Mode choice for urban work-based daily trips: a multi-criteria decision making model using the Analytical Hierarchical Process

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Abstract

The research work attempts to gain an understanding of the importance of various parameters affecting the mode choice made by urban transport users e.g. time, fare, comfort, reliability and accessibility, etc. The research aims to understand the major influences on user behaviour in an environment where all modes are available for use. In order to find the optimal decision, attempts were made to develop a model using the Analytical Hierarchy Process (AHP). An eight by eight matrix of parameters was developed where the users were asked to rank the pairwise relative importance of the parameters. The users were then classified based on income, age, city, mode used, etc., and the relative importance of each parameter was calculated in order to identify the varying trends between users of different demographic and economic groups.
Keywords: user mode choice, work-based daily trips, Analytical Hierarchical Process.

1 Introduction

Mode choice by the user in an urban scenario is always a function of supply and demand. The supply side is responsible for the level of service provided by developing the transportation system and various routing options for a specific trip. Each of these routing options would have their costs and benefits attached with the mode choice and could be termed as consumer attitude towards a certain option for a certain time. Most of these cost and benefits are the outcome of the investment and policies made by the urban transit service providers. Hence, the costs and benefits have two sides to be analysed as the final mode choice of

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the user. Barff *et al.* [1] define the simplest form of mode choice model as the probability-based sum of deterministic component (perceived utility-based attraction of a mode) and random component.

$$U_i = D_i + \epsilon_i \quad (1)$$

Hence, for mode i to be chosen by a user

$$P_i > P_r(U_i > U_j) for\ all\ i \neq j \quad (2)$$

This can be more generically categorized in two categories – quality and performance of service provided. The quality and performance is measured through service delivery (the operator's perspective on system performance) and service quality (passenger's perspective) [2]. These two sides can be analysed through multiple variables/parameters. Bunker [3] states that reliability is a measure of consistency and dependability, measured on a day-to-day basis on travel time for the same trip. This can be also translated as the reliability in terms of performance during the peak hours, since highest share of a day-to-day daily trip happens during the peak hours.

The providers of the specific mode improve these variables and parameters through various interventions, while the mode choice depends upon the attitude of the user towards these parameters and variables. The following sections would first outline the variables and parameters provided the various urban systems to improve accessibility and quality attached to it, then various parameters, a user analyses before choosing a certain mode and finally how they influence each other. In the end the research work would attempt towards developing a Multi-Criteria Decision Making (MCDM) model to quantitatively analyze the mode choice.

Various modes that are going to be discussed would be – Metro System, Bus Systems, IPT (Intra Para Transits) in Public Systems and Personal Vehicles – Car and Motorized Two Wheelers. The study would consider that all of these modes are available for the intended trip. Additionally, since variance of mode choice for a non-work trip remains high due to varied trip purpose the study would be confined to work-based routine trips only.

2 Urban transit systems modal choice parameters

Various parameters for the choice of mode within an urban transportation system are based on cost (comparative cost structure and affordability), time (analysed through relative delays), Number of Transfers required other than the Primary Mode, accessibility of the mode (distance travelled to access the primary mode), frequency, safety and security, comfort, routinisation [4, 5] and environmental sensitivity [6]. Parameters like time, safety and security, frequency and number of transfers required are basic input for reliability for the system, whereas cost, time, comfort and environmental sensitivity can be factored as affordability, mostly reflected through income levels and place of residence (urban/rural/semi-urban).

Technically, a reliable system is one that performs its required functions under stated conditions for a specified period of time [7]. The only focus of all the operations strategy implied in the area of Transit systems is towards managing the peak hour traffic volume (passenger volume) without any major disruptions. The major goal is to provide travel time reliability and comfort to the commuters, which have a direct relation with the commuter satisfaction [8, 9]. The measure for the same is loss of no. of passengers hours, which can be further quantified in terms of economic loss based on the size of the city's economy [8]. Table 1 identifies the type, measures, classification of reliability used by the urban system managers.

Table 1: Reliability operations vs. passenger [8].

Operation oriented	Passenger oriented
Level of service	Travel Time Index (peak vs. off-peak)
Number of train cancellations	Planning Time Index (total time for travel)
Average punctuality	Buffer Time Index (extra time due to lesser reliability)

The Travel Time Index is the time taken to take the same trip during peak hour and off peak hours. The Planning Time Index is the total time considered by a commuter in order to complete the journey, which includes the actual travel time and waiting time. The Buffer Time Index is the additional time taken into account by the commuter due to non-reliability of the service.

An alternative definition of reliability draws on the attribute of predictability [7]. The UITP (International Association of Public Transport), Metro Division identifies five major operational indicator under its strategy for improving performance and reliability; service regularity, passenger density, service availability, service punctuality and service reliability. They further state that the first three are the ones reflecting better quality perceived by commuters [10]. The UITP core brief further identifies KPI (Key Performance Indicators) to quantify these measures [10].

However, these measurements could only be used for a system which is being managed at an integrated level i.e. either a metro system, a light rail transit system, a bus rapid system or a radio or GPS-based taxi system. For Indian cities such an analysis of mode choice could only be done for a few cities with Metro and Bus Rapid Transit Systems, additionally, modes like taxi and Intra-Para Transit (IPT) could not be analysed and so would be the case for private modes of transportation like cars and two wheelers. Hence, user perspective from a certain socio-economic group for specific trips needs to be analysed to understand the modal choice for daily work-based trips.

2.1 Cost–fare–income

An increase in income has direct impact on the mode choice and cost or fare of daily transportation. As Moses and Williamson [11] argue that an increase in one's income would allow to value the work as well as leisure more than what was valued through previous income, this would put the person or the household at a higher utility curve, thereby compensating the extra-time taken by a public transport system because of accessibility and reliability, the higher utility curve would lead towards use of personalized mode of transportation at higher cost [12]. This has been shown in Figure 1, where with increase in income the person would shift from curve I_1 to I_2 to I_3. Hence, it becomes important to study the importance given on the fare structure or the cost of commute for a certain income group.

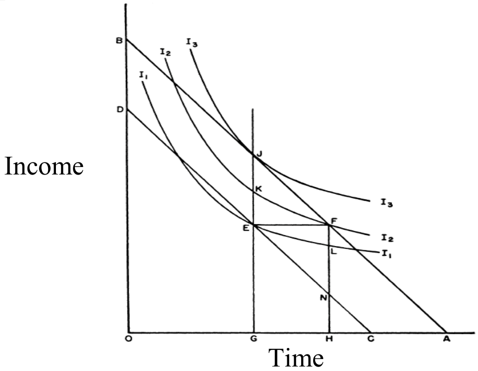

Figure 1: Cost–fare–income affordability [12].

2.2 Time taken/duration

User choice of mode also depends upon the usual daily mean time taken by the mode for that specific time. That is, a person may use a faster mode of public transit during peak hours to avoid the congestion or may value comfort more than cost and use his personalized mode during off peak hours. Naess [13] describes this phenomenon by plotting 'probability of using a car' by against the 'various time ratios of transit is to personalized mode'. According to him when travel time ratio of car is to transit increases from 0.5 to 1.5 the probability of car use reduces from one to 0.1 (refer to figure 2). Hence, time and its comparative importance against other parameters needs to be analysed.

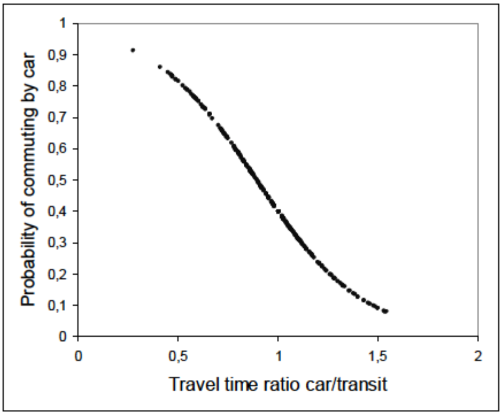

Figure 2: Travel time ratio and user choice – public vs. private mode [13].

2.3 Comfort – level of service

Comfort is mostly defined as level of service provided by a certain mode [10, 14]. However, the user perception of comfort comes in terms of the microenvironment the modes provide, how the user perceives it and how much it is compared alongside time and cost of the mode.

2.4 Affordability

Affordability is a mix outcome of income, time, comfort and fare. Based on the total planner behaviour [15] our mode choices are a mix of reasoned, controlled and planned decision making to optimize our utility [16]. This utility derived or expected from transportation is reflected within the income and consumption trends of the household. In developing countries this becomes an important aspect by being a decision making variable between choosing to travel vis-à-vis housing location choice [17].

2.5 Accessibility (proximity to transport networks)

Accessibility to a certain mode is measured through the distance travelled and the secondary mode used to reach the primary mode boarding point i.e. how a certain user reaches a metro station, a bus stand or a taxi/IPT stand. Though most of the time, a user walks to the primary mode access point, it has been analyzed that the probability of using the system drops to 0.5 after a distance of 200 m [13, 18, 19].

2.6 Routinisation

Aarts *et al*. [4] argue that, a bit of inconvenience or discomfort or even affordability could be sacrificed if the mode choice has become a part of the habit of the user. This comfort seeking behaviour and the non-information seeking approach for a new mode and natural inclination towards use of tried and tested mode for specific purpose influences mode choice. Bamberg *et al.* [16] discuss this habitual tendency as the behaviour to not seek information leading towards a biased analysis, thereby, choosing sub-optimal modes.

2.7 Reliability – user perception

Perceptions of reliability comes through information availability of the service [20]. For a highly reliable transit service peak hour frequency would be between 2 and 10 minutes (headway) and will shift towards an off peak frequency of 20–30 minutes [21]. However, reliability as a parameter is based upon the concept of fare paid is to utility derived in terms of having a mean travel time with minimum variance. Thereby reliability of a system as per the user perception becomes an important part of the decision choice model. Additionally, one of the system-generated parameter influencing reliability is ‘Transfers’. Transfers allow the transit systems to increase its reach, without developing standalone corridors.

However, transfers lead towards increased travel and wait time, which are major disincentive to the commuters [22]. Vuchic [23] and Cervero [18] quantify transfer time to be around 2–4 minutes for highly reliable systems and 4–6 minutes for systems with low reliability. However, Nielson and Lange [20] have coined the term “forget the timetable” as an ideal case when the system is highly reliable and the lowest frequency is between 8 and 10 minutes. Hence, an increase in number of transfers may increase travel time as well as reduce reliability and comfort for the user, therefore it becomes another parameter to be analysed.

2.8 Safety and security

Safety and security can be considered as our normative expectation of other and the trust in the cooperative behaviour of others [24]. Safety and security define our comfort with a certain mode. However, some amount of safety and security functions alongside what time of the day the trip is made and how much of it could be sacrificed against affordability factors.

2.9 Environmental sensitivity

Though not extensively researched, the mode choice due to environmental sensitivity is a new phenomenon. However, based on the common dilemma, leading to a feeling of social responsibility [24], there could be sensitivity in terms of environment. Anable [24] categorises these people as ‘aspiring environmentalists’. Hyard [6] discusses the same within the ambit of developing systems as sustainable.

3 The construct

The model and the construct have been shown in figure 3. The model argues that daily work-based trips are dependent upon cost/fare, comfort, duration, affordability, safety, security and routine. These would be a reflection of socio-economic and demographic characteristics e.g. income, age, etc. [25, 26]. Hence, classifying the respondents on the basis of socio-economic and demographic characteristics would allow us to identify the various eigenvector values of each of the travel behavior parameters.

4 Methodology for data collection and analysis

For the data collection the survey questionnaire was developed using the research work of Kengpol *et al.* [27]. Their scale of relative comparison between two conflicting variables at a time (Pairwise Comparison Criteria) nine point scale has been used to find the significant weight of each criterion [27–30]. Additionally, a few more questions have been asked to focus on the various target groups and their routes. For analysis, the AHP model was used [31]. The AHP would provide the weights for the various variables [27, 28].

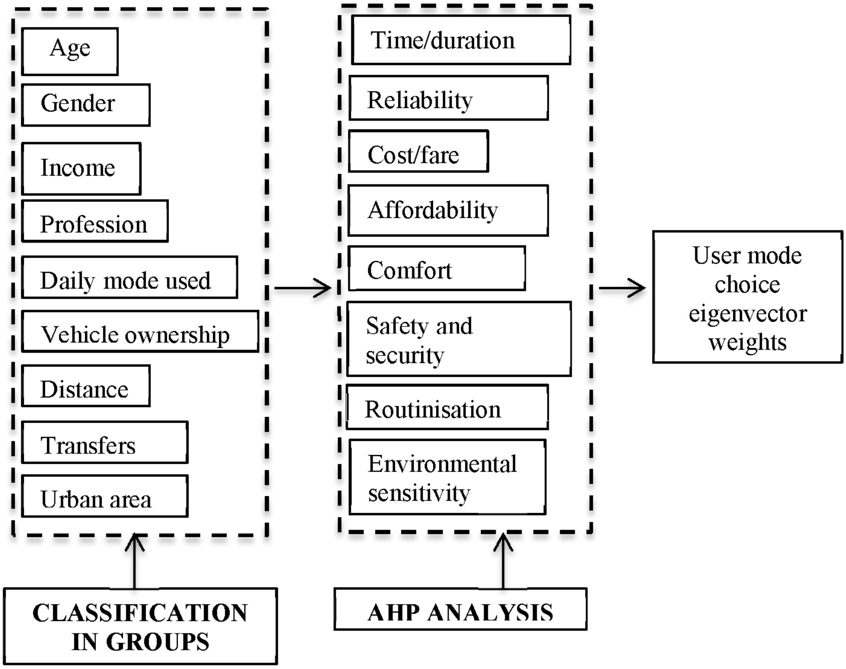

Figure 3: Construct – mode choice – user perspective.

The goal was to identify the relative importance given to various parameters, which affect the mode choice of a certain user group. For weightages the AHP, 2 x 2 comparison matrix was analyzed between fare, comfort, environmental sensitivity, time, reliability, routine and affordability, which were extracted based on the literature review. A pilot survey was floated among the transportation management professionals and students (31 respondents), who can actually tell the deficiencies of the survey and the construct, based on the initial analysis further data was collected from 134 respondents. The survey was focused on the target group that has the socio-economic propensity to shift between public and private modes and does not uses public mode due to compulsion of income and affordability only. The data was analysed using R Studio 0.98.1091 package on Mac OSx Mavericks (Codes and primary data available on request).

5 Results and conclusion

5.1 Pilot survey

A total of 31 respondents filled the questionnaire out of which 27 were found valid. The respective Saaty Inconsistency Index was high for cluster 1 but within acceptable limit for cluster 2. Koczkodaj Inconsistency Index for both the clusters was less than one, which is acceptable (<1) for a pairwise comparison matrix of order 7 and highest value as 9 [32, 33].

Income and profession being two most important variables all 27 respondents were segregated in two clusters cluster one with 8 students and cluster two with 19 professionals. The average age of cluster one was 22.62 years and that of cluster two was 29.26 years. Average vehicle ownership stood at 0.12 and 0.80 respectively and students were travelling 17.5 kms per trip which was more than professionals (13.6 kms.). It was expected that with such distinct travel characteristics the various weights of pairwise eigenvectors would also show significant difference using AHP analysis. Within the two clusters differences were observed in terms of priority. While cluster 1 (Students) travel longer distances and value reliability (0.45), safety (0.16) and routine (0.16), professionals in cluster 2 valued, comfort (0.28), time (0.26) and fare (0.20) relatively more than reliability which comes fourth with 0.10. The Saaty Inconsistency Index for cluster one and two were 0.72 and 0.34 respectively.

5.2 Result and findings

Out of the 134 responses only 112 were found useful. These responses were collected from major Indian metropolitan areas – Delhi, Mumbai, Bangalore, Chennai, Kolkata and Jamshedpur, all being million plus cities in India. The age of the respondents varied between 21 and 50 years with mean being 31.2 and median as 30 years respectively. 27 were managers, 24 were students, 18 worked in IT and ITES, 13 each worked in government services and as engineers and 11 were consultants. 18 respondents resided in Bangalore, 16 each in Delhi, Mumbai and Jamshedpur, 12 in Hyderabad and 6 in Chennai. Monthly income varied from nil to INR 250,000 per month with median being 63,750 and mean 71,720. Daily trip length ranged between 50 meters and 42 kms, median and mean being 10 and 12.5 kms respectively. Daily expenditure ranged between nil and INR 482 with median and mean as INR 40 and 77 respectively. Further results have only been discussed for the categories where the Satty Consistency Index (SCI) was less than 0.1. This has been intentionally done as SCI less than 0.1 shows that the user mode choice is consistent based on the specific categorization parameter and hence, eigenvector preferences as homogenous within the group. For a value of SCI more than 0.1 it could be safely assumed that that specific parameters does not leads to homogeneity within the group. The results have been further analysed based on the existing Indian socio-cultural travel behavior.

When the categorization was done based on the urban area matrix developed for Mumbai only had the SCI close to 0.1, meaning that there is coherence in eigenvector preference among the residents of Mumbai. This is in coherence with the fact that nearly 80% of the residents rely on public transportation/ walking and out of which nearly all of them use the urban rail as the preferred mode [34]. Respondents of Mumbai consider affordability (0.24), give importance to routine (0.19) and value reliability (0.17) more than fare, time or comfort (Table 2).

Table 2: Eigenvector values: city based categorization.

City	Fare	Time	Comf.	Env. Sen.	Safety	Rel.	Rout.	Afford.	SCI
Mumbai	0.05	0.05	0.08	0.10	0.12	0.17	0.19	0.24	0.10
Delhi	0.02	0.19	0.18	0.07	0.14	0.17	0.13	0.10	0.50
Bangalore	0.04	0.12	0.13	0.10	0.12	0.11	0.21	0.18	0.52
Hyderabad	0.04	0.06	0.26	0.01	0.25	0.17	0.04	0.16	0.53
Jamshedpur	0.32	0.05	0.12	0.02	0.22	0.15	0.04	0.08	0.51

Based on the mode chosen by all the 112 respondents, consistency was found for 18 users using the bus for the daily commute. Table 3 shows the eigenvector preference for these users. It was found that affordability (0.23) again remains the major parameter to decide mode choice, with routine (0.19) and reliability (0.17) coming second and third respectively.

Table 3: Eigenvector values: mode-based categorization.

Mode	Fare	Time	Comf.	Env. Sen.	Safety	Rel.	Rout.	Afford.	SCI
Bus	0.05	0.05	0.08	0.10	0.12	0.17	0.19	0.23	0.11
IPT	0.04	0.06	0.26	0.01	0.25	0.16	0.04	0.16	0.53
Car	0.02	0.19	0.18	0.06	0.14	0.17	0.13	0.10	0.51
2-wheeler	0.07	0.21	0.03	0.02	0.25	0.17	0.05	0.19	0.50

Among the professions, the matrix for respondents belonging to government services was consistent (Table 4) and though the number of respondents was 13, the results are very much a replication of output for bus as the preferred mode.

Table 4: Eigenvector values: profession-based categorization.

Profession	Fare	Time	Comf.	Env. Sen.	Safety	Rel.	Rout.	Afford.	SCI
Govt. serv.	0.05	0.05	0.08	0.10	0.12	0.17	0.19	0.23	0.11
Student	0.12	0.07	0.03	0.02	0.33	0.06	0.01	0.27	0.40
IT/ITES	0.01	0.02	0.32	0.12	0.04	0.10	0.10	0.27	0.50
Engineer	0.02	0.32	0.07	0.05	0.16	0.10	0.12	0.15	0.34
Manager	0.02	0.19	0.18	0.07	0.15	0.17	0.13	0.10	0.50
Consultant	0.01	0.04	0.04	0.07	0.39	0.22	0.15	0.07	0.35

No significant consistent matrix was found for classification based on gender, age or income. The same matrix values were populated for people whole own no personal vehicles.

From the fare perspective, which also reflects the affordability of the respondents' consistency was found for people who spent more than INR 100 per day for daily trips as well as some consistency, was found for respondents spending between INR 50 and 100 (SCI = 0.35).

Table 5: Eigenvector values: fare-based categorization.

Fare (INR)	Fare	Time	Comf.	Env. sen.	Safety	Rel.	Rout.	Afford.	SCI
0 to 20	0.07	0.21	0.03	0.02	0.25	0.18	0.05	0.19	0.50
20 to 50	0.02	0.19	0.18	0.06	0.15	0.17	0.13	0.10	0.50
50 to 100	0.01	0.05	0.04	0.07	0.39	0.21	0.15	0.07	0.35
>100	0.05	0.05	0.08	0.10	0.12	0.17	0.19	0.23	0.11

6 Conclusion and future research

Other than a group of people belonging to Mumbai, who use the bus as the preferred mode and work in government service spending more than INR 100 per trip consistency was not found for most of the categories however, there remains a clear pattern of choice among the various group with affordability being the highest valued in all groups and some groups valuing time, safety and reliability e.g. consultants, managers or people travelling by car respectively. For such a detailed analysis 112 respondents do not seem to be large enough sample. Ideally, the analysis should categorize respondents first through cities, and then subsequent sub-categorization should be based upon mode used, income, vehicle ownership and distance travelled. These subcategories would require a data set of nearly 600 respondents distributed among these cities for a robust analysis. The use of the Likart type scale is also recommended.

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