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# Application of Fuzzy Logic for Determining Metro Rail Ridership

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**ABSTRACT**
Provision of Public Transportation System is the need of the hour for large metropolitan cities, like Pune. Bus Rapid Transit System has been implemented in Pune City and now Metro Rail is being implemented under various phases as part of the improvement of Public Transportation System. Assessment of Public Transportation Systems before its implementation is necessary to assess its benefits and impacts on travel demands. In this regard, analysis of commuters' behavior especially in preferring mode plays vital role in estimation of trips based on particular mode of public transportation. Commuter's behavior in selection of particular mode of transportation is highly governed by its degree of uncertainty. Analyzing this degree of uncertainty is important and highly complex in its quantification. Fuzzy Logic based Human Perception Model is one the appropriate approaches to quantify commuters' behavior while selecting particular mode of public transportation.
In this research paper, variables have been identified which affect commuters' behavior especially while selecting particular mode of public transportation; and Stated Preference Survey is conducted to develop Fuzzy Logic based Human Perception Model in MATLAB for determining Metro Rail Ridership.
Development of such model is helpful to implementing authorities to analyze commuters' behavior to improve ridership of particular Public Transportation System.
**Keywords**: Fuzzy Logic, Metro Rail Ridership, Commuters' Behavior, Public Transportation System

## I. INTRODUCTION

Mobility demands in Indian cities are increasing at an exponential rate due to rapid population growth coupled with lopsided urbanization phenomena and rising income levels. Exponential increase in mobility demand is met broadly by either personal or public modes of transportation. A significant aspect in the transportation scenario is the availability and requirement of Public Transportation System. It is widely recognized as an effective medium towards the improvement of people's mobility across the rapidly expanding cities and their metropolitan region. It provides access across various parts of cities and their metropolitan region by linking major activities, population and employment centers. It provides mass transportation as a primary or preferred mode of transportation and substitute for the private vehicles, and mobility for those with no other transportation alternative. Public Transportation System in any city makes it easier for common people to travel from one place to another at a faster speed and cheaper cost. The various Public Transportation Systems, like Bus Rapid Transit System (BRTS), Mass Rapid Transit System (MRTS), Mono Rail, etc. are developed depending upon the population, passengers per hour per direction in peak hour, geographical constraints and the involved cost. Pune, the eighth largest city in India and the sixth largest metropolitan economy; has followed similar trend in terms of transportation. Growth and economic supremacy has brought with it an unprecedented stress on the city's Public Transportation System. This has resulted into disproportionate rise in the use of private vehicles. Heterogeneous traffic conditions with limited road capacities and the absence of a ring road despite radial expansion of the city have further aggravated traffic problems faced by it. One of the biggest challenges the city facing is the ability to keep up with the growing transportation needs of the city. To overcome the challenge, BRTS has already been implemented and now Metro Rail is being implemented to strengthen the Public Transportation System of the city.

## II. METRO RAIL IN PUNE CITY

Metro Rail under Phase-I having length of 16.5 km has been proposed from Pimpri to Swargate, and under Phase-II it has been proposed from Vanaz to Ramwadi covering distance of 14.66 km (Pune Metro Rail Project, 2016). Metro Rail under Phase-III will run from the Rajiv Gandhi

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InfoTech Park in Hinjewadi to Civil Court covering distance of 23.33 km. All three proposed Metro Rail lines under various phases will align at the Civil Court Interchange Station. The most likely peak traffic demand on "Pimpri to Swargate corridor has been assessed as 18110PHPDT for 2011 and this is likely to increase to 20035PHPDT by the year 2031" (Delhi Metro Rail Corporation Limited, 2015). Similarly, on Vanaz to Ramwadi corridor, the "optimistic peak traffic demand has been assessed as 10048PHPDT for 2011 and this is likely to increase to 22414PHPDT by the year 2031. However, the most likely PHPDT values for the Vanaz to Ramwadi corridor in 2011 and 2031 are 5817 and 10982 respectively" (Delhi Metro Rail Corporation Limited, 2015). Pimpri to Swargate corridor has been selected for the study since this corridor hosts competitive modes of transportation. There is presence of BRTS, Suburban Trains Service and the proposed Metro Rail corridor in the selected study area. The routes of all these transportation modes are overlapping; thus it becomes imperative to determine mode preferred by commuters for their daily commute. The vision of Metro Rail in Pune is "to create energy efficient Metro Rail System of International Standard which will enhance the quality of life of its citizens and be instrumental in the overall development of the city". With the introduction of Metro Rail in Pune, the envisaged changes in existing conditions are given in following Table No. 1. The Pune Metro forecasts the number of commuters who would actually shift to Metro Rail for daily commute by Mathematical Models; however, misses the variation of commuters' perception in selecting a particular mode. Therefore, it becomes necessary to assess commuters' perception to know the probability of commuters who would shift to Metro Rail by leaving their existing mode of transportation.

## III. ROLE OF COMMUTERS' BEHAVIOR IN SELECTION OF PARTICULAR TRANSPORTATION MODE

Evaluation of Public Transportation System before its implementation is necessary to assess its benefits and impacts on travel demands. In this regard, analysis of commuters' behavior especially in selection of mode plays vital role in estimation of trips based on particular mode of public transportation. Prediction of commuters' behavior in selection of transportation mode has become critical issue for Transportation Planners. Commuters' behavior is dynamic and varies from individual to individual and also shows temporal variations within individualistic behavior. The choice of an individual commuter in arriving at the decision to perform a trip is namely to decide on the route amongst the available alternatives, and to decide on the mode amongst the available modes. This decision is governed by numerous explanatory variables which are given unique weightage by each individual commuter depending on his / her functional, socio-economic profile at that instant. Therefore, the choice is a function of all these explanatory variables. The basic assumption of the choice function is that each individual commuter is attempting to maximize his / her utility from the trip. Therefore, the probability of selection of particular transportation mode depends upon the choice sets available to the individual commuter and the choice set he / she believes has the maximum utility (Seetharaman, et al. 2009). The "selection of transportation mode is not always governed by the objective function and also fuzziness prevails in the mind of commuters" (Kumar, Sarkar and Madhu, 2013) in selecting the particular mode of transportation. Commuter's behavior in selecting particular mode is highly governed by its degree of uncertainty. Analyzing this degree of uncertainty is important and highly complex in its quantification. Fuzzy Logic based Human Perception Model is one of the appropriate approaches to quantify commuters' behavior while selecting particular mode of public transportation. Accordingly, Fuzzy Logic technique has been applied to model the probability of choosing a particular transportation mode by the commuters.

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**Table No. 1: Envisaged Changes in Existing Condition due to Introduction of Metro Rail**

| Sr. No. | Parameters | Existing Condition prior to Introduction of Metro Rail | Condition after Introduction of Metro Rail |
|---|---|---|---|
| 1 | Traffic Congestion | Bumper to Bumper Traffic visible on several roads in peak hours | Commuters will get diverted to Metro reducing the congestion on roads. |
| 3 | Convenience | Not very convenient due to traffic jams, bad roads, traffic signals, etc | Very convenient as the mode is highly comfortable, reliable and timely |
| 4 | Travel Time | Is excessive due to traffic congestions and traffic signals | Will reduce the travel time by around 50% |
| 5 | Travel Cost | Is high due to high fuel consumption & high fuel cost & more running time due to traffic congestion | Will be much less as compared to cost of running individual vehicles |
| 6 | Energy Saving | Uses Fossil fuels and has high energy consumption | Uses around only 1/5th of energy as compared to Road Transportation |

Source: (Delhi Metro Rail Corporation Limited, 2015)

## IV. METHODOLOGY FOLLOWED TO DEVELOP FUZZY LOGIC BASED HUMAN PERCEPTION MODEL

The methodology followed to develop Fuzzy Logic based Human Perception Model has been organized into three stages. The first stage comprises of Variable Identification and Data Collection. Extensive literature review has been carried out to for variable identification, data collection pertaining to them and developing fuzzy logic model. Questionnaire has been prepared for conducting the Stated Preference Survey to understand the perception of commuters towards selection of particular transportation mode. Study area has been determined on the basis of presence of competitive modes of public transportation. Appropriate ranges of the variables have been taken from the Service Level Benchmarks for Urban Transportation given by the Ministry of Urban Development, Government of India. Depending on Expert Opinion and analysis of the Stated Preference Survey, If-then Rules have been prepared. The second stage involved developing Fuzzy Logic Model in MATLAB; where a Fuzzy Inference System has been built up and iterations have been carried out by building various scenarios. In the third stage, the model's output has been used to determine Metro Rail ridership.

### 1.1. Variable Identification and Data Collections pertaining to them

Based on extensive literature review, five variables have been identified which affect the decision making process of individual commuter while selecting particular transportation mode. These identified variables include Waiting Time, In-vehicle Time, Level of Comfort, Travel Cost, and Safety and Security. The research has been limited to four variables only excluding Safety and Security to reduce the combinations for preparation of 'If-then' Rules. The values of the variables have been taken from the 'Service Level Benchmarks for Urban Transportation' given by the Ministry of Urban Development and presented in following Table No. 2. These benchmarks are helpful to Urban Local Bodies and other operating agencies in identifying performance gaps and effecting improvements. Table also presents ranges for the Average Waiting Time for Public Transportation Users, Level of Comfort and Mass Transit Travel Speed along the major corridor. In this, Level of Comfort is defined by the ratio of total number of passengers to the total number of seats available. Level of Service (LOS) is determined by the cumulative weightage of all variables identified, for individual variable, benchmarks for LOS have been determined by the Central Government for the cities in Indian context. LOS - 1 is the best condition which shows Less Waiting Time, more

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1733-1740 www.ijaem.net ISSN: 2395-5252

Level of Comfort and more Mass Transit Travel Speed along major corridors.

**Table No. 2: Service Level Benchmarks for Identified Variables**

| Sr. No. | Level of Service | Average Waiting Time for Public Transportation Commuters (in minutes) | Level of Comfort in Public Transportation (Commuter per seat) | Mass Transit Travel Speed along Major Corridor (KMPH) |
|---|---|---|---|---|
| 1 | 1 | <=4 | <=1.5 | >=20 |
| 2 | 2 | 4-6 | 1.5-2.0 | 15-20 |
| 3 | 3 | 6-10 | 2.0-2.5 | 10-15 |
| 4 | 4 | >10 | >2.5 | <10 |

Source: (Ministry of Urban Development, GoI)

These variables have been classified as fuzzy and classical sets based on collection of secondary data. Collection of secondary data includes Norms and Standards from Comprehensive Mobility Plan for Pune City, 2008, Service Level Benchmarks for Urban Transportation, Detailed Pune Metro Report and other guidelines for deciding the ranges for an attribute. Following Table No. 3 presents Fuzzy Set based secondary data collected from the various sources for identified variables. Further, fare structure of Metro Rail, BRTS Bus, and Sub-urban Train has been studied to determine the range of fare for the input in Fuzzy Set and the same is presented in following Table No. 4. Data collected as such have been used in MATLAB for modeling purpose.

**Table No. 3: Identified Variables and their Respective Fuzzy Sets**

| Sr. No. | Identified Variables | Fuzzy Sets | | |
|---|---|---|---|---|
| 1 | Waiting Time (in minutes) | Less (2-8) | Medium (5-11) | More (8-14) |
| 2 | In-vehicle Time (minutes per km) | Less (1-4) | Medium (2.5-5.5) | More (4-7) |
| 3 | Travel Cost (INR per km) | Cheap (0.2-4.1) | Moderate (2.15-6.05) | High (4.1-8) |
| 4 | Level of Comfort | Low (2-3) | Moderate (1.5-2.5) | High (1-2) |

Source: Extensive Literature Review conducted in 2017-18

**Table No. 4: Fare Structure of Competitive Transportation Modes in Study Area**

| Sr. No. | Metro Rail | | BRTS Bus | | Sub-urban Train | |
|---|---|---|---|---|---|---|
| | Distance in Km | Fare in INR | Distance in Km | Fare in INR | Distance in Km | Fare in INR |
| 1 | 0-2 | 10 | 0-2 | 5 | 0-18 | 5 |
| 2 | 2-4 | 20 | 2-6 | 10 | >18 | 10 |
| 3 | 4-12 | 30 | 6-10 | 15 | | |
| 4 | 12-18 | 40 | 10-14 | 20 | | |
| 5 | >18 | 50 | 14-20 | 25 | | |

Source: Primary Survey conducted in January, 2018

### 1.2. Stated Preference Survey from Prospective Commuters

Stated Preference technique has been used to determine the commuter behavior with respect to proposed Metro Rail system in the study area. This technique is used to determine the commuter preference and willingness to shift to the proposed Metro Rail system. Stated Preference Survey in the form of Questionnaire is taken from commuters. Survey has been conducted at potential areas in both online and offline fashion. Numbers of respondents, appropriate locations for survey, and

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Volume 5, Issue 3 March 2023, pp: 1733-1740 www.ijaem.net ISSN: 2395-5252

peak hours for conducting survey have been decided based on pilot survey conducted in study area. Face to face interviews have been carried out and Google Forms have been shared to fill questionnaire formats. This survey is to model the choice behavior as perceived by commuters along with their willingness to opt for better services. The questionnaire includes the details about the socio-economic background of the commuters, details of existing commuting pattern and the travel characteristics. These questions are such prepared that they help in understanding the background of commuters. The next section of the questionnaire had the Stated Preferences designed for identified variables. These variables are playing major role in attracting the commuters from the existing alternate transportation modes. The survey experiment is designed as a rating cum choice experiment by constructing several options with different attribute levels. Three attribute levels have been considered for each variable and four identified variables and thus gives rise to 81 questions. Orthogonal Design Tool of SPSS software has been used to reduce the complexities and make the questionnaire easier. Use of this tool helped in reducing the number of questions to nine. The respondents are asked to relatively study the options of each variable and select one preferred option from the choice scale. The choice scale includes five options for each question, ranging from definitely existing mode of transport to definitely metro. Results obtained based on Stated Preference Survey are presented in following Table No. 5.

**Table No. 5: Commuters' Response based on Stated Preference Survey**

| Sr. No. | Choice Scale | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 | Option 8 | Option 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 65 | 64 | 50 | 2 | 7 | 4 | 13 | 18 | 2 |
| 2 | 2 | 11 | 30 | 26 | 6 | 5 | 0 | 24 | 17 | 22 |
| 3 | 3 | 15 | 2 | 17 | 22 | 16 | 4 | 17 | 15 | 21 |
| 4 | 4 | 9 | 2 | 7 | 48 | 41 | 17 | 26 | 31 | 42 |
| 5 | 5 | 0 | 2 | 0 | 22 | 31 | 75 | 20 | 19 | 13 |

Source: Stated Preference Survey conducted in January, 2018

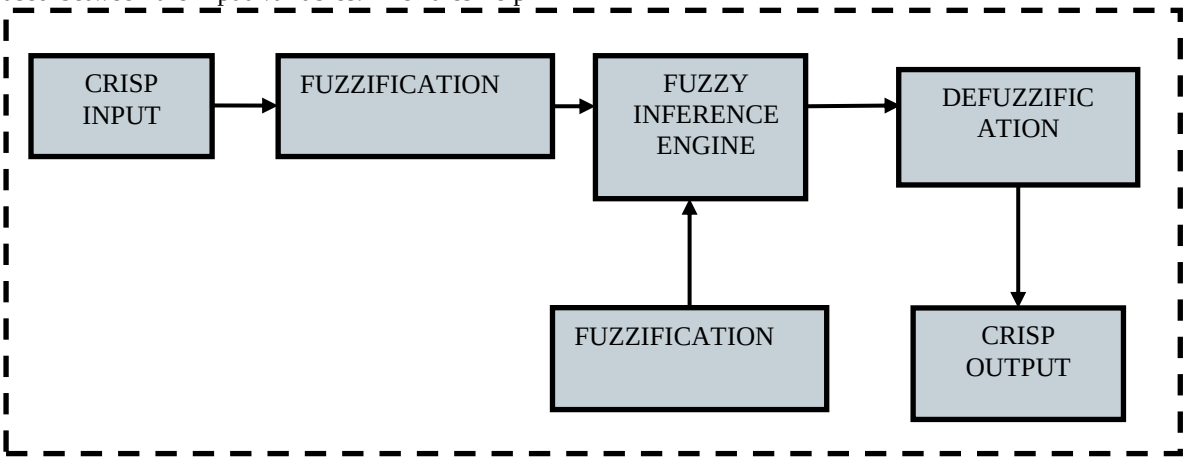
Total eighty-one rules have been prepared and their outputs have been determined based on Stated Preference Survey and Expert Opinion. These rules have been prepared to formulate the conditional statements that specify a relationship between the input and output variables. A single If-then Rule assumes the form "If x is Tx then y is Ty". These rules have been used in model making to consider the commuters' perception and to determine the probability of selection of Metro Rail and its ridership.

### 1.3. Development of Fuzzy Logic based Model in MATLAB

Fuzzy Logic toolbox in MATLAB has been used to model the commuters' perception for determining Metro Rail ridership. The Fuzzy Inference system comprises of majorly three processes, Fuzzufication, Rule Bases and Defuzzification. Components of Fuzzy Inference System in MATLAB are presented in following Figure No. 1. In this system (Kumar, Sarkar and Madhu 2013), input is given as Crisp Values and is processed for Fuzzification as per Membership Function. In Fuzzification Process, every input is being analyzed according to different Membership Functions. After Fuzzification, they are further analyzed on the basis of Fuzzy If-then Rules in inference engine to generate output; however, the generated output is in the linguistic form which cannot be used directly. To make them usable, a process of Defuzzification is used to convert output into Crisp Value. In this research paper, four input variables have been identified and one output variable has been defined. Identified variables include Waiting Time, In-vehicle Time, Level of Comfort, and Travel Cost. The output variable has been defined as Metro Ridership and the Fuzzy Inference System chosen is Mamdani Inference Engine. Identified input variables as presented in Table No. 2 are fed in the form of Crisp Values which go through a process of Fuzzufication. Table No. 3 presents Fuzzy Sets and the Linguistic Variables for the input variables. During Fuzzufication, every input variable has been analyzed and ranges have been made considering appropriate Membership Function. In this stage, the ranges for the inputs have been defined and the variables and the type of the function have been identified. All the variables have been given

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1733-1740 www.ijaem.net ISSN: 2395-5252

triangular type of Membership Function. The output variable, Metro Ridership, has been defined on five linguistic variables; which are, Negligible, Poor, Medium, Good and Best. The third stage of modeling is an integral part where Rule Base for the system is prepared. The Fuzzy Logic systems consist of If-then Rules that specify a relationship between the input and output variables. Fuzzy Logic mechanism deals with these rules to capture the psychology of commuters on identified variables. Later set of combinations of these rules have been fed and loaded in the Fuzzy Inference Engine. The 'And Connection Operator' has been used between the input variables. The rules help in determining ridership by taking consideration of all variables at one instance. The output generated by fuzzy logic technique cannot be used directly. Defuzzification is carried out to convert the fuzzy quantities into crisp quantities for further processing. The input to the Defuzzification process is a fuzzy set, and the output of the Defuzzification process is a single number. In the Defuzzification stage, crisp outputs have been obtained back in the form of Metro Rail ridership i.e., the probability of people who will shift to Metro Rail from the existing modes of transportation.




Source: (Kumar, Sarkar and Madhu 2013)

**Figure No. 1: Components of Fuzzy Inference System developed in MATLAB**

## V. RELATION BETWEEN INDIVIDUAL INPUT VARIABLES AND OUTPUT VARIABLE

Relation of each input variable with the output variable can be determined by surface viewer option. Metro Rail ridership would be maximum when Level of Comfort lies between 1.0 to 1.5 and then it starts decreasing with decrease in Level of Comfort. Metro Rail ridership is observed to be maximum when Waiting Time is lesser than 9 minutes. In case of In-vehicle Time, ridership is maximum when time lies between 1-2.5 minutes per km. With increase in Travel Cost, ridership decreases, it is highest when Travel Cost lies between INR 1-2 per km. Relation between Level of Comfort, Waiting Time, Travel Cost and In Vehicle Time with Metro Rail ridership are presented in following Figure No. 2 to 5 respectively.

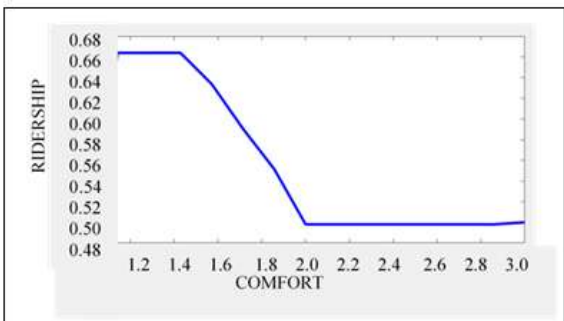



**Figure No. 2: Relation between Level of Comfort and Metro Rail Ridership**

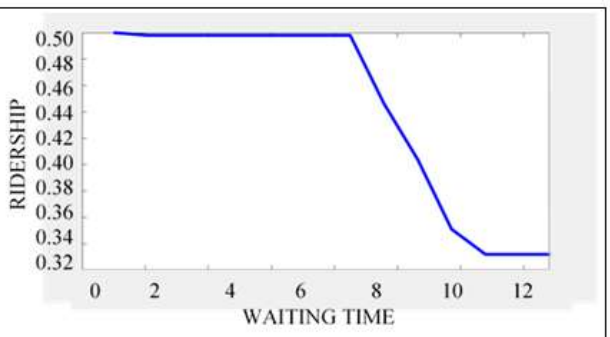



**Figure No. 3: Relation between Waiting Time and Metro Rail Ridership**

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1733-1740 www.ijaem.net ISSN: 2395-5252

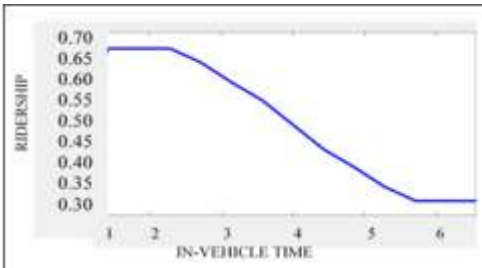



Figure No. 4: Relation between Travel Cost and Metro Rail Ridership

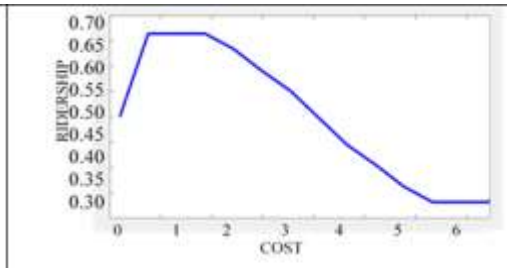



Figure No. 5: Relation between In-vehicle Time and Metro Rail Ridership

Output of the model is that with the existing attributes of Metro Rail, i.e., 5 minutes waiting time, 2 minutes / km In-vehicle Time, Travel Cost of INR 6.5 per km and Comfortable Standing, the probability that commuters will shift to Metro Rail has been found out to be 0.664. For validation of the model, data has been taken from analysis of the questionnaire executed in the primary survey, i.e., responses to the direct question, 'If new service of Metro Rail is provided, would you prefer it for daily commute? (Write Yes or No)', have been analyzed. Around 75 % of the respondents say that they will shift to Metro Rail with the existing condition. The output of the model which is a result of the Stated Preference analysis shows that the probability that people would shift to metro is 0.664. On the basis of comparison of questionnaire output, i.e. 75 % and model output, i.e. 0.644 probability, it can be concluded that model has an accuracy of 81.1 % showing good statistical validity. To achieve 0.75 probability that commuters would shift to Metro Rail various scenarios have been built. The scenarios have been built by changing the values of the identified input variables in the model. Scenarios built for simulation of model are presented in following Table No. 6. It is further observed that Travel Cost holds higher priority by the commuters while selecting particular mode of public transportation. Highest probability of selection of Metro Rail ridership can be obtained by implementing the optimum scenario generated.

**Table No. 6: Scenarios Built for Simulation of Model in MATLAB**

| Sr. No. | Scenario | Waiting Time (minutes) | In-Vehicle Time (minutes / km) | Travel Cost (INR / km) | Level of Comfort |
|---|---|---|---|---|---|
| 1 | 1 | 3.5 | 2 | 3 | 2 |
| 2 | 2 | 3.5 | 1.5 | 5 | 1.5 |
| 3 | 3 | 5 | 4 | 4.3 | 1.2 |
| 4 | 4 | 8.0 | 2.5 | 3.8 | 1.12 |

## VI. CONCLUSION

Evaluation of Public Transportation System before its implementation is necessary to assess its benefits and impacts on travel demands. In this regard, analysis of commuters' behavior especially in selection of mode plays vital role in estimation of trips based on particular mode of public transportation. Commuters' behavior is dynamic and varies from individual to individual and also shows temporal variations within individualistic behavior. Commuter's behavior is highly governed by its degree of uncertainty; and analyzing this is important and highly complex in its prediction. Prediction of commuters' behavior has become critical issue for Transportation Planners as fuzziness prevails in the mind of commuters in selecting mode of transportation. Most of the transportation decisions take place under imprecision, uncertainty and partial truth. The element of uncertainty involved in the transportation planning process can be well addressed using Fuzzy Logic approach to generate more accurate results in comparison with the traditional models. With the help of fuzzy logic, a Human Perception Model can be developed to determine Metro Rail ridership. The model can also helps transportation authorities in studying the behavior of Metro Rail riders and hence improving the ridership. Further, highest probability of selecting Metro Rail can be obtained by implementing the optimum scenario generated.

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