Development of Accessibility Standards by Using Fuzzy Set Theory in Context of Journey to Work in Delhi Urban Area, India

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ABSTRACT: Commuting is a major part of urban life. If the journey time or length or cost exceeds the perceived expectation, then suffering gets magnified. An attempt has been made to develop a methodology for measuring the perception of accessibility for journey to work place using Fuzzy measures leading to the development of accessibility standards. The weights are assigned and are operated on the sample data. An attempt has been made to develop a membership function. From the perceived values, the rating matrices, aggregate matrices and dominance matrices have been formed. Finally, the accessibility standards for various modes, in an urban system, have been presented.

1 INTRODUCTION

The largest cities of India are increasingly confronted with the problem of poor accessibility. Often it assumes the dimension of a serious and complex issue to be addressed for improving the quality of life of existing residence and for locating new residential neighbourhood. As long as this issue remains unaddressed, citizens suffer in terms of one or more of the following conditions; relative isolation from the rest of the city, spending disproportionately high amount of energy, time and money in order to participate in the diverse urban activities.

Delhi, capital city of India, having experienced phenomenal growth and physical expansion during second half of the 20th century, appears to be no exception. Different types of residential areas such as plotted houses, government employees, squatters, corporate housing apartments, and resettlement colonies have been developed in different parts of the city. Beginning from mid 1980's, subcities have been planned and developed farther and farther away from the central areas of Delhi. As a result, the commuting times to work access to shopping and recreational areas and trip length for educational purposes continue to increase.

As a part of a research work, perceptions of accessibility by various income groups have been studied for commuting to places of work. In this paper, an attempt has been made to develop a mathematical framework for measuring the perception of accessibility by predominant modes by various interest groups of people using fuzzy measures.

2 CONCEPT OF FUZZY SETS

As its name implies, the theory of fuzzy sets (Zadeh, 1965) is, basically a theory of graded concepts - a theory in which every thing is a matter of degree or, to put it figuratively, every thing has a elasticity. During the last 20 years, the fuzzy sets are increasingly being used in a variety of ways in many applications. Most of our traditional tools for formal modeling, reasoning, and computing are crisp, deterministic and precise rather than more or less type. But real situations are not often crisp and deterministic and these can not be described precisely. According to Zadeh, as the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (relevance) become almost of mutually exclusive characteristics. Fuzzy set theory deals with imprecision relating to vagueness.

Fuzzy set theory provides a strict mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied. It can also be considered as modelling language well suited for studies in which Fuzzy relations, criteria, and phenomena exist. For example, change in weather conditions can be demonstrated by using fuzzy measures. A Fuzzy set representing the concept of cloudy weather may assign a degree of membership value of nearly zero as compared to sunny weather to nearly one. Depending on degree of cloudiness, the membership value may change from nearly zero to 0.2, 0.4, values indicating lesser degree of cloudiness. These grades signify the degree to which each percentage of cloud cover approximates subjective concept of sunny and the set itself models the semantic flexibility inherent in such common linguistic term.

3 METHODOLOGY FOR MEASURING ATTITUDES, PERCEPTIONS AND PREFERENCES

It is imperative to study these linguistic variables that would form the basis of analysis of fuzzy set theory. The study of attitudes by different sections of household groups reveals their perceptions and preferences of travel. The measurement of perception and preferences by different sections of household groups has been noted with their responses indicated by degree of satisfaction in terms of extremely satisfied, very satisfied, satisfied, acceptable and unsatisfied and unacceptable. These degree of satisfaction are given numerical values such as 1, 0.8, 0.6, 0.4, 0.2 and 0 representing extremely satisfied, very satisfied, satisfied, acceptable and unsatisfied and unacceptable condition of travel respectively. An ease of reaching to a destination can be viewed only when any respondents experience an acceptable satisfaction limit in terms of travel time, travel distance and travel cost with minimum membership grade value of 0.4. A brief description of the methodology to conduct this research using fuzzy set theory is as follows:

1. Specifying the major alternatives (modes of travel) for which accessibility standards are to be worked out. Examples: Bus, Bicycle, Car, Scooter, Chartered Bus etc.
2. Identification of the main travels attributes /factors of the alternatives such as travel time, travel cost, travel distance...
3. (a) Grouping of respondents in terms of their income for which the data had been collected.

   Example:

Income Group	*Ranges of income per month in Rupees*
1	*Up to 5000*
2	*5000 - 10000*
3	*10000 - 20000*
4	*20000 - 40000*
5	*Above 40000*

   (b) Responses were collected for objective type (i.e.25 minutes travel time, 5 Rupees fare/travel cost, etc)) data and subjective type (Satisfied, Acceptable, etc) judgement.
4. Conversion of subjective responses (Extremely satisfied, Very satisfied, Satisfied, Acceptable, Unsatisfied) into numerical (graded) values (like 1,0.8,0.6,0.4 and 0.2 respectively.
   For example: "Extremely satisfied ⇒ 1.0, Very satisfied ⇒ 0.8
5. Preparation of data set for different modes of travel in relation to travel attributes.
6. Identification and selection of the ranges of each travel attributes based on maximum occurrence of the type of graded value in that ranges of travel attributes.
   For example: If number of occurrence of responses with graded value of 0.8 in the travel time ranges of 10 - 20 minutes is observed to be maximum as compared to other numbers of occurrence in remaining of travel time ranges such as 20 to 30, 30 to 40 ...etc, this graded value of 0.8 is to be selected representing the most favorable situations expressed by majority of respondents. The 10 to 20-minute range is considered as 20 minute. For further steps we will follow the same approach.
7. From step 6, the values may be used to develop the ordered pair (i.e., (20, 0.8)). Similarly a number of ordered pairs can be developed that will help in developing membership function
8. Development of membership function using the above ordered pair of data leading to a mathematical form for travel time, travel cost and travel distance.
9. The travel attributes such as travel distance and travel cost are to be related with corresponding travel time values from the data file so that corresponding graded values for different ranges of travel can be obtained.
   For example for the range of travel time say 30 to 40 minutes, the degree of satisfaction to travel distance to the corresponding travel time for bus of Rupees 5000 to 10000 household income group is to be found from the data file. The maximum occurrence of responses for a particular degree of satisfaction (say acceptable), within the specified travel time is to be selected as appropriate membership graded value. Similarly these steps are to be followed for travel cost.
10. All the above estimated graded values under the different travel attributes are to be placed in a matrix form as shown below:
    For travel time range of 30 to 40 minutes with respect to household Income group of Rupees 10000 to 20000.

	Bus	*CBus*	*Sc*	*Car*
Travel time	*0.8*	*0.8*	*0.2*	*0.5*
Travel cost	*0.8*	*0.8*	*0.5*	*0.3*
Travel Distance	*0.7*	*0.8*	*0.5*	*0.4*

Cbus and Sc represent Chartered Bus and Scooter respectively.

11 Construction of number of Rating Matrices for different ranges of travel times for different income groups of respondents.
Say we have n number of Rating Matrices for n groups

12 Then the Dominance Matrix is to be prepared. *Hence we have n number of dominance matrix for n number of Household Income groups.*

13 From the above steps the hierarchy of preferences of mode for different ranges of travel time that indicate the ease of reaching to a destination can be determined.

14 The steps of 14 and 15 can be done in an alternative way also, i.e. by making one aggregate matrix combining all the n number of income groups. Using the various arithmetic operations on fuzzy set, various aggregates Rating Matrices can be determined. In this study Optimistic / Pessimistic aggregation technique has been applied to develop the aggregate rating matrix.

15 Then for optimistic aggregate matrix we get one dominance matrix and for pessimistic aggregate matrix, another dominance matrix will be generated.

4 MATHEMATICAL FRAMEWORK

4.1 *Conceptualization*

For development of mathematical framework for application of fuzzy set measure, initially income groups with respect to their usage of predominant mode were identified and selected for further analysis. Travel characteristics for different income groups of respondents were also analysed with respect to various travel attributes i.e. travel time, distance, cost, etc. As described in the previous section, responses, viz. extremely satisfied (ES), very satisfied (VS), satisfied (S), acceptable (A), unsatisfied (US) and unacceptable (UA) have been considered and the grades have been assigned for these responses according to the level of satisfaction of commuting. Travel attributes are also grouped in different ranges. For example, if travel time is taken as an attribute, then the travel time between 0 minute and 10 minutes, 10 minutes and 20 minutes, etc. have been considered different ranges of travel time against which the responses of commuting ranging from extremely satisfied to unacceptable have been observed. We can assume α_1, α_2, α_3, α_4, α_5 are the level of satisfaction regarded as responses for commuting. Similarly the travel attribute range can be written as x_1, x_2, x_3, $x_4 \ldots x_n$. In most of the decision making process, views of the majority in terms of maximum responses in favor of particular attribute in a given environment play an significant role. When the decision making tends to be uncertain leading to fuzzy situation, appropriate fuzzy membership value for the maximum responses of the majority respondents may be considered to represent in the set.

In order to analyse the relationship between the responses and travel attributes, the highest number of responses from all different types of satisfaction levels are considered to be appropriate value of the travel attribute for a particular range of travel. If $\alpha_4 > \alpha_1$, α_2, α_3 and α_5 then responses assigned as unsatisfied will be considered for a particular range of travel attribute (say x_4). Further the last values of the range arising out of x_1 and x_2 or x_2 and x_3 etc. have been considered and regarded as β_1, β_2, β_3 etc. This set of co-ordinates forms a pair and are defined as (β_1, α_1), (β_2, α_2), (β_3, α_3)….. etc.The above set of ordered pairs are represented in Cartesian co-ordinates. Now we are required to find the locus of those points. The locus of these pair elements would form the basis of membership function. The function can be generated such that the values assigned to the elements of the universal set fall within a specified range and indicate the membership grade of these elements in the set. Larger values denote higher degrees of set membership. Such function is called a membership function and the set defined by it is a fuzzy set. This forms the part of generating the fuzzy set data for further analysis.

Various standard methods of curve fitting for the membership function were tried to find the best fit.

4.2 *An Approach to Analysis*

In order to develop accessibility standards for journey to work, the following steps have been considered

4.3 *Development of Membership Function*

The development of membership function has been made after synthesizing the data collected as a part of primary survey according to household income group and travel attributes and mode of travel. Now the points are plotted on X axis as travel time in minutes and on Y axis as membership values with ES (1.0), VS (0.8), S (0.6), A (0.4), US (0.2), UA (0) and final value of ordered pair in (X, Y) co-ordinate points is presented in fig.1.

It was observed during survey / interview of commuters in Delhi Urban Area (DUA) that membership values of "1" and "0" are rarely encountered with any of the travel time ranges as the journey is being performed in peak hour. As negligible amount of data was available relating to the feeling of extremely satisfied. Therefore it was decided that membership function should be constituted with the membership values ranging between 0 and 0.8 for different travel time ranges to represent the actual feeling of the DUA commuters. This kind of fuzzy function developed is known as subnormal fuzzy set (**Klir G.J. and Yuan B.**, 2000) where maximum membership value is considered less than 1 or say,

$h(A) < 1$.

Where the **height**, h(A), of a fuzzy set A is the largest membership grade obtained by any element in that set.

The above membership function can be presented in the fuzzy mathematical form also as shown below:

Car (Income group Rupees 20000 to 40000):

$$\mu_A(t) = \begin{cases} 0.8 \text{ when } 0 < x < 10 \\ y = -0.0116x + 0.9322 \text{ when } 10 < t < 50 \\ 0.2 \text{ when } 50 < x < 70 \\ -0.02x + 1.6 \text{ when } 70 < x < 80 \\ 0 \text{ when } x = 80 \end{cases}$$

4.4 *Development of Rating Matrix*

When a group evaluates the set of alternatives (J_1, $J_2, \ldots J_5$) against the attributes (I_1, $I_2, \ldots I_5$), a Rating matrix with alternatives along one axis and factors on the other axis can be constructed. The rating matrices were originally developed by **Znotinas and Hipel** (1979) as mentioned by **Deb** (1985).A cell in the rating matrix represent the value of a factor for the particular alternative. Each cell in the matrix represents an element of the fuzzy set while each column indicates a fuzzy set. Thus the entries in a column represent the degree to which the alternative satisfies the given factors. Each element of above matrix is expressed as r_{ij}, where i represent the travel attributes and j represents travel alternatives. An example of Rating Matrix is presented in the table.1

Table 1 Rating Matrix for Travel Distance of 8 to 10 Km
(Income Rupees 10000 - 20000)

	VARIOUS TYPES OF MODES			
ATTRIBUTES	BUS	CBUS	SC	CAR
Travel Time	0.6	0.7	0.6	0.6
Travel Cost	0.7	0.6	0.7	0.5
Travel Distance	0.6	0.7	0.6	0.6

4.5 *Aggregation of the Rating Matrices*

The different rating matrices can be combined by different aggregation methods. Pessimistic and Optimistic Aggregation Methods have been used in this study. For purpose of development of accessibility standards, these two techniques were used.

Construction of Dominance Matrix:

Following steps may be followed to construct Dominance matrix.

(1) The number of alternatives in the Rating matrix determines the dimension of square Dominance matrix; hence both **row** and **column** are **alternatives**.

$$\begin{matrix} d_{11} & d_{12} & \ldots & d_{1n} \\ d_{21} & d_{22} & \ldots & d_{2n} \\ \ldots & & & \\ d_{(n-1)1} & d_{(n-1)2} & \ldots & d_{(n-1)n} \\ d_{n1} & d_{n2} & \ldots & d_{nn} \end{matrix}$$

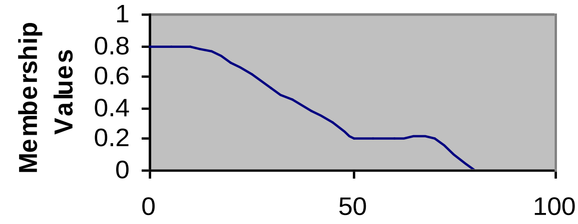

Fig.1 Membership Function of Travel Time by Car for HH Income Rs.20000-40000, WORK

(2) An element d_{ij} in the Dominance matrix depicts that the number of times the membership values of the different attributes for alternative say (J_i) is greater than that of alternative (J_j).

(3) The element of Dominance matrix which exists in the diagonal are recorded as dashes (' - '). The row and column in the diagonal matrix belong to same alternative. Hence the question of comparison does not arise.

For example, the alternatives considered here are various modes of transport. It would be worthwhile to demonstrate an example how a dominance matrix is developed. After having developed the rating matrix for travel distance of 8 to 10 kilometers for households' income group of Rupees 20000 - 40000 as presented in Table 1, an attempt has further been made to develop dominance matrix as explained below:

Each element in a row is compared with each other i.e. r_{i1}, r_{i2}, $r_{i3}, \ldots$etc (where i=1,2,…m) are compared and is established as being >, or =, or < than the other. The dominance matrix is found as a square matrix making both row and column as alternatives. Row elements of first column is compared with that of row elements of the second column and if r_{i1} >, or = ,or < r_{i2} (where i=1,2 …. m) then 1.0 ,or 0.5, or 0.0 would be considered respectively and sum of these forms the element of dominance matrix i.e. d_{12}. For example considering the rating matrix (table 1) and comparing all the rows of Bus (Column 1) with the corresponding rows of Chartered Bus (Column2), this can be found as follows,

$r_{11} < r_{12}$ then value score is 0.0,
$r_{21} > r_{22}$ then value score is 1.0,
$r_{31} < r_{32}$ then value score is 0.0

Now adding up 0.0+1.0+0.0 = 1.0, Hence the value of element d_{12} is 1.0 i.e. Bus dominates Charter Bus and scores only 1.0.

Similarly comparing all the rows of Chartered Bus (Column2) with the corresponding rows of Bus(Column 1), this can be found as follows,

$r_{12} > r_{11}$ then value score is 1.0,
$r_{22} < r_{21}$ then value score is 0.0,
$r_{32} > r_{31}$ then value score is 1.0

The value of element d_{21} i.e. Chartered Bus dominates Bus and scores (1.0+0.0+1.0) = 2. The other elements of dominance matrix are computed following the same procedure. Now adding rows, the dominance of one alternative over other is found, e.g. for Bus, the dominance ratio is (d_{11} +d_{12} +d_{13}+= 1.0 +1.5+2=4.5). Similarly the dominance for the chartered bus, two-wheeler and car are calculated as 7.0, 4.5 and 2 respectively. Thus the dominance ratio obtained is Bus : Charted Bus : Scooter : Car :: 4.5: 7.0: 4.5: 2.0 The dominance matrix is given below:

	Bus	CBus	Sc	Car	
Bus	---	1.0	1.5	2.0	4.5
CBus	2.0	---	2.0	3.0	7.0
Sc	1.5	1.0	---	2.0	4.5.
Car	1.0	0.0	1.0	---	2.0
	4.5	2.0	4.5	7	18

From the above table it can be observed that sum of rows and sum of columns are equal i.e. 18

5 DATA INPUT

A questionnaire was designed to collect information relating to socio-economic and travel characteristics of different income groups with special emphasis of degree of satisfaction (DOS) of travel by different modes of transport. Primary data of about 380 random sample size from the different income groups was collected by personal interview method in Delhi Urban Area. Data were coded and fed in the computer for further analysis.

6 DEVELOPMENTS OF ACCESSIBILITY NORMS

The detailed analysis as explained earlier has further been carried forward to work out the maximum and minimum ranges of accessibility to work for travel by various modes of transport irrespective of household income groups by using pessimistic and optimistic aggregation. According to this technique, the different rating matrices can be combined together by different aggregation methods. Pessimistic and Optimistic Aggregation have been used in this study. The mathematical operation of this method has been demonstrated. Pessimistic Approach is regarded as a cautious approach in decision making. It attempts to minimize the risk involved when attempting to find minimum risk. The risk may be defined to be as a value that may cross the limit of acceptability or affordability of a system in some difficult situations. On the other hand, Optimistic aggregation is an acceptance towards maximum value considering an element of maximum risk. The accessibility standards are, therefore, worked out in view of considering minimum risk and maximum risk. The accessibility values as presented for each mode for different types of activities are therefore indicated with maximum and minimum. These could also be assumed to be synonymous with road geometric standards like ruling gradient and limiting gradient for design of vertical curve. These two values of accessibility should be selected based on planner's perception of the accessibility problem of the city.

Tables 2 and 3 present the final results of perceptions and preferences to accessibility for travel by various modes of transport. It can be seen from the tables that the accessibility range for work by charted bus as well as by ordinary bus is highest in regard to the mass transport facilities. The accessibility standard by chartered bus in terms of distance ranges from 18 km to 20 km is even higher than that of ordinary bus primarily due to its higher speed and limited stops within the same range of travel time. The lowest range accessibility for work is offered by cycle up to a range of 5 km of travel distance and 30 minutes of travel time. The acceptable range of travel for work by car varies from 40 minutes (12 Km) to 50 minutes (18 km). Table 4 presents the maximum and minimum range of accessibility based on the analysis optimistic and pessimistic aggregation technique.

7 CONCLUSIONS

This research study was primarily concerned with the application of fuzzy set theory in developing accessibility norms for predominant modes of transport. As the response to same type of travel varies to a great extent from individual to individual and seems to include a great deal of imprecision, the application of fuzzy measures is considered to be appropriate in appreciating this kind of response of travel for different income groups of households. A detailed procedure for application of this theory has been demonstrated step by step including the development of rating matrix and dominance matrix. An attempt has also been made to develop membership functions exhibiting the relationship between membership values and other attributes of travel such as travel time and travel distance. The accessibility standards developed have been tested and validated by conducting the primary survey again after the accessibility results were obtained. Finally, accessibility norms for predominant modes of transport for different income groups of commuters can be used for planning of residential areas in Delhi urban area.

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Table 2. Perception and Preference of Predominant Mode up to an acceptable and Maximum Travel time for Various Households Income Groups-Work

		Range of Travel Time in Minutes									
Income Group Rupees	Rank	Up to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90	Above 90
Up to 5000	I	**Cycle**	**Cycle**	**Cycle**	**Bus**	**Bus**	Bus	Bus	Bus	Bus	Bus
	II	**Bus**	**Bus**	**Bus**	**Cycle**	Cycle	Cycle	Cycle			
5001 to 10000	I	**Cycle**	**Sc**	**Bus**	**Bus**	**Bus**	**Bus**	Bus	Bus	Bus	Bus
	II	**Sc**	**Cycle**	**Sc**	Cycle	Sc	Sc				
	III	**Bus**	**Bus**	**Cycle**	**Sc**	Cycle	Cycle				
10001 to 20000	I	**Car/Sc**	**Sc**	**CB**	**CB**	**CB**	**CB**	CB	CB	CB	CB
	II	**Bus** **CB**	**Car**	**Bus** **Sc**	**Bus**	**Bus**	Bus	Bus	Bus	Bus	Bus
	III		**Bus** **CB**	**Car**	**Sc**	**Sc**	Sc	Sc			
	IV				**Car**	Car	Car				
20001 to 40000	I	**Car/Sc**	**Car/Sc**	**CB** **Car**	**CB**	**CB**	**CB**	CB	CB		
	II	**Bus/CB**	**Bus/CB**	**Sc** **Bus**	**Sc**	**Bus**	Bus	Bus	Bus Car		
	III				**Car** **Bus**	Car Sc	Car Sc	Car Sc	Sc		
Above 40000	I	**CB** **Car**	**CB** **Car**	**CB** **Car**	**CB**	**CB**	**CB**	CB	CB		
	II	**Sc**	**Sc**	**Sc**	**Car**	**Car**	Car	Car			
	III				Sc	Sc	Sc				

Note: Modes of travel shown continuously in bold up to certain travel time indicate the perceptions of accessibility up to which travel time is acceptable for journey to work and beyond which commuters travel with difficulty.

Table 3 Perception and Preference of Predominant Mode up to an acceptable and Maximum Travel Distance for Various Households Income Groups-Work

Range of Travel Distance in Kilometers											
Income Group Rupees	Rank	Up to 2	2 to 4	4 to 5	5 to 6	6 to 8	8 to 10	10 to 12	12 to 15	15 to 20	20 to 25
Up to 5000	I	**Cycle**	**Cycle**	**Cycle**	**Cycle**	**Bus**	**Bus**	**Bus**	Bus	Bus	Bus
	II	**Bus**	**Bus**	**Bus**	**Bus**	**Cycle** (7)	Cycle	Cycle			
5001 to 10000	I	**Cycle**	**Sc**	**Sc**	**Sc**	**Sc**	**Bus**	**Bus**	**Bus** (14)	Bus	Bus
	II	**Sc**	**Cycle**	**Bus** **Cycle**	**Bus**	Bus	Sc	**Sc**	Sc	Sc	
	III	**Bus**	**Bus**		Cycle	Cycle	Cycle	Cycle			
10001 to 20000	I	**Car/Sc**	**Sc**	**SC**	**Sc**	**CB**	**CB**	**CB**	**CB**	**CB**	CB
	II	**Bus**	**Car**	**CB**	**CB**	**Bus**	**Bus**	**Bus**	**Bus**	Bus Sc Car	Bus
	III	**CB**		**Car**	**Car**	**Sc**	**Sc**	**Sc**	**Sc**		
	IV		**CB** **Bus**	**Bus**	**Bus**	**Car**	**Car**	**Car**	Car		
20001 to 40000	I	**Car/Sc**	**Car/Sc**	**CB** **Car**	**CB**	**CB**	**CB**	**CB**	**CB**	**CB**(18)	CB
	II	**Bus/CB**	**Bus/CB**	**Sc** **Bus**	**Sc**	**Bus**	**Bus**	**Bus**	**Bus** **Car**	Bus **Car**(16)	Bus Car
	III				**Car** **Bus**	**Car** Sc	**Car** **Sc**	**Car** **Sc**	**Sc**	Sc	Sc
Above 40000	I	**CB** **Car**	**CB** **Car**	**CB** **Car**	**CB** **Car**	**CB** **Car**	**CB** **Car**	**CB**	**CB**	**CB**(18)	CB
	II	**Sc**	**Sc**	**Sc**	**Sc**	**Sc**	**Sc**	**Car**	**Car**	**Car**(18)	Car
	III							**Sc**	Sc	Sc	

Note: Modes of travel shown continuously in bold up to certain travel distance indicate the perceptions of accessibility up to which travel time is acceptable for journey to work and beyond which commuters travel with difficulty.

Table 4. Maximum and Minimum Acceptable Accessibility Standards for Various Modes of Transport Derived from Pessimistic & Optimistic Aggregation

Type of Activity	Range of Travel	Range of Acceptable Accessibility by Different Modes of Transport									
		Cycle		Scooter		Car		Bus		Chartered Bus	
		Time In Min	Distance In Km.	Time In Min	Distance In Km.	Time In Min	Distance In Km.	Time In Min	Distance In Km.	Time In Min	Distance In Km.
Work	Maxi-mum	40	7	50	15	50	18	60	15	60	20
	Mini-mum	30	5	40	12	40	12	50	12	50	18