable and affordable transportation can be a significant barrier to participation of different groups of population in a developing society. The current approach for planning for informal population in developing countries such as India is sadly not based on informed policy decisions backed up by scientific investigation of travel behavior of such communities. As a result, the transport investment decisions are more political in nature, which do not adequately address the needs of the informal community in their day-to-day mobility requirements. In this context, Travel Probability Fields offer a potential analytical tool to understand the travel behavior of population under study and evolve need-based transport investment decisions particularly when the resources are scarce in the context of developing countries. The present paper is an attempt to assess the mobility needs of slum dwellers in the city of Kolkata in east India to identify their travel behavior using Travel Probability Fields (TPF) in order to arrive at scientific based transport policy intervention for urban poor. The paper based on mobility patterns of slum dwellers located in different locations in the city of Kolkata develops Travel Probability Fields for various trip purposes and travel modes in order to assess the impact of location of slums and accessibility to public transport on travel patterns.

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1. Introduction

Due to rapid urbanization in the last few decades, more than half the world's population live in urban areas and this proportion is expected to grow. Urban poor face a complex trade-off between residential location, travel distance, and travel mode, in an attempt to minimize the social exclusion associated with low earning potential

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(Baker, 2008). In particular, urban poor have suffered negative consequences of the growth of motorization and its impact in several ways such as increased travel times for journey to work, increasing urban transport costs in comparison to their incomes, inadequate access to public transport, and low priority to NMT infrastructure planning, biases in investment and regulatory policies etc. The Master Plans or City Development Plans have very little emphasis to address the mobility issues of urban poor specifically through more rationale location of job centers in proximity to their residential areas. There are hardly any significant urban poor targeted mobility strategies reported or seen in cities in India largely owing to the absence of an in-depth understanding of the mobility of urban poor and scientifically informed approach towards evolving transport policies and strategies enabling an inclusive mobility environment for them. In this context, there is great relevance of analytical tools like Travel probability field, which will help in the understanding of the mobility pattern of urban poor and enable policy decision-making process, which can result in an inclusive mobility environment.

2. Concept of Travel Probability Field

2.1. Structure

According to Zahavi (1979), travel probability fields can be defined as the spatial distribution of activity sites visited by households in a particular residential location which can be depicted by a probability density function described in location coordinates. The theory of travel probability fields, as put forward by Zahavi et al (1981), may be summarized as: People travel to increase their choice of activity sites and so increase the benefits associated with the destination. Because of the cost of travel (assumed here to be travel time) increases with travel distance, travel is restricted to an area where the benefits exceed the travel time. This area, the ‘travel probability field’, can be described analytically provided that simplifying assumptions can be made on the way in which the density of activity sites varies with distance from the urban Centre. Such travel fields are methodologically consistent with attempts made in urban geography to describe the spatial distribution of activity patterns .

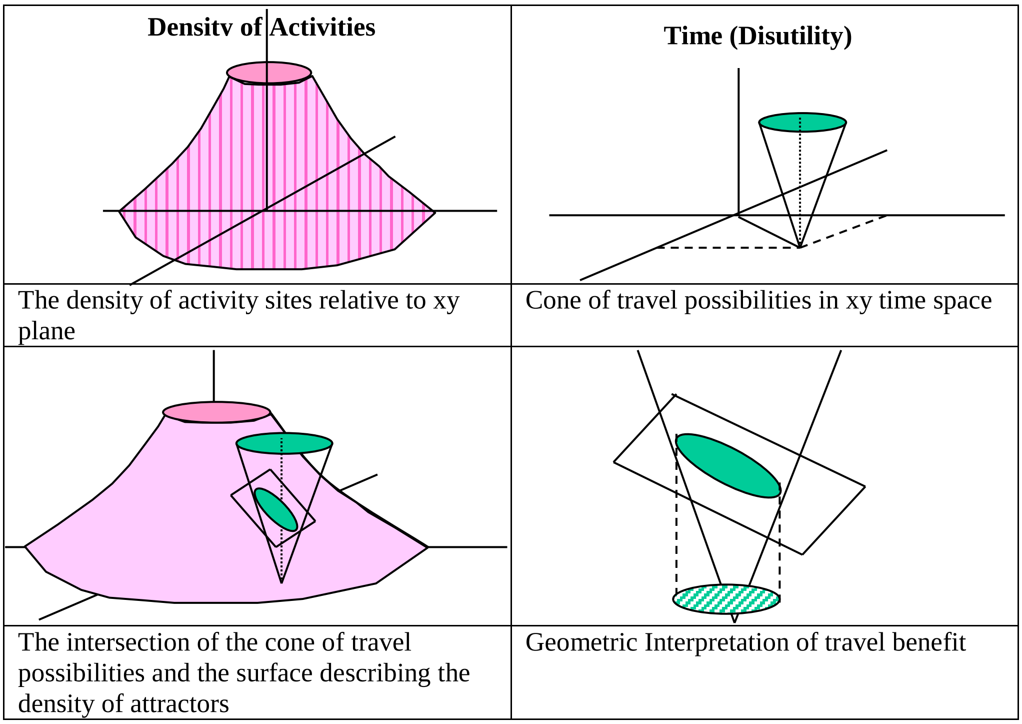


Figure 1 Theory of Travel Probability Fields

The concept is specified for the homogeneous group of households: each group defined by locational proximity and socio-economic strata. It is postulated that the trips generated by such a homogeneous group are influenced by a small number of discrete urban centers. Each center defines a spatial distribution of trip attractors. Outside the immediate vicinity of the urban center, it is assumed that the density of the activity sites falls off as a monotone-decreasing convex function of radial distance. The area that can be potentially be covered by trips originating from a household located at a distance from the urban center is generated by projections from a cone in x-y space which has its apex at the household location and an angle which is equal to some measure of the speed of the transport system. If the cone of travel possibility and the surface describing the density of attractors are superimposed, the intersection of the two surfaces circumscribes an approximately elliptical area on the density of attractor's surface. (Figure 1).The intersection of the surface is then precisely an ellipse and the volume within the core under the ellipse is related to the travel benefits which can be realized by a household located at a certain distance.

Gupta and Manglik, 2007 in their study using the concept of travel probability fields attempted to understand the travel behaviour of households for a city in north India close to Delhi named Noida. The authors found that travel probability fields provided reliable estimate of trip length which was in close resemblance to observed trip length from household travel data. Further this concept assisted in understanding the impacts of spatial location of households and the transport accessibility on the trip lengths of the residents of Noida.

2.2. Parameters of Travel Probability Fields

The parameters of travel probability fields used for analysis are as follows
Centroid Distance (d_c) is the distance from the centroid of the households to the activity site centroid.

$$d_c = \{(\overline{X} - \overline{x})^2 + (\overline{Y} - \overline{y})^2\}^{1/2} \quad (1)$$

Standard Distance otherwise known as standard distance deviation or root mean square distance deviation is the spatial equivalent of standard deviation. It provides the most concise description of the spread of points around the mean center. It is a convenient measure of dispersion in point patterns since it summarizes the spread of points in just one value. It is given by –

$$d\sigma = (\sigma x2 + \sigma y2)1/2 = (\sigma'x2 + \sigma'y2)1/2 \quad (2)$$

Another parameter is the Shape Index. The most commonly measured characteristic of shape is compactness. This is effectively a measure of how far a shape deviates from the most compact possible shape, a circle. The elongation of an ellipse is given by b/a, where 'b' is the major axis of the ellipse and 'a' is the minor axis of the ellipse. It signifies the direction of an ellipse if any. The area of the travel probability field is the area within the ellipse, which signifies the extent or ability of an individual to travel.

The process of generating travel probability fields as proposed by Zahavi constitutes the following steps

Step 1: Locate household centroid: Given the X and Y coordinates of sampled households location, the weighted households centroid is calculated as –

$$\overline{X} = \sum wiXi / \sum wi \text{ , } \overline{Y} = \sum wiYi / \sum wi \quad (3)$$

Where, Xi, Yi = Co-ordinates of household, wi = Expansion factor of sample

Step 2: Locate trip destinations centroid: Given the x and y co-ordinates of each trip destination, generated by sampled households, the weighted trip destination centroid is calculated as –

$$\overline{x} = \sum wixi / \sum wi \text{ , } \overline{y} = \sum wiyi / \sum wi \quad (4)$$

Where, xi, yi = Co-ordinates of trip destinations, wi = Expansion factor of the sample (Trips for purpose as return home were excluded, in order to derive the centroid of trip destinations away from home)

Step 3: Calculate standard deviations of trip destinations: The standard deviation of trip destination distributions about their respective centroids is calculated (σx and σy).

$$\sigma_x = (\sum wixi^2 / wi - \overline{x^2})^{1/2} \quad (5)$$

$$\sigma_y = (\sum wiyi^2 / wi - \overline{y^2})^{1/2} \quad (6)$$

Calculate Correlation Coefficient: The correlation coefficient between the two distributions is calculated (r).

$$r = \frac{\Sigma wixiyi - ((\Sigma wixi)(\Sigma wiyi) / \Sigma wi)}{\sigma_x \sigma_y} \quad (7)$$

Step 5: Calculate Angle of Rotation: In order to find the new coordinate system along which σx and σy take the minimum and maximum values, the angle of rotation between the initial and the new coordinate system is calculated (a).

$$\alpha = 0.5 \tan^{-1} (2r\, \sigma_x \sigma_{y\,/}\, \sigma_x^2 - \sigma_y^2) \quad (8)$$

Step 6: Perform transformation of Co-ordinates: The initial coordinates of all trip destinations are transformed into the new coordinate system.

$$\sigma'_x = (\sum wixi'^2 / wi - \overline{x_i^{\,2}})^{1/2}, \quad \sigma'_y = (\sum wiyi'^2 / wi - \overline{y_i^{\,2}})^{1/2} \quad (9)$$

3. Case-Study Profile

Kolkata Metropolitan Corporation area (KMC), capital of West-Bengal, which has an area of 1875 sq. km. with a population of 4.58 million in 2011 comprising 141 wards, are selected as a case study area. The slum-dwellers account for one-third of Kolkata's total population. There are approximately 7,000 notified and un-notified slums in Kolkata Metropolitan Areas and 1236 notified slums within Kolkata Metropolitan Corporation Area. The transportation infrastructure consists of various modes ranging from the original ferries to metro rail via hand driven rickshaws, trams, buses and trains which currently share the same right of way. Historically, the core city of Kolkata was based on mobility by ferries, hand rickshaws and trams, complemented by the pedestrian movement.

4. Data Collection

The data required for the research was mainly identified with two purposes i.e., to develop travel probability fields and to evaluate the impact of background variables (location, trip length, travel time, trip cost, etc.) on travel probability fields based on existing household, urban structure, and transport system characteristics.

4.1. Primary Surveys

A sample of 200 slum pockets in the city was selected taking into account factors such as accessibility to transit services, geographically location, and access to work centers and local shopping areas besides other social infrastructure facilities such as health centers, schools, community halls, etc. Random slum dwellers were enumerated in each case slum pocket utilising a survey questionnaire detailing out their household (residential location, household size, number of household members with jobs, number of children under school age, number and type of household vehicles and monthly household income) , personal attributes (gender, occupation, age, education level) besides their trip attributes (trip starting and ending time, origin and destination, mode used, trip purpose and travel cost) for a representative day of the week. Also, bus-stop boarding alighting survey was also conducted at the nearest bus stop of case slums which helps in computing of public transport accessibility index. Further, about 200 stakeholders were surveyed in the case-slums to get an opinion regarding the efficiency of transport facility (convenience, affordability, comfort, safety, connection to the city, transport infrastructure) and stakeholder's mark on these indicators out of three in increasing order of marking decreasing the satisfaction level facility.

4.2. Secondary Surveys

Secondary information (detailed maps of Kolkata Municipal Council Area from Kolkata Development Authority and its surroundings, population details, employment density, etc.) was also collected to supplement the database.

5. Profile of Case Slums

For this study within KMC area eight case slums has been selected and among which three (slum number 1 to 3) are located in inner area, namely old CBD area (Zajaria road slum, Garcha road slum and Gossain para basti), two (slum number 4 and 5) are located in middle area (Suren Sarkar street and Jojbagan basti) and three (slum number 6,7 and 8) are in outer area (Ghol para basti, Tangra, and Ayub nagar basti) which is relatively undeveloped low-density outskirts area respectively. The case slum dwellers reside in three different areas and have different socio-economic characteristics and mobility pattern.

The socio-economic analysis reveals that in case slum areas 38% slum dwellers are illiterate while 46% of people have a literacy level of primary education. Further, their monthly household income ranges between Rs. 9000-5000 while per capita income ranges between Rs. 1000-1700. The income of slum dwellers tends to vary spatially by slum location. While outer areas exhibit lower monthly household incomes in the range of Rs 4500 to 7000, the inner areas have relatively higher median monthly household's income ranging between Rs 7000-9500.

It is observed that majority of slum dwellers predominantly walk (56%) for their travel needs followed by bus travel (26%). In terms of trip purpose, the slum dwellers predominantly commute for work (65%) and followed by education purpose (27%). In terms of travel distance nearly 50% of slum dwellers, commute within 0.8 km., while 75% travel within 1km. Slum dwellers limit their travel distance due to poor public transport availability and to avoid incurring high expenditure on transport through personalized transport. The monthly expenditure on transport as a percentage share of income tends to increase for slum dwellers residing away from the city center, which exhibits that slum dwellers tend to limit their travel distance in order to optimize their travel expenditure. It has also been observed that slum dwellers residing in peri-urban areas tend to spend more per trip compared to inner area slums.

6. Assessment of Travel Probability Fields

Travel Probability Fields for the slum dwellers was developed in order to evaluate the impact of various travel behaviour determinants. The fields were developed through the development of a standard deviation ellipse. The Travel Probability Fields were calculated for eight case areas for all modes and all travel purposes (Table 1).

Table 1 Travel Probability Fields for all purpose by all modes

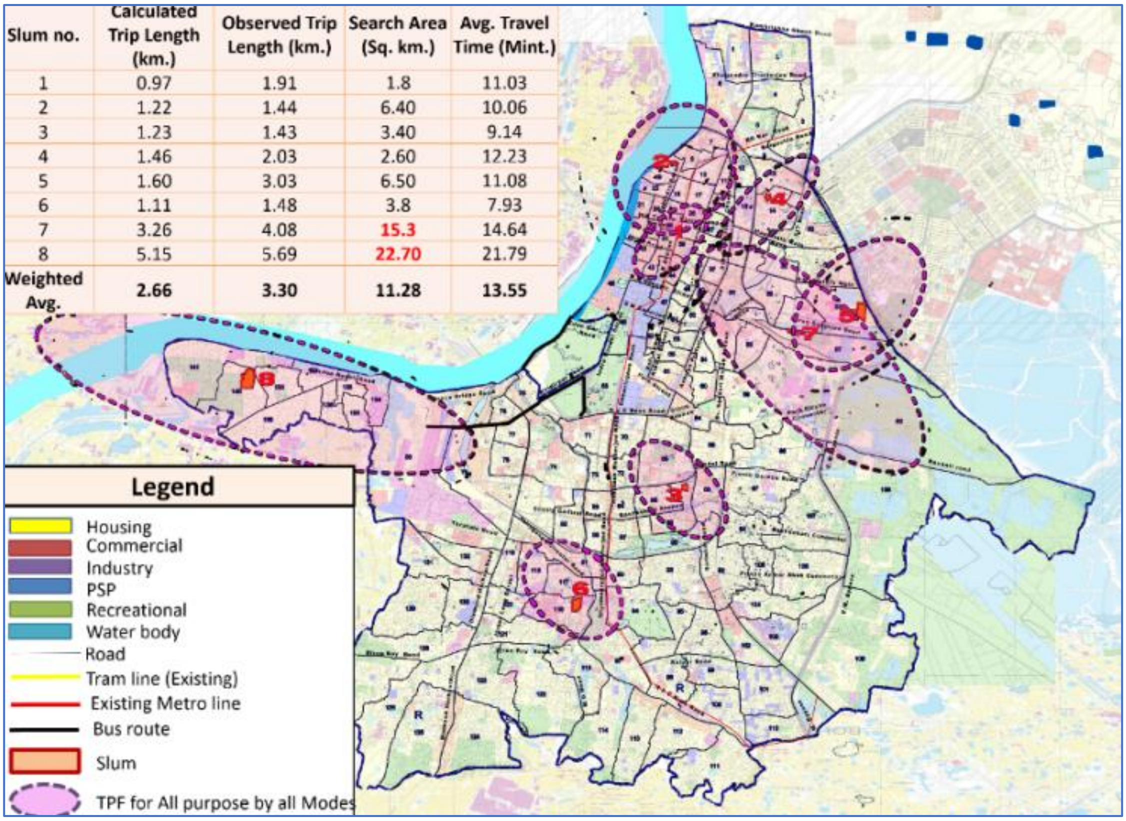
Slum	SDx (km.)	SDy (km.)	Elongation	Cal. Trip Length (km.)	Obs. Trip Length (km.)	SD (km.)	Centroid Distance (km.)	Angle of Rotation	Search Area (sq.km.)
1	1.06	0.55	1.93	0.97	1.91	1.19	0.41	45.05	1.83
2	1.30	1.58	1.21	1.22	1.44	2.05	0.82	45.17	6.46
3	1.38	0.79	1.75	1.23	1.43	1.58	2.04	45.17	3.40
4	1.53	0.56	2.74	1.46	2.03	1.63	0.66	45.17	2.69
5	1.83	1.14	1.60	1.60	3.03	2.16	1.29	45.05	6.58
6	1.32	0.92	1.44	1.11	1.48	1.61	1.85	45.05	3.80
7	3.45	1.42	2.44	3.26	4.08	3.73	1.90	45.05	15.35
8	5.27	1.38	3.83	5.15	5.69	5.44	9.90	22.50	22.74

6.1. Overall Travel Probability Field

Travel Probability Fields based on mobility patterns for all modes and all travel purposes for eight slums are shown in Figure 2. It is observed that the trip length calculated from the travel probability field method is almost similar to that of observed trip length from the primary survey (Table 1). Here, the standard distance (SD) implies the distance between trip generation center and attraction center. It is observed that slum located on the periphery of the city (slum 8) has high search area reflecting poor amenities forcing the affected population to travel for longer distances compared to inner areas located slums.

6.2. Variation in Travel Probability Fields

Analysis of Travel Probability fields (TPFs) for all travel purpose by different mode reveals that travel fields for a walk are circular in shape indicating people walk is any directions as per their requirements and in some cases majority of people walk to access to public transport wherein the fields are elliptical. Travel probability field by bus (Figure 3) indicate that these fields of slum dwellers are elliptical in nature indicating that these are directed along the bus route. Travel Probability Field for intermediate Paratransit (IPT) indicates that these are either parallel to public transport or act as a feeder (Figure 3). It is observed that on average Travel Probability Fields described in terms of the range of search areas are highest for the bus (8.7 to 84.66 sq. km.), moderate for IPT (2.24-22.77 sq.km) and less for a walk (0.16 to 3.48 sq.km) respectively.



Slum no.	Calculated Trip Length (km.)	Observed Trip Length (km.)	Search Area (Sq. km.)	Avg. Travel Time (Mint.)
1	0.97	1.91	1.8	11.03
2	1.22	1.44	6.40	10.06
3	1.23	1.43	3.40	9.14
4	1.46	2.03	2.60	12.23
5	1.60	3.03	6.50	11.08
6	1.11	1.48	3.8	7.93
7	3.26	4.08	15.3	14.64
8	5.15	5.69	22.70	21.79
Weighted Avg.	2.66	3.30	11.28	13.55

Figure 2 Travel Probability Fields for all purpose by all modes

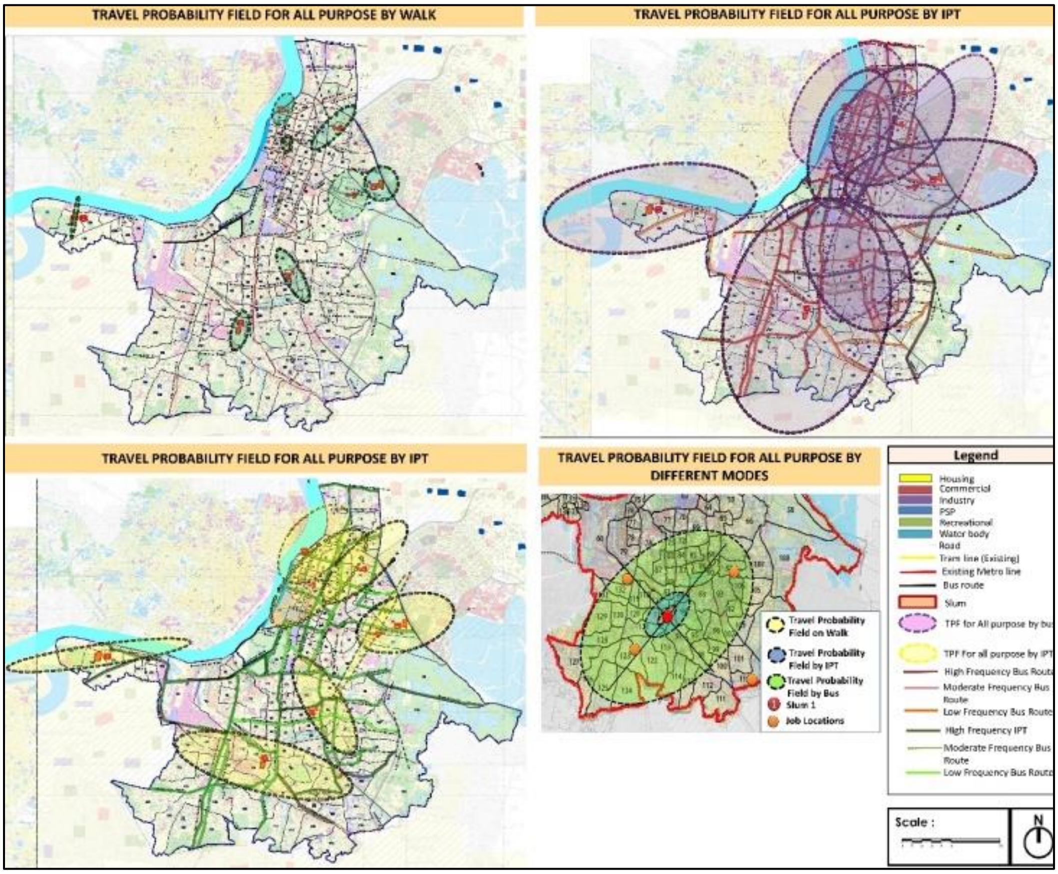


Figure 3 Travel Probability Fields by different Modes

Travel Probability field for work is computed (Figure 4) and from the overlap area of various search fields, the major employment opportunity centers are identified. Also, the TPFs for education trips was calculated and it is observed that Travel Probability Fields of education trips is smaller than Travel Probability Trips for work trips indicating that school facilities are located at much closer distances compared to work centers.

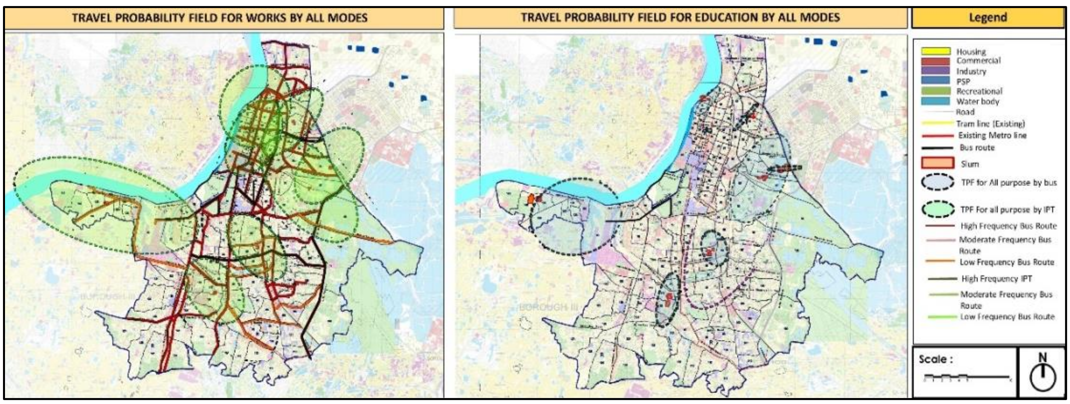


Figure 4 Travel Probability Fields by a different purpose

7. Impact of Background Variables on Travel Probability Fields

The eight case-study areas are categorized with respect to the location of the city as core, middle and outer zone respectively. The slum 1 and 3 are located in the core, slums 2, 4, 5 and 6 in the middle zone and slums 7 and 8 in the outskirts respectively. From Figure 5 it is evident that the search area at outskirts slums is higher compared to inner zone slums. However, in some areas due to poor public transport facility prevailing the slum dwellers limits their travel search field as observed in slum 4 to optimize their travel expenditures. It is also observed that with the increase in travel search fields the average travel time to increases.

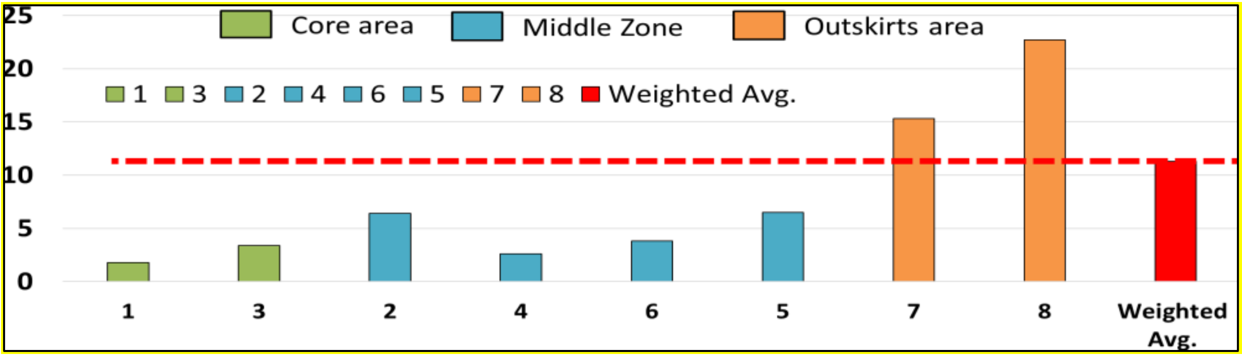


Figure 5 Relationship between Travel Probability Fields and Location of Slums

It is also observed that Travel Probability Field for work increases in slums with poor public transport accessibility as slum dwellers have to depend on walking being the only alternative cheap mode available to the bus for commuting (Figure 6). Poor worker's mobility patterns depend on both accessibilities to the employment opportunity and transport accessibility. It is observed that areas where access to employment opportunity is high the travel search field is lower since job satisfaction is achieved at a much lower distance. In cases where accessibility to employment opportunity is lower but public transport accessibility is moderate to good the slum dwellers are able to travel for longer distance resulting in high search fields. Finally, in cases where both accessibilities to employment opportunity as well as public transport accessibility are lower than either people limit their search field (slum 6 and 7) or resorting to higher search fields, which is more out of compulsion than choice resulting in high transport costs.

PT Accessibility Index	Accessibility to Employment Opportunity Index	Search Area for work	Slum No
Good	Good	Low	1 &3
Good	Moderate	High	2
Moderate	Moderate	Moderate	4 & 5
Poor	Poor	Low	6 &7
Poor	Poor	High	8

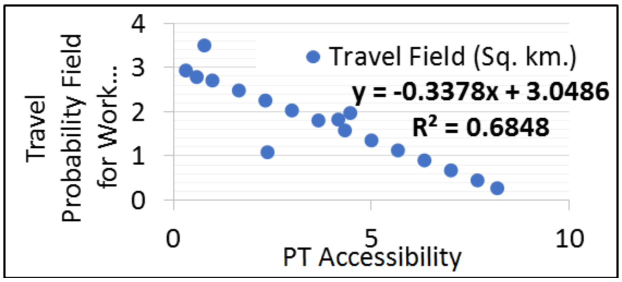


Figure 6 Impact of Accessibility

8. Conclusions

Since 1970's extensive research on travel, the behavior has resulted in several new concepts and tools, but most of them are data intensive and complex in nature. Thus, availability of lack of narratives makes it difficult to analyze the travel pattern within time and cost constraint in the context of developing country and also there is very limited research in the context of hindrance caused in the social inclusion of urban poor due to transportation disadvantages. This research on Travel Probability Field is an attempt to have a better understanding of the travel behavior of urban poor in order to improve transportation planning techniques in a city of developing country like India. It is concluded that travel probability fields is a useful scientific concept in the understanding travel behavior of households in relation to their location and the opportunities available with comparatively small sample size. In particular, the calculated average trip length from travel probability fields is almost identical to the observed trip length from household survey data. The findings from the present research provides a useful insight into the relationships between travel behavior of households and the travel search fields which aids in evolving appropriate policy inputs for deciding the transport supply provisioning as well as operational service of various hired modes around slum dwellers location. It also provide insights into the likely demand on various transport services as well as informed policy decisions on deciding the fare levels and subsidy, if necessary to enable an inclusive mobility environment to slum dwellers.

Some of the potential application of this research can be in the following areas:

i. Travel Behavior Research: As discussed, these fields can serve as a useful tool to understand travel behavior. Also, it can help understand the household location process useful in urban planning.
ii. Transport systems planning: The travel probability fields can help in identification of need-based transport systems by identifying the disadvantaged group with low search areas. It can also evaluate the sensitivity of travel patterns to transport system policies of subsidization, the introduction of new modes, etc.
iii. Urban Structure Planning: The impact of variables of urban form observed on travel fields can help understand the existing and potential direction of development. Since it captures information beyond that captured by aggregate non-spatial characteristics, it can help in a detailed evaluation of urban form and can also evaluate the inequalities in the location of opportunities. Further, this research might indicate ways by which transportation requirements could be minimized in the redevelopment of older urban complexes, as well as in the planning for new areas.

In order to exploit the true potential of the concept of travel probability fields, there is a need to carry out more empirical studies in other cities of India to assess the relationships analyzed in the present study across different geographical settings and check transferability of various parameters across space.

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