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Original Article

A Comprehensive Travel Behaviour Analysis of Working Commuters in Bengaluru City

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Abstract *- Bengaluru is one of the most populated cities in India. As it is well known for its IT industry, people migrate from different parts of the world due to which there is a rapid increase in population. The increase in population leads to many problems like traffic congestion, pollution, etc. One of the main reasons for congestion on roads is the increased usage of personal vehicles. This study attempts to analyse the factors associated with vehicle ownership and mode choice behaviour of working commuters in Bengaluru city. Data collected in 2018 and 2020 are pooled together and are used for analysis purposes. Graphical analysis has been adopted to study the effect of each variable on vehicle ownership and mode choice behaviour. An MNL model was built to analyse mode choice behaviour for commuting trips in Bengaluru. Based on graphical analysis and results from the model, the study summarizes the effect of demographics, trip-related factors, and other subjective factors on mode choice behaviour. The study also summarizes the effect of household characteristics (income, number of members in the household, number of working individuals in the household, house type) and personal characteristics (age, marital status, driving knowledge of two-wheeler and car) on vehicle ownership.*

Keywords *- Maximum likelihood, Mode choice, Multinomial logit model, Work trip.*

I. Introduction

Bengaluru is one of India's most populous cities. It covers an area of 741km2 and is divided into eight zones. It has an estimated 1.23 crore population, larger than that of many advanced nations. Since the city is well known as an IT hub, people migrate to Bengaluru from various parts, leading to a rapid increase in population. Traffic congestion, pollution, global warming, and resource shortages become more prevalent as the population grows. One big issue that the city is dealing with is traffic congestion. Inadequate public transportation, poor, intermediate public transportation facilities, and an increase in the number of private vehicles owned by a household are some of the causes of traffic congestion. The rapid increase of personal vehicles (particularly two-wheelers) in the metropolis is the major cause of traffic congestion.

According to recent studies, Bengaluru has the world's highest two-wheeler ownership and the greatest car growth rate. People who own a vehicle are more likely to use it for work. As a result, research into mode sharing is required. Vehicle ownership isn't the only factor influencing mode share. Other factors, such as demographics and trip-related characteristics, influence mode share and are continually changing. In terms of social situations and transportation systems, there have been many developments in the recent decade. As a result, people's travel preferences, such as the mode that a person uses to get from home to work in the city, change. Many factors influence mode share, including demographics (age, income, gender, number of working people, education), travel duration, travel cost, trip-related variables (distance from home to work, access and egress distance in the case of metro), and service-related variables (safety, comfort).

As a result, there is a need to analyse the changes in these aspects over the last decade and the changes in mode share. There is a need to analyse vehicle ownership as a factor that influences mode share. Bengaluru city, as previously said, has several challenges such as population explosion, traffic congestion, and pollution, which necessitates a study of the changes that have occurred over the last decade. As the IT industry and other work opportunities grow year after year, so does the population, so does the number of trips produce, which are uncontrolled. As a result, the number of vehicles on the road must be reduced, lowering pollution levels and other adverse effects. As there is a need to travel, people in Bengaluru city like to commute by two-wheeler because it is the most convenient and fastest means of transportation. As a result, vehicle ownership (particularly two-wheelers) is fast expanding in the city each year. If vehicle ownership is not limited, it will reach a stage when a person owns a vehicle but cannot go because there is no space on the roadways. As a result, vehicle ownership must be regulated to eliminate traffic congestion by providing excellent public transportation and IPT services.

There is a need to research the existing demographics, mode share, and vehicle ownership situation in Bangalore. It is essential to analyse the interrelationships between demographics and other trip-related factors regarding mode share and vehicle ownership—these aid in city transportation planning and the formation of policies that enhance public transportation and IPT.

The following objectives have been identified to analyse the issues mentioned above:

- To determine temporal variations in mode share, average trip length, average HH size.
- To analyse the demographics, mode share, vehicle ownership, and activity pattern of commuters in Bengaluru.
- To identify and analyse the factors that influence vehicle ownership mode share and build an MNL model to study Mode choice.

2. Literature Review

Most previous studies have been limited to a single state [1–9], and only a few have been conducted nationwide [10-13]. The benefit of researching a specific city or state is that it can be determined how the city is behaving; however, the policies developed for that city cannot be extended to other cities or states. A national study can help understand how a country or nation behaves on average, but it cannot explain how an individual city inside that country behaves.

Data collecting is an important stage before any city, or a country's travel behaviour is analysed. The majority of the studies collected data through household interview surveys or household travel surveys, both of which collect similar types of information. Only a few research conducted surveys such as household income survey, household vehicle ownership survey, and consumer expenditure survey, each of which collected additional data than household interview survey. In these researches, the data was collected using a different technique. Face-to-face interviews [14-16, 1, 5] drop-off, and pick-up [8], and online [6] data collection techniques were used. Different platforms, such as Google Forms and Qualtrics [17], were used in the online survey. As data collection is challenging, particularly when large amounts of information are needed for analysis, researchers relied on secondary sources [10-12, 3, 4, 18, 19]. The majority of these research that has conducted surveys preferred face-to-face interview approach and online technique over others since the former aid in collecting high-quality data. At the same time, the latter is quicker, cost-effective, and more flexible.

Most studies used a random sampling technique [19-21, 1, 14] to collect the data. Other studies have been carried out using stratified random sampling techniques [8, 22] and convenient sampling techniques [6, 17, 23]. The random sampling technique is used in most studies since it is the simplest way to extract data for research.

Almost all studies include questions about personal characteristics, household variables, and trip-related information. Personal information such as age, gender, education, qualification, and household data such as location and type of residence, household income, number of people living in a household, number of working persons, and number of vehicles owned are requested [2, 8, 10]. Trip-related questions included the mode of transportation used for daily commutes/the most recent trip, travel time, travel cost, distance travelled, waiting time, start and end times, location, and purpose of travel [2, 24]. Apart from the data listed above, only a few research have gathered additional data for the analysis. Subjective factors include comfort, reliability, dust, and noise [1]. Other surveys such as traffic volume count, speed and delay surveys, and occupancy counts were conducted in Pune [5]. Land use characteristics were collected in a study conducted in Dhaka and Chennai [4, 14]. In Mumbai, an API (Application Program Interface) for Google Maps was integrated into the survey form, allowing respondents to see the best route options for their particular trip [6]. In Vadodara, questions about the public transportation system and its inadequacies were asked. Additional information such as the reasons for choosing the current mode and the problems associated with it, vehicle kilometres travelled by each vehicle, household vehicle sold in the last ten years, future vehicle preference, inclination towards an electric vehicle, behavioural changes due to gasoline prices, and operating costs during a vehicle purchase [17].

The analysis or modelling of the collected data is an essential process. Mathematical models and graphical analysis can be used to examine the collected data. Regression models are most utilised to analyse temporal and spatial changes in travel behaviour. Regression models are used to examine temporal shifts in trip length, travel duration, travel cost, mode choice, and the factors that influence these changes [3, 5, 14]. Four pooled regression models were built to assess the effect of time on the peak car phenomenon. Multiple linear regression models were created to discover factors affecting this phenomenon and behavioural variations between different groups [19]. Regression analysis is also used to investigate the factors contributing to a decrease in per capita vehicle miles travelled [10]. Descriptive analysis was used to examine temporal changes in trip frequency [2], while discrete choice models were used to look at spatial changes in trip frequency [22].

Analysis of mode choice behaviour has been done in many cities. Mode choice behaviour can be analysed using descriptive statistics, regression models, and logit models. Mode choice behaviour is influenced by socio-demographic

(age, gender, income, education, employment) and trip-related characteristics (travel time, travel cost, distance, trip purpose). Models like binary logistic regression model [4], logit model [1], Multinomial logit (MNL) [24], and mixed logit (MXL) models are built where mode choice is considered as a dependent variable. The independent variables that influence mode choice behaviour are socio-demographic variables [6], trip-related variables [1, 4], spatial characteristics, user preference variables [4], convenience, comfort, reliability, dust, and noise [1], the purpose of travel [24], and car ownership [6]. Apart from all these factors, GPS usage impacts the user's mode choice behaviour [6].

Many cities adopted similar models to analyse vehicle ownership. MNL models are used to study household vehicle ownership choices [17] and private vehicle ownership patterns [11]. A binary logistic regression model was developed to predict household vehicle ownership. Household size, average monthly income, number of working members, number of children in school, and males in the household are explanatory factors [18]. The annual vehicle trip distance was calculated using an ordinary least square linear regression model [17]. The analysis of variance (ANOVA) technique was used to examine the variation in vehicle ownership growth throughout the four decades [12].

2.1. Temporal Changes in Travel Behaviour

The data collected were analysed to study temporal changes in travel behaviour. It was observed that there is an increase in trip length, travel time, and travel costs over the years [2, 3, 8]. The factors that affect temporal changes in trip length are increased travel time, individual monthly income, and vehicle ownership [5]. A similar study in Chennai also showed that travel time varies over the years. State dependency (influence of past choices on current decisions) variables affect across-mode transition tendency and user's sensitivity to other factors such as travel time [14]. The trip frequency increased throughout the study period in Seoul, whereas trip distance initially increased and then decreased. Bus and car use declined during peak hours, while modes like walking and bikes increased their frequency. Metro was used for all trip purposes [2]. In the United States, where car travel is dominated, there was a decline in automobile travel during the study period due to increased public transportation, walking, and bicycle use. This declining trend is influenced by demographics and social changes [10]. In Brisbane, a similar observation was made, i.e., the decline in car travel which was mainly caused due to external factors such as the promotion of sustainable transportation options [19]. Contrastingly in China, where bicycles predominate, there has been an increase in the use of private cars and public transport ridership at the expense of cycling. The mode chosen is influenced by income [3]. The location of respondents also affects travel time, cost, frequency, and mode choice [22].

2.2. Vehicle ownership

Several studies have been done to understand the factors which influence vehicle ownership. Discrete decision models can be utilized to examine and predict a decision-maker choice of one elective from a limited arrangement of totally unrelated and all things considered thorough options [25, 26]. Such models have various applications since numerous behavioural responses are discrete or subjective in nature; that is, they relate to decisions of some of an arrangement of choices. An ultimate interest in discrete decision modelling, as in most econometric demonstrating, lies in having the capacity to anticipate the basic dissensions are conducted by gathering people. An additionally intrigue is to decide the relative impact of various properties of options and qualities of decision-makers when they settle on decision choices. For instance, transportation experts might be occupied with predicting the portion of workers utilizing each of a few travel modes under a variety of administration conditions or promoting specialists might be keen on analyzing the portion of car buyers choosing every one of a few decision-makers and models with various costs and properties. Further, they might be occupied with predicting this part for a different group of people and recognizing people who are well on the way to support one or another alternative. Likewise, they might be occupied with seeing how unique groups esteem diverse traits of an alternative; for example, business air travellers are more sensitive to total travel time or the frequency of flight takeoffs for a picked goal.

Most of the studies revealed that monthly household income has a significant impact on vehicle ownership. Economic standard, household size, location (rural), regular salary earning members, and the presence of children and the elderly all impact personal vehicle ownership, particularly car ownership. The presence of young adults was found to incline on two-wheelers [11]. Similarly, in Sri Lanka, household size, the number of males, and the number of workers in the household have a significant impact on vehicle ownership [18]. The household's total vehicle expense accounts for a large amount of the household's income. The price mechanism alone may not be sufficient to control vehicle ownership. Alternative modes, such as public transit, should be provided at a reasonable cost [27].

2.3. Mode Choice

The main factors considered were a comfort in travel and travel cost while choosing the mode. Other factors like gender, car ownership, license, alternative mode options, and parking have influenced mode choice. People are more inclined to personal vehicles as their income rises [4]. The likelihood of users using their car as their mode of travel grew as vehicle ownership increased. The usage of GPS has positively impacted the possibility of driving a car or taking an autorickshaw /taxi [6]. Two-wheelers have the highest share of all modes of transportation [24]. Personal vehicle

users are giving maximum importance to comfort, dust & noise, and waiting time.

on the other hand, transit users try to maximize their travel costs and travel time [1]. Public transit is mainly used for mandatory trips as it is economical in the long run [6]. But some studies have concluded that the existing city's public transportation system is not satisfactory. This implies that to reduce the share of personal vehicles on roads, and an excellent public transportation facility has to be provided.

2.4. Gaps from Literature Review

Bengaluru is one of the most populated cities in the country. People migrate from all across the country since the city's IT sectors are well-known. The population is rapidly growing, accounting for 16% of the state's total (worldpopulationreview.com). Issues such as traffic congestion, pollution, global warming, and resource shortages become more evident as the population expands. Traffic congestion is a significant concern in the city, and it is stated that Bengaluru has the world's worst traffic congestion (Times of India). Bengaluru has the world's highest two-wheeler ownership and the world's highest car growth rate compared to all other cities. In other cities, such as Chennai, long-term temporal changes in mode share have been studied, and it has been found that the percentage of personal vehicles has not increased significantly [14]. This is not the situation in Bengaluru, so long-term temporal changes in travel behaviour, particularly in terms of mode choice, must be studied. Another reason for this study is that there are very few extensive studies on Bengaluru. Recent research in Bengaluru has looked at the autorickshaw sector (https://cistup.iisc.ac.in/), non-worker mode choice [15], and gender differences in work trips [20]. It has been noticed that the mode choice analysis for daily commute trips has not been thoroughly investigated. There hasn't been comprehensive research on travel behaviour since the implementation of the metro system.

3. Data Collection and Analysis

Bengaluru city is divided into eight zones, namely, Bengaluru East, Bengaluru South, Bengaluru West, Bommanahalli, Dasarahalli, Mahadevapura, Rajarajeshwari Nagar and Yelahanka zones. Further, these eight zones are sub-divided into 198 wards.

To analyse any city or country, a considerable amount of data should be collected. Data should be collected based on the population in each ward, and all the wards should be covered such that the data collected will be unbiased.

Regarding 2007 data, details on mode share, distance travelled, and household details are obtained from the report published by Rail India Technical and Economic Service Limited [28]. In 2018, the survey was conducted based on a simple random sampling technique, which means that each sample has equal chances of getting selected. In this survey, every house after ten houses is chosen so that the whole area is covered. The limited number of samples for all the wards has been fixed before the survey using the formula given below.

$$Number\ of\ samples = \frac{(total\ population\ in\ the\ ward)}{(overal\ population\ of\ Bangalore} * total\ number\ of\ samples\ to\ be\ collected$$

About 26 enumerators, divided into a group of 2, were assigned to collect the data in different wards such that each group gets an equal number of data to be collected. The face-to-face interview was adopted to collect the data. The data collected was related to working individuals in the household as they are the contributors for maximum daily trips. A one-day holiday was given to enumerators on weekdays. The timings considered for the survey was between 6 pm to 9 pm to collect the accurate work trip details. A total of 1315 responses were collected. After data cleaning and sorting, 1131 samples came out to be valid. The raw data is entered into an excel sheet for analysis purposes. All the enumerators are given a fixed number of survey sheets for the data entry.

Descriptive statistics of the data: Statistical analysis is the technique used to analyse the collected data. It is used to identify the trends and patterns from the data. Data is analysed with the help of graphs and tables. Information is collected by conducting the survey and then analysed to conclude. The data is divided into categories and are analysed in the following subsections.

3.1. Effect of age

Fig.1 depicts the age distribution of individuals in Bengaluru. The minimum and maximum age of the working population was found to be 18 and 60, respectively. The average age of the sample was found to be 38.6 years.

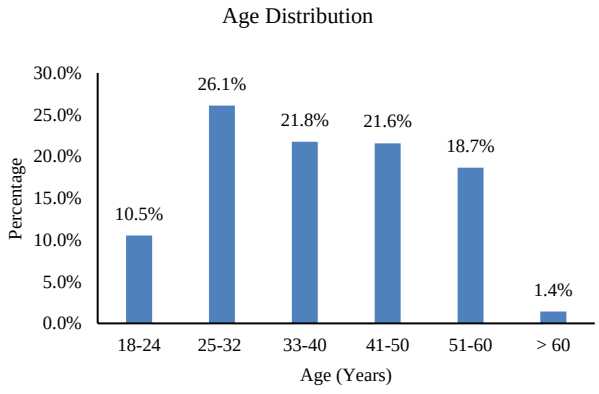


Fig. 1 Distribution of age

For a better understanding of the effect of age on mode choice during the model estimation, working members were

classified as young adults (ages 18-32 years), middle-aged adults (ages 33-50 years), and older adults (aged older than 55 years). It is observed that nearly 37% of the population were young adults, 43% were in the middle-age group, and the remaining 20% were older adults. This suggests that the majority of the population living and working in Bengaluru are in the young and middle-aged group.

3.2. Driving Knowledge of Two-Wheelers and Cars

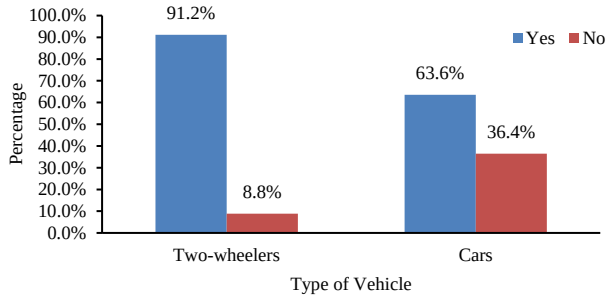


Fig. 2 Driving knowledge of two-wheeler and car

Driving knowledge plays a vital role in vehicle ownership. If a person has driving knowledge, they are more likely to own a vehicle and use it for work trips. As shown in Fig.2, about 91% of people in Bengaluru know how to drive a two-wheeler, and about 64% know how to drive a car. This means that the vast majority of Bengaluru residents have driving knowledge. So, these people are most likely to travel from home to work in private vehicles, causing traffic congestion in the city.

3.3. Travel Distance

Fig.3 shows the variation of travel distance in various modes such as two-wheeler, car, bus, and metro if all the individuals in the sample use these modes. It is observed that the average distance travelled is more in the case of the metro (18.44kilometres) and is almost the same in the other three modes (10-11 kilometres). The maximum distance travelled in the metro is around 46.16 kilometres, while it is 29-31 kilometres in the other three modes. The distance from home to work is less than 9 kilometres in two-wheeler, car and bus for 50% of the commuters whereas in metro it is 17.05 kilometres.

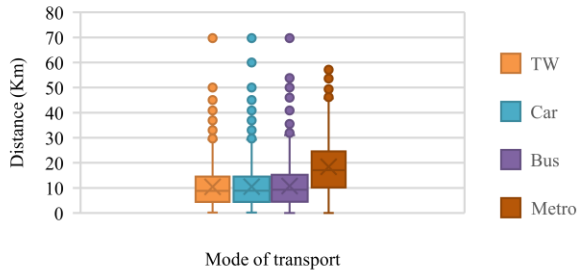


Fig. 3 Distance travelled in different modes

3.4. Travel Time

Fig.4 shows travel time variation in various modes such as two-wheeler, car, bus, and metro if all the individuals in the sample use these modes. It can be observed that the average travel time in two-wheelers is less when compared to other modes. The average travel time in a two-wheeler is 24.90 minutes, in-car it is 30.25 minutes, in the bus it is 49.50 minutes, and in the metro, it is 63.60 minutes. The minimum time to travel from home to workplace in two-wheeler or car is 1 minute, and in the metro, it is 5 minutes. The maximum travel time in private vehicles (two-wheeler = 69 minutes and car = 80 minutes) is very much less when compared to public transport (bus = 120 minutes and metro = 149 minutes). About 50% of people have their travel timeless than the median value. It is very much clear that the median value in the case of the bus (46 minutes) and metro (59 minutes) is very much higher than two-wheeler (21 minutes) and car (26 minutes). Travel time is widely distributed in bus and metro, implying that they have a wide range of travel times. There are many individuals (outliers) who travel more than the maximum travel time in the case of the bus when compared to other modes. Travel time is one of the essential factors in choosing a mode to travel from home to work. Since the average travel time is less in two-wheelers when compared to other modes majority of the individuals tend to use two-wheelers as their work mode.

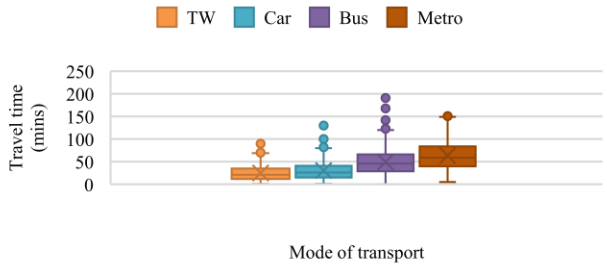


Fig. 4 Travel time by different modes

3.5. Travel Cost

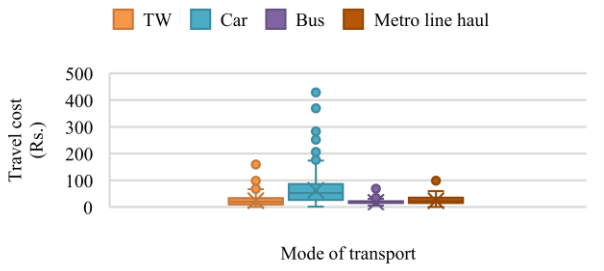


Fig. 5 Travel cost in different modes

Fig.5 shows the variation of travel cost in various modes such as two-wheeler, car, bus, and metro if all the individuals in the sample use these modes. It can be observed that the average travel cost in the bus is less when compared to other modes. The average travel cost in a two-wheeler is Rs. 24,

in-car it is Rs. 63, in a bus it is Rs. 18, and in a metro, it is Rs. 24. The minimum travel cost in two-wheelers (Rs. 1) and cars (Rs. 1.2) is less when compared to the bus (Rs. 5). The maximum travel cost in public transport (bus = Rs. 31, and metro = Rs. 60) is less compared to personal vehicles (two-wheeler = Rs. 67, and car = Rs. 174). About 50% of people have their travel cost less than the median value. The median value in the bus (Rs. 19) and two-wheeler (Rs. 20) is less than the metro (Rs. 22) and car (Rs. 52.3). Travel costs are widely spread in the case of the car. Many individuals pay more than the maximum travel cost in the case of the car when compared to other modes. Even though the average travel cost in the bus is less, most commuters choose a two-wheeler as it is more convenient.

3.6. Number of Vehicles Owned in Household

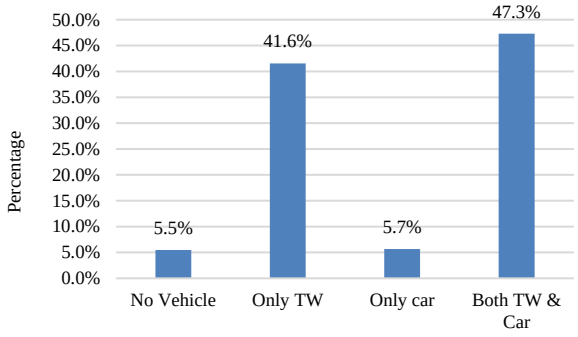


Fig. 6 Category-wise number of vehicles owned in household

Vehicle ownership is defined as the number of vehicles present in the household. As there is an increase in personal vehicles, it is necessary to analyse vehicle ownership and the factors influencing it. From Fig.6, it is observed that around 6% of the respondents do not own any vehicle and the rest have either a two-wheeler or car or both in their choice set.

3.7. Work trip mode share in Bengaluru city

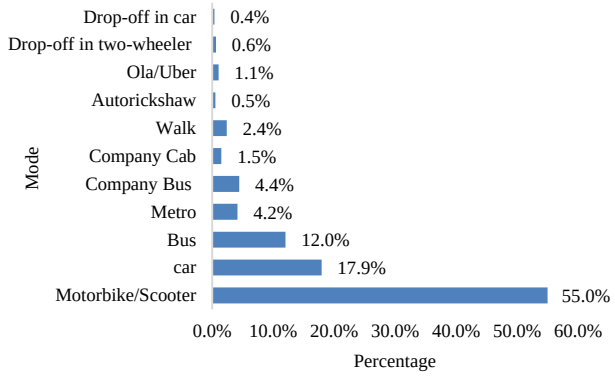


Fig. 6 Work trip mode share in bengaluru city

The samples collected clearly show that the leading cause for congestion is private transport in the city, accounting for up to 74%. The majority (56%) of the individuals are using motorbikes/scooters for their commuting trips. After motorbike, about 18% individuals prefer to travel by car. The percentage of individuals travelling by bus is significantly less (i.e., 12%), which is not even equal to the shares of cars. The shares of the bus are substantially less when compared to the network of the system. The percentage of the metro is around 4.2% which is a good number as it is not operated in all the areas of the city. The shares of company bus and company cabs are 4.4% and 1.5%, respectively, as shown in Fig.6. As the city is known for its IT sector which produces a higher number of work trips, the share of company bus needs to be increased. The walk shares are around 2.4% which is very little and can be improved by providing good infrastructure like walkways. The shares of other modes such as drop-off in TW, the drop-off in the car, autorickshaw, and app-based services (ola/Uber) are very few. From this, it is evident that people tend to use personal vehicles more when compared to public transport, IPT, and non-motorized mode (Walk and Bicycle) in Bengaluru city, which is the main reason for congestion.

3.8. Effect of Trip Distance on Mode Choice

Distance from home to work has an impact on the overall mode share. If the distance is significantly less, then commuters prefer to walk. As the distance increases, commuters shift to personal vehicles or app-based cabs, and with further increase in distance, commuters change to public transport or company-provided buses/cabs. From Fig.7, the average distance travelled from home to work by commuters in different modes is 2.12 kilometres for a walk, 7.38 kilometres for hired auto, 8.99, 10.99 and 11.20 kilometres respectively for motorbike/scooter, app-based cabs and car, 16.48, 16.83 and 21.07 kilometres respectively for metro, company cab and bus respectively.

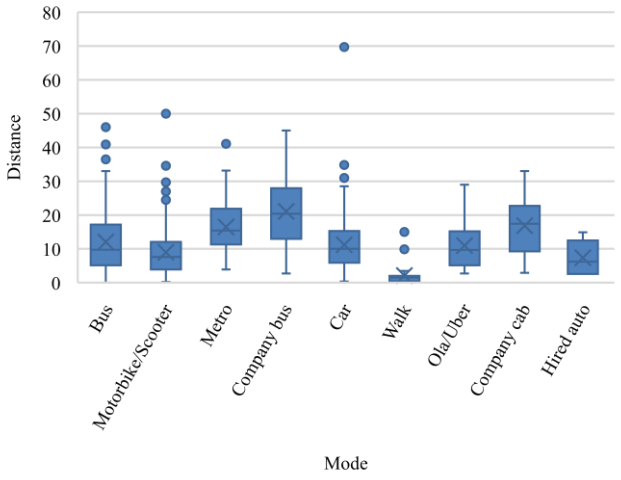


Fig. 7 Mode share v/s Distance travelled

3.9. Effect of Access Distance to Metro Stations on Mode Choice

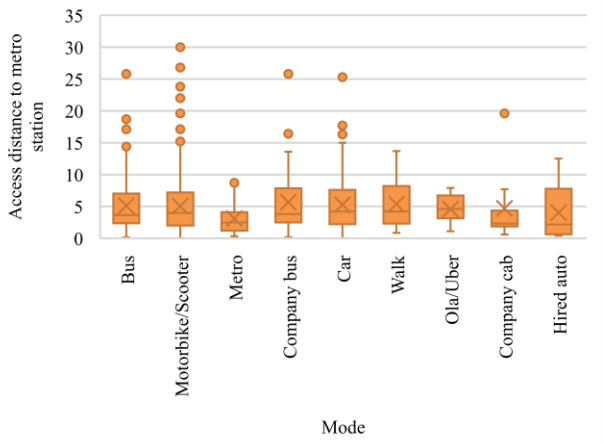


Fig. 8 Mode share v/s Access distance to metro station

Metro is one of the fastest modes to travel within the city. However, one of the primary concerns when choosing the metro as work mode is access and egress distance. People will choose the metro only if there is shorter access and egress distance.

As the access distance to the metro increases, people will prefer to choose the different modes to travel from home to work. From Fig.8, it is evident that the average access distance is about 3 kilometres for people who are choosing the metro. and for those who have chosen other modes as their work mode, the average metro access distance is greater than 4 kilometres. People prefer to use the metro if the access distance is within 3 kilometres.

3.10. Effect of Egress Distance from Metro Stations on Mode Choice

As the egress distance from the metro station to the workplace increases, people will prefer to choose different modes to travel from home to work. From Fig.9, it is evident that the average egress distance is about 2.8 kilometres for people who are choosing the metro. and for those who have chosen other modes as their work mode, the average metro egress distance is greater than 3 kilometres. People prefer to use the metro if the egress distance is within 3 kilometres.

3.11. Mode share comparison between the years 2007 and 2020

Over the last decade, the number of vehicles in the study area has increased substantially. Residents have begun to use personal vehicles instead of public transportation. There is a significant variation in mode share in the city. In 2007, Fig. 10(a) half of the residents used public transport (bus) and active modes (walk and cycle), but by 2020, Fig.10(b) three-quarters of the residents started taking their personal vehicles (motorbike and car) to travel to the workplace. The percentage of individuals riding a motorbike has increased from 29% to 56%, whereas individuals travelling by bus have declined from 42% to 12%. The percentage of individuals who travel by car has increased by 10%. The percentage of individuals walking to the workplace has dropped from 8% to 2%, and autorickshaws have declined from 12% to 1%. In 2007, the company bus/cab shares were 0%, but by 2020, they had increased to 6%. In addition to these modes, the metro has been included in the system, with a share of around 4%, which is a good percentage because the metro is not operating throughout all areas of the city. It was observed that the combined bus and metro share in 2020 is less than the share of the bus alone in 2007. The percentage of passengers in public transportation should be increased to establish a sustainable transportation system and can be accomplished by providing a cost-effective, time-saving, and easily accessible public transportation system and limiting vehicle ownership.

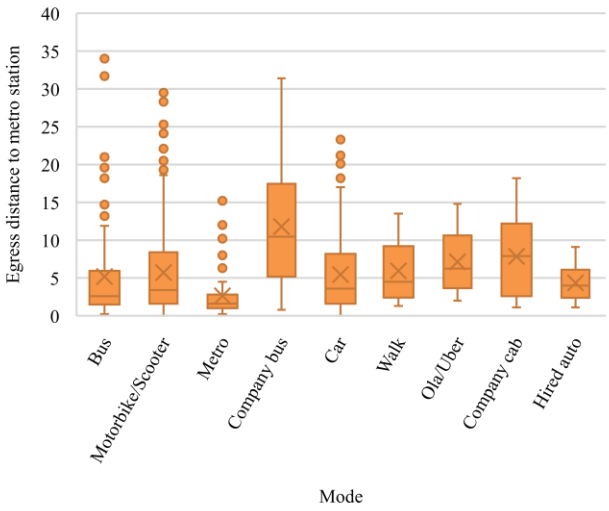
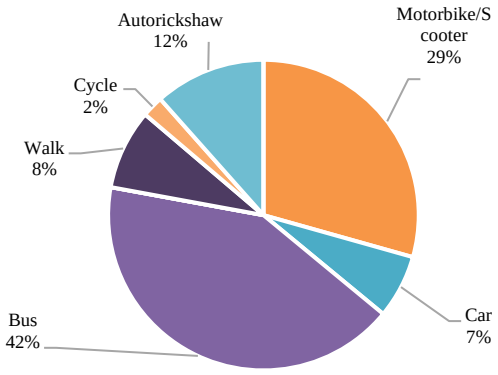
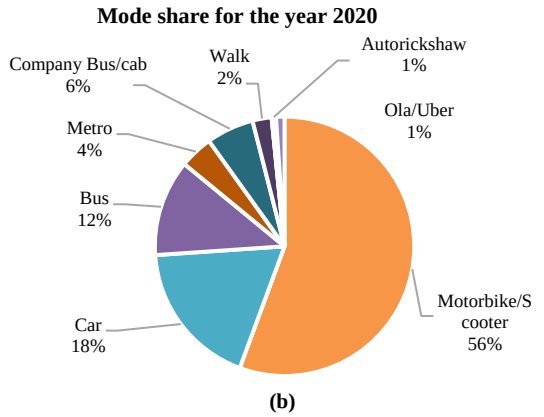


Fig. 9 Mode share v/s Egress distance from metro station

Mode share for the year 2007



(a)



(b)

Fig.10 Mode share comparison between the years 2007 and 2020

Table 1. Average trip length by each mode in the years 2007 and 2020

Average trip length (KM) by each mode	The year 2007	The year 2020
Motorbike/Scooter	8.02	8.99
Car	11.59	11.205
Bus	14.99	12.067
Metro	-	16.48
Company bus/cab	-	20
Walk	1.01	2.125
Cycle	3.88	-
Autorickshaw	8.59	7.38
Ola/Uber	-	10.99

On the other hand, table 1 shows that the average trip length by each mode remained almost the same in 2020 compared to 2007. The average household size in 2007 was 3.88, while in 2020, it is 3.70. This indicates that the average household size has not changed in the last decade.

3.12. Analysing Mode Share using Model

3.12.1. Methodology

Commuters make decisions in various scenarios, but there is no reliable data about how they make those decisions or the process they go through. The general frameworks for decision-making are checking the available alternatives, evaluating the factors associated with each mode, and summarizing the approach used to choose the model.

3.12.2. Alternatives

A set of alternatives that are available for an individual to choose is called a choice set. Commuters select the mode that is available in their choice set. Around ten options are available in Bangalore City for work trips, namely active modes (walk, bicycle), personal vehicles (two-wheeler and car), public transport (bus and metro), company bus/cab, autorickshaw, app-based services (ola/uber and bounce/vogo). Since the share of bicycle and bounce/vogo are significantly less, they are not considered in the analysis, and the remaining eights modes are considered for analysis. All the modes mentioned above are not available for every commuter; hence choice sets are defined and based on that, mode choice is analyzed.

3.12.3. Attributes

They are nothing but explanatory factors that explains the mode choice behaviour of commuters. The attributes that are used in this analysis are personal characteristics (age, gender), trip characteristics (travel time, cost, and distance), and household characteristics.

3.12.4. Model

The utility associated with the alternative j is given by Equation 1, which has two components –

- Deterministic component, $Vi(j)$, (Equation 2), which is a function of the attributes of the alternatives, individual and work trip-related characteristics (X) and the sensitivity (β) to these attributes,
- The random unobserved component, $\varepsilon i(j)$, which is assumed to be Gumbel distributed with mean 0 and constant variance. The probability that individual i chooses an alternative j is given by Equation 3.

The likelihood of the model is given by Equation 4 in the sample of N commuters, K alternatives in the choice set, where (k) (= 1 if k is chosen, = 0 if k is not chosen) is a binary choice indicator variable with respect to an alternative k. The Maximum-likelihood estimation technique is used to estimate the model parameters.

$$U_i(j) = V_i(j) + \varepsilon_i(j) \quad (1)$$

$$V_i(j) = \beta X \quad (2)$$

$$P_i(j) = \frac{e^{V_i(j)}}{\sum_k^K e^{V_i(k)}} \quad (3)$$

$$L(\beta) = \prod_{i=1}^{N} \prod_{k=1}^{K} P_i\,(k)^{\delta_i(k)} \quad (4)$$

4. Result

To evaluate the significance of explanatory factors and the logical relationship between alternatives and the respective attribution, the coefficient calibrated from the MNL model is investigated and presented in Table 2. An 85 per cent confidence interval is used to check the explanatory components.

4.1. Alternative Specific Constants

These indicate the unobserved characteristics that influence the usefulness of an alternative, as well as an innate preference for that mode. In the analysis, the two-wheeler is used as the base mode, and the preferences of other modes are contrasted against it. Car, bus, metro, company bus/cab, and walk were found to be significant constants, implying that they had the same effect as base mode. After two-wheelers, the most preferred mode of transportation is walking, followed by autorickshaws, buses, metros, company buses/cabs, and cars. App-based cabs (ola/uber) are the least preferred mode.

4.2. Household Characteristics

The household characteristics are put into sections such as vehicle ownership, age, and driving knowledge. In this category, most of the explanatory factors are found to be significant. Households with only a two-wheeler (and no car) and only a car (and no two-wheeler) may have a significantly higher tendency to use the two-wheeler (0.28) and car (1.26), respectively. The greater the number of cars and two-wheelers in a household, the greater the chances of using a car (0.92) or a two-wheeler (0.49), respectively. The use of a two-wheeler (1.46) and a car (1.64) may be on the higher side for those who enjoy driving TW and cars, respectively. Commuters in the old age category have a higher chance of using a car (0.7) than those in the low and middle age categories. Commuters in households where the number of people exceeds the number of vehicles owned in that household may have a higher chance of taking the bus (1.21).

Table 2. Results

	Variables (Mode)	*Coefficient*
Alternative specific constant	Two-wheeler	0
	Car	-2.42*
	Bus	1.63*
	Metro	1.2*
	Autorickshaw	1.73*
	Company bus/cab	0.85*
	Walk	3.19*
	Ola/Uber	-0.48
Household characteristics	Number of TW in the household (TW)	0.49*
	Young age group travelling a long distance (TW)	-0.23
	TW driving knowledge (TW)	1.46*
	Owning only TW (TW)	0.28*
	Number of cars in the household (Car)	0.92*
	Old age group (Car)	0.7*
	Driving knowledge of car (Car)	1.64*
	Owning the only car in a household (Car)	1.26*
	Young age group (Bus)	0.05
	working people greater than the number of vehicles (Bus)	1.21*
Accessibility	TW always accessible (TW)	1.68*
	The car is always accessible (Car)	2.4*
	direct bus (Bus)	0.67*
Level of service fact	TW travel time (TW)	-0.03*
	TW travel cost (TW)	-0.05*
	Car travel cost (Car)	-0.02*
	Bus travel time (Bus)	-0.02*
	Metro line haul travel time (Metro)	0.01
	Metro line haul cost (Metro)	-0.02
	Auto travel cost (Auto)	-0.03*
	Company bus /cab cost (Company bus/cab)	0.02*
	Ola travel cost (App-based)	-0.01
Trip characteristics	Metro egress distance (Metro)	-0.2*
	Metro access distance (Metro)	-0.07
	Walk distance (Walk)	-0.67*
	Bus short distance (<2.5 KM) (Walk)	0.26
	Low-cost company bus facility (Company bus/cab)	-0.01*

**Significant at 85% confidence interval*

4.3. Accessibility Factors

In this category, TW, car, and bus accessibility are considered, with the accessibility of all three modes having a significant impact on the usage of the respective modes. The explanatory factors used in this category are always accessibility of car, always accessibility of two-wheeler, and direct bus facility, which also tells us the order of the significance value, with always accessibility of car having the highest significance value so on. The greater the accessibility, the more likely people will use a car (2.4) a two-wheeler (1.68). The provision of direct bus service from home to the workplace may increase bus usage (0.67).

4.4. LOS Factors

LOS factors include travel time and travel cost. TW, car, auto, and company bus travel costs and TW and bus travel time were found to be significant explanatory factors. The metro and app-based cab/ola travel times and costs were found to be insignificant. The significance value of each explanatory variable is ordered from high to low in the order of car travel cost, TW travel cost, bus travel time, auto travel cost, TW travel time, and company cab/bus cost, with car travel cost having the highest significance value. The longer it takes to get to work and the more money it costs to get there, the less likely you are to use that mode.

4.5. Trip Characteristics

Travel distance is taken into account in this group. The greater the distance from the metro station to the workplace, the lower the possibility of using the metro (-0.2), which has the highest significance value compared to the distance covered by a commuter walking. People may not prefer to walk as the distance between home and work increases (-0.67).

5. Conclusion

The rapid growth in urbanization has led to an increase in urban population vehicles (personal and public). Due to the ease of owning a vehicle, the percentage of personal vehicles has increased rapidly over the last decade. An increase in human population and vehicle population is the main cause of congestion in the city. Hence, it is necessary to analyse the household characteristics, vehicle ownership, and other factors associated with mode choice. There is one main problem that the city is facing is traffic congestion. Personal vehicles have increased rapidly, causing less usage of public transport. To analyse this study of mode choice behaviour is important. To analyse the above mentioned, huge data is required, collected through household interview surveys and online surveys in 2018 and 2020, respectively. As there was no difference observed in both the year's data, it is pooled and analysed together. Since the percentage of trips made by working commuters is more, the survey was targeted to working individuals, and their details are collected along with their family member details. The questionnaires include household details, trip-related details, vehicle ownership details, qualitative factors, and activity characteristics.

In the present study, analysis of household characteristics, vehicle ownership characteristics, and subjective factors are done. Vehicle ownership and the factors associated with it are analysed. Choice sets are defined, and mode choice behaviour is analysed both graphically and in an MNL model. From this, it can be concluded that factors like income, household size, number of working members, type of house, and age group significantly affect vehicle ownership. When it comes to choice sets, most of the commuters have personal vehicles in their choice set, among which more than half of them are travelling by personal vehicles. Very few have only public transport in their choice set, indicating that very few are captive to public transport. Coming to mode choice behaviour, three-quarters of them use personal vehicles while the remaining are travelling by public transport or company-provided services or IPT. Many factors affect this type of behaviour. Demographic factors (age, gender, income, household size, number of vehicles in the household, driving knowledge, etc.), trip-related factors (distance travelled, bus pass or metro card availability, access to and egress distance from metro station), travel time and travel cost affect mode choice behaviour.

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