Development of Travel Mode Choice Model for Inter-Regional Passenger Trips-a Case Study of Bhavnagar Region and Surat City

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1. Title of Thesis and Abstract

Title: Development of Travel Mode Choice Model for Inter-Regional Passenger trips- A Case Study of Bhavnagar Region and Surat City

Abstract:

The modal split model is one of the foremost elements in transportation planning and policymaking. The review of past studies unveiled that the choice among modes for inter-regional passenger trips depends not only on inter-regional modal characteristics but also on ingress and egress modes' facilities available at the origin and destination. The study aims to develop the mode choice model for inter-regional passenger trips among major public transportation modes shared in the study area. Multinomial logit (MNL) model has been developed from the collected data for the passenger trips between Surat city and Bhavnagar region of Gujarat state in India. The developed model can give proper insight for the improvement of public transportation facilities in the region. It is revealed that egress cost, vehicle ownership, waiting time at egress, level of service offered, supply availability, types of destination region are more significant parameters for the proposed study. It is also observed that binary parameters representing sleeper seat availability, lesser travel cost, lesser egress distance, availability of night journey are found important during travelers' thinking process for mode selection. The elasticity values of egress waiting time and egress cost per income variable for railway mode are -0.239% and -0.117%, which are higher than other modes. The Analysis of the level of service variable shows that there are 13.1% and 20.1% rise in the probability of choosing GSRTC bus and train mode with the improvement in the level of service perceived by the travelers. The Artificial Neural Network (ANN) model was developed with the same variables to compare with the MNL model. To improve the results, a revised ANN model was developed. The revised ANN model which reflects a difference of attributes has a 90.52 % mode prediction capability against 80.37 % of the ANN model. In the study, an attempt has been made to find out the sensitivity of the various input parameters in the ANN model.

2. Brief description on the state of the art of the research topic

Much of the advancement in the discrete choice theory in modeling travel choice is due to the pioneering work of Domencish and McFadden (1975) as well as Ben-Akiva and Lerman (1985). Broadly, mode choice modeling has two approaches, namely the aggregate discrete

choice models and disaggregate discrete choice models. The former were popularly used up to the late 1970s while later became more popular during the 1980s. Disaggregate models can provide a rich prediction of behavioral attributes (Koppelman and Bhat, 2006). Moreover, it has a higher degree of transferability of the model in context with location and less suffers from biases.

Selection about data collection technique, instrument format, and sample design are crucial steps in transportation planning. Revealed preference (RP) data are based on observations of actual choices, while stated preference (SP) data provide information about user preference for new alternatives or for alternatives that differ radically from existing ones. Travelers are interviewed to collect the data. Generally, a well-designed questionnaire is used to serve the purpose (Yao and Morikawa, 2005; Miskeen and Rahmat, 2011; Ibrahim Sheikh et al., 2006). A personal interview may be combined with mail (Jang, 2003) or Telephone (Ewing et al., 2004) for efficient data collection. Data collection is usually conducted at the home by household travel survey (Philip et al., 2013), at working place (Yarlagadda and Srinivasan, 2008), or intercept survey at a convenient location (Wang et al. 2020). Rastogi and Rao (2002) designed a travel diary for the data collection of the Mumbai Metropolitan Region. The authors found that the face-to-face personal interview method is suitable for the collection of revealed information and the delivered and mail-back method is suitable for the collection of the stated information. Muralidhar et al. (2006) developed a time-space diary. They have concluded that formulated time-space diary performed better than the conventional travel diary and the face-to-face survey method emerged as the best way of administration. While Subbarao and Rao (2013) used an activity-travel diary to overcome the limitations of traditional travel diaries for the collection of activity-based data.

The discrete choice model is a mathematical function based on utility maximization theory. According to Ben-Akiva and Morikawa (1990), utility-based models are considered as one of the most accurate tools for making predictions about human decisions and behavior. Based on the error distribution of the utility equation, there are three popular families of the models namely logit models, probit models, and General Extreme Value (GEV) models. Due to simple mathematical form, Multinomial Logit (MNL) models are widely used by several researchers (Miskeen and Rahmat, 2011; Almasri and Alraee, 2013; Ashalatha et al., 2013; Subbarao and Rao, 2013). However, the logit model is laden with the drawback of the Independence of Irrelevant Alternatives (IIA) property (Bhat, 1995). The binary logit model is generally used to predict model shift among two modes (Wang et al., 2013; Arasan et al., 1996;

Okoko, 2007). The nested logit model allows estimation of proportions among selected sub-modes, prior to the estimation between modes.

For better results, researchers have looked forward to more recent soft computing techniques like Artificial Neural Network (ANN), fuzzy logic, and hybrid techniques. Zhu et al. (2010) have used ANN to model travelers' behavior in China. Sikdar and Sekhar (2005) and Ramanuj and Gundaliya (2013) have modeled mode choice behavior of commuters in Nagpur and Ahmedabad city respectively using ANN. When compared with the logit model, the ANN model was found to be comparable and consistent in predicting choice behavior (Madhu et al., 2004). Moreover, Minal and Sekhar (2014) have observed that hybrid models give better results compared to individual models. However, such models rarely examine behavior output useful for improvement and policy decisions.

The significant characteristics in determining the mode selection of the travelers are classified into three groups: characteristics of trip makers, location factors, and transport facility available. Effects of these influencing parameters are analyzed by many researchers all over the world. However, Almasri and Alraee (2013) have pointed out that the model developed for developed countries cannot be directly suitable for developing countries due to different conditions and circumstances.

On the other hand, intercity passenger travel mode choice modeling has not developed to the same extent (Miller, 2004). However, analysis of intercity travel behavior is crucial to a variety of commercial, industrial, and social activities (Landinois, 1987). Philip et al. (2013) have developed MNL model with an activity-based approach using Statistical Package for the Social Sciences (SPSS) software for the village area of Kerala, India. Walk, bicycle, auto-rickshaw, two-wheeler, car, and bus modes are included in the study. Authors have observed four-wheeler and three-wheeler ownership, license ownership, trip walking time, waiting time, cost, and duration as the most influencing factors for the choice of mode. Thomas et al. (2016) have developed MNL model between flight and train mode using NLOGIT software for the university township of IIT Mumbai. The most influencing factors in the main mode are travel time, travel cost, and household income. While for the ingress mode- waiting time, travel time and travel cost of ingress mode, household income, and personal income were the most influencing factors. The authors also studied regarding airport choice study. Jana and Varghese (2017) have analyzed mode choice for long-distance travel. Authors have observed the importance of trip purpose, time of year, type of stay, rural/urban trip in travel decisions about the mode choice for long travel. In India, railway and road networks have served a large part of the population (Jana and Varghese, 2017). The proportion of travelers served by the bus

mode is higher than the private mode in roadways (Bardhan and Varghese, 2015). The result obtained from the neural network model has higher prediction accuracy compared with the conventional logit model (Sayed and Razavi, 2000; Zhao et al., 2020).

Looking at the reviewed literature, it can be deduced that more research work on traveler's mode choice behavior among public transportation between large urban centers and non-urban areas is needed, particularly in developing countries like India.

3. Definition of problem

Problem defined in two categories, (i) finding research gap and (ii) Problem definition

(i) **Finding research gap:** Significant research exists on travel behavior within the urban center, while considerably much less research on travel between metropolitan areas (Miller, 2004). Though, intercity / inter-regional travel behavior is crucial to a variety of commercial, industrial, and social activities (Landinois, 1987). The available travel modes for low to middle-income groups in developing countries are either bus or railway systems. Because of a developing country, a large part of the population in India is dependent on the extensive rail and road network (Jana and Varghese, 2017). The proportion of travelers' dependence on bus travel is high though the road network is used by both public and private modes (Bardhan and Varghese, 2015). Therefore, mode choice analysis for the inter-regional passenger trips between highly acceptable and most competitive public transportation modes i.e. bus and railway trips is needed to analyze for Indian conditions. Such extensive multi-modal study which includes modal shift among private bus, Government-operated bus, and railway is not available. Though it has served a large part of the population and is useful to study travelers mode choice behavior in Indian conditions. To fill the gap, the present study is concentrated on the inter-regional trips by popular public transportation. The passenger trips by private bus, Gujarat State Road Transport Corporation (GSRTC) bus, and railway mode are selected due to their major share in the study area. The study might be useful to improve existing facilities as per travelers' thinking process.

(ii) **Problem definition:** There is a huge migration of the people from the study area situated in the Saurashtra region to the Surat metropolitan, mainly due to employment opportunities. There are significant numbers of native trips made by this migrated population to their native districts. Travelers mainly prefer private bus mode, though government-operated GSRTC bus and railway service are available. Private bus mode has a very high demand-oriented fare structure due to limited supply availability and

unequal/ higher demand especially during festival season. It is desirable that the authorities should provide efficient transport facilities in developing countries. Therefore, it is required to study the factors which affect the trip maker's mode choice decision. The study is helpful to understand the reason behind the lesser popularity of GSRTC bus and railway mode in the study area. The study will be helpful to improve existing services available in the study area considering traveler's thinking process.

4. Objectives and Scope of Work

Aim of the study

This research aims to enhance the understanding of the factors that affect mode choice decisions for inter-regional passenger trips in the Indian condition.

Objectives of the study are:

- To understand the existing public transportion passenger travel pattern in the study area.
- To develop a model to predict public transportion passenger mode choice in the study area.
- To understand the influence of the various parameters in the model.
- To suggest improvement in the existing public transportation facilities of the study area.

Scope of the Study:

- This research is limited to the analysis of home-bound inter-regional public transport passenger mode choice behavior.
- This study includes public transport passenger trips between Surat city and the Bhavnagar region.
- For the study, travelers' present trip data can be collected for the major public transport modes such as private bus, GSRTC bus, and train.
- After the analysis of the collected data for different parameters, the MNL mode choice model can be developed.
- Sensitivity analysis can be used to suggest improvements in the existing public transport modes. The knowledge gained through the study is useful for the analysis of such trips in the developing conntries.

5. Thesis Contribution

Due to the distinction in culture, the supply available, and economic condition the model formulated for the developed country cannot directly be applicable to developing countries (Almasri and Alraee, 2013). The research uses Multinomial Logit Modeling

techniques to predict mode choice in Indian conditions. This study addresses a need for more research on traveler's mode choice behavior between large metropolitan centers and non-metropolitan areas for developing countries. Trips made by the migratory population from Surat city to their home are extensively analyzed in the study. From the theoretical perspective, parameters considered in the research will be valuable to inter-regional mode choice modeling in similar circumstances of a developing country.

The present study is useful for understanding the travelers' behavior for the mode selection among existing passenger travel modes - Private Buses operated by Travel Agencies, Government buses, and railways. Unlike most of the previous literature, the study addresses home-bound passenger trips, which are more complex than daily trips prediction and mode shift between private and public transportation mode. The study emphasizes the traveler's thinking process to study the influence of the parameters, which are considered as governing parameters by travelers. Arc elasticity obtained for some policy attributes reflects the scope for improvement in the transportation system. Moreover, sensitivity analysis carried out in the study is useful for suggesting the improvement of the transport service as per traveler's requirements in the study region.

6. Methodology of Research, Results

6.1 Methodology

The proposed study intends to analyze trip makers' mode choice behavior within the study space for the public transport passenger trips. Defining the study problem is the first task in the methodology which is followed by the literature review concerned with the study problem. The next phase is the definition of the study area and preliminary data collection. A pilot survey has been conducted to determine the most relevant attributes for the travelers in the study area. The subsequent section includes data collection with the well-designed questionnaire and data analysis. The logit model is easier than the probit model from the analytical point of view. Furthermore, The MNL model structure selected for the proposed study has been widely used for intercity mode choice models, mainly due to its simple mathematical form, ease of estimation and interpretation, and the ability to add or remove choice alternatives. The software NLOGIT was used to build the MNL model. The best model has been chosen based on the coefficient of the variable with other statistical parameters. Likelihood Ratio Test Statistics (LRTS) is calculated using the difference of the log-likelihood ratio values for restricted and unrestricted parameters. However, a non-nested hypothesis test

proposed by Horowitz (1982) is used for the case where both the models have the same number of parameters (Koppelman and Bhat, 2006). McFadden ρ^2, logical sign, and p-values are used as goodness-of-fit statistics. The ANN model was developed with the database and compared with the MNL model in the ANN Model section. The feedforward backpropagation technique was used for the model developed in Matlab software. The relative importance of input variables is found by the proportioning of weights (Sikdar and Sekhar, 2005). The conclusion section includes inference from a few important findings obtained from the data analysis, model result, and sensitivity testing for the important variables by elasticity or scenarios.

6.2 Study Area and Data Collection

The study area selected for the present study is Surat city and Bhavnagar Region. Bhavnagar, Amreli, and Botad districts of Gujarat state, India are grouped as a Bhavnagar region, which is shown in figure 1 by blue boundaries. People from the Bhavnagar region migrate to Surat for employment, business, and improvement in the standard of living. There is a higher trip rate between the Surat city area and the native region of the migrated people. The distance by roadway between Surat city and Bhavnagar region is comparatively longer due to the gulf of Khambhat as shown in figure 1. Also, the distance by railway between the origin and the destination is much longer than the distance by roadway.

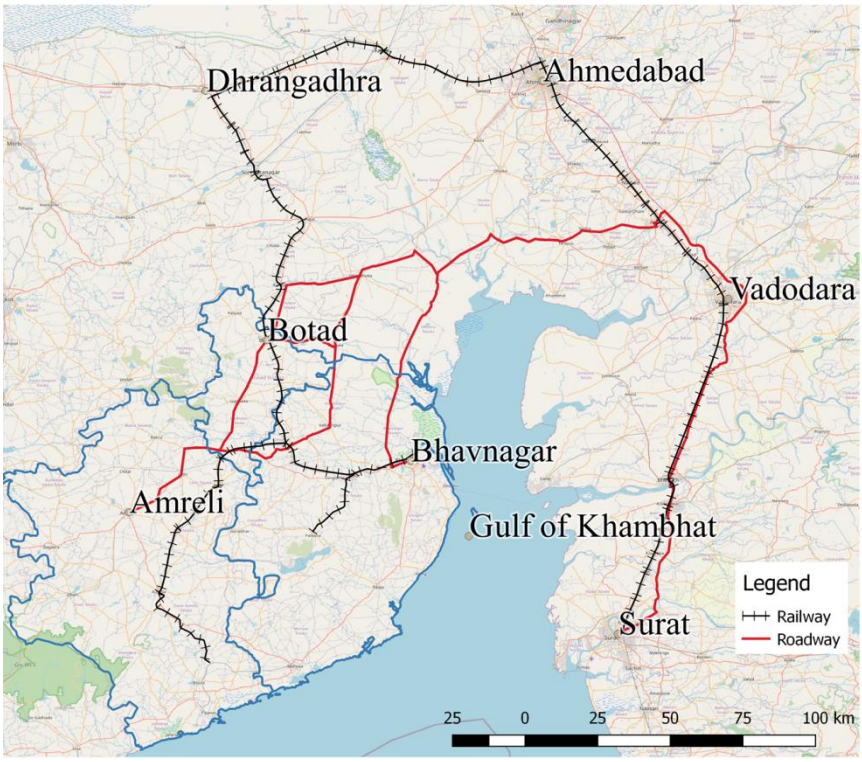

Fig. 1. Connecting routes in the study area

The present study is concentrated on the native/home-bound trips made by travelers using public transportation services available between Surat city and the Bhavnagar region. The data collected for the trips originated from Surat metropolitan region to the Bhavnagar region. Initially, data pertaining to the availability of public transportation facilities were collected to understand travel patterns in the study area. The main survey, followed by the pilot survey was carried out at Surat with a carefully designed questionnaire as presented in Appendix I. Targeted travelers were the population who have migrated from the Bhavnagar region and living in Surat city. Data pertaining to trips made by randomly selected travelers during one year were collected by intercept survey done at the Surat. The data regarding passenger trips made by privately operated buses, GSRTC buses, and Indian railway mode have been collected at a railway station, GSRTC bus station, and private bus service office in Surat city. The questionnaire includes socio-economic parameters of travelers, trip data, and data representing existing transportation facilities. Respondents were also asked for their governing criteria such as availability of reserved seats, convenient time, lesser travel time, lesser travel cost, better service, ingress distance, egress distance, sleeper seat availability, and a night journey responsible for particular mode selection. Total 2216 cleared trip data has been collected from 1256 traveler's interviews. The sample size is larger than the required sample size as per the empirical formula for infinite population presented by Levy and Lemeshow (2008) and also Hogg et al. (2015). Cleared 2004 trip data were used for model building while 212 data were used for model validation.

6.3 Data Analysis

Mode-wise travel time and distance between Surat to destination district headquarter are presented in Table 1.

Table 1. Mode wise Travel distance and Travel time

Origin-Destination	Travel distance (KM)		Travel time (Hours-h. Minutes-m)	
	Private bus/ GSRTC bus	Railway	Private bus/ GSRTC bus	Railway
Surat – Bhavnagar	335	526	7h 45m to 8h 45m	9h 33m
Surat – Amreli	427	537	8h 30m to 11h 0m	9h 30m
Surat- Botad	338	434	7h 30m to 9h 00m	7h 40m

Travelers were also asked to select the parameters responsible for the particular mode selection. The travel costs from the Surat to the destination district headquarter are presented in Table 2. There is demand-oriented travel cost fluctuation during peak/ festival season for

private bus mode. From Table 2 and initial data pertaining to the trip pattern in the study area, it is clear that the private bus has the maximum share though it has a comparative higher fare structure.

Table 2. Mode wise Travel Cost

Origin-Destination	Travel Cost range (Rs.)		
	GSRTC Bus	P Bus: Off peak Season (Peak Season)	Railway
Surat - Bhavnagar	190 – 304	350 – 450 (600 – 1000)	185 - 335
Surat - Amreli	227 – 337	400 – 500 (600 – 800)	150 - 305
Surat- Botad	170 – 307	400 – 500 (700 – 900)	140 - 290

Zhao et al. (2018) have suggested that feeder accessibility is indeed crucial in enhancing the mode share of trunk service. Out-of-vehicle distances were analyzed to study the effect of ingress and egress attributes in the present study. The distribution of ingress and egress distances presented in figures. 2 and 3 represent study area characteristics on either end. Lesser ingress distance for the private bus (pbus) reveals due to the number of pick up facilities available in the Surat city area. There is a very high egress distance for railway mode because of its poor track distribution in the Bhavnagar region. Whereas, pbus mode has lesser egress distance due to its well-distributed network throughout the Bhavnagar region.

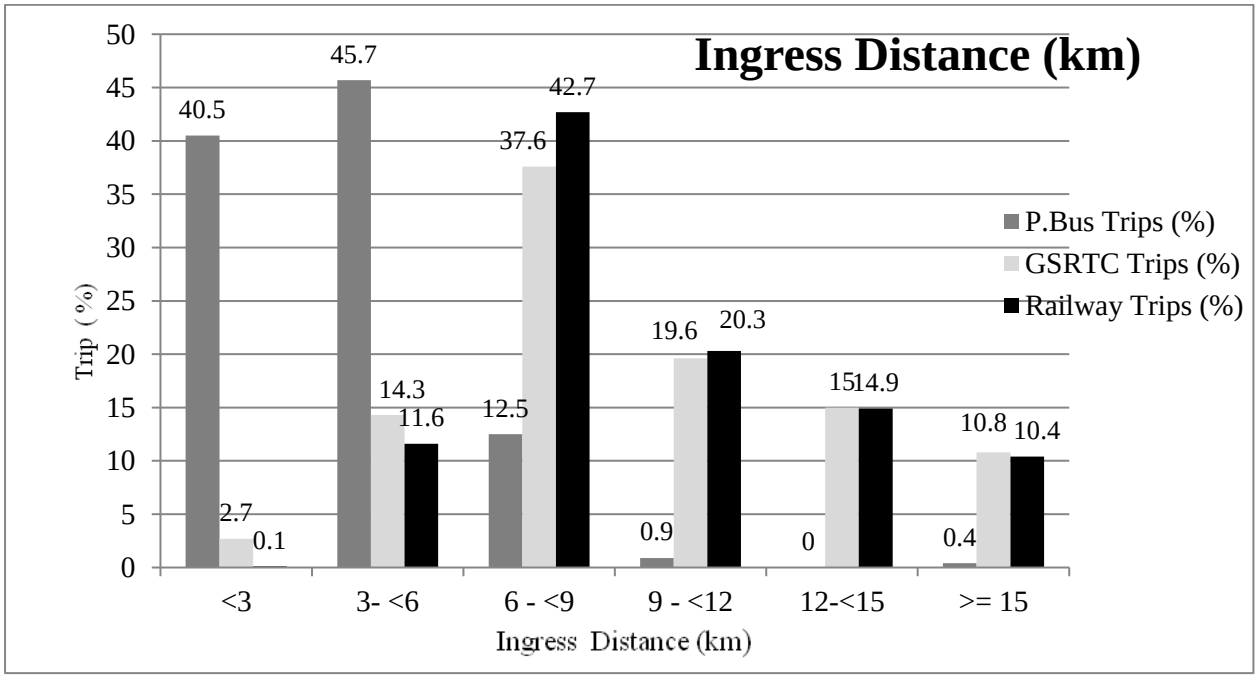

Fig. 2. Distribution of ingress distance (km)

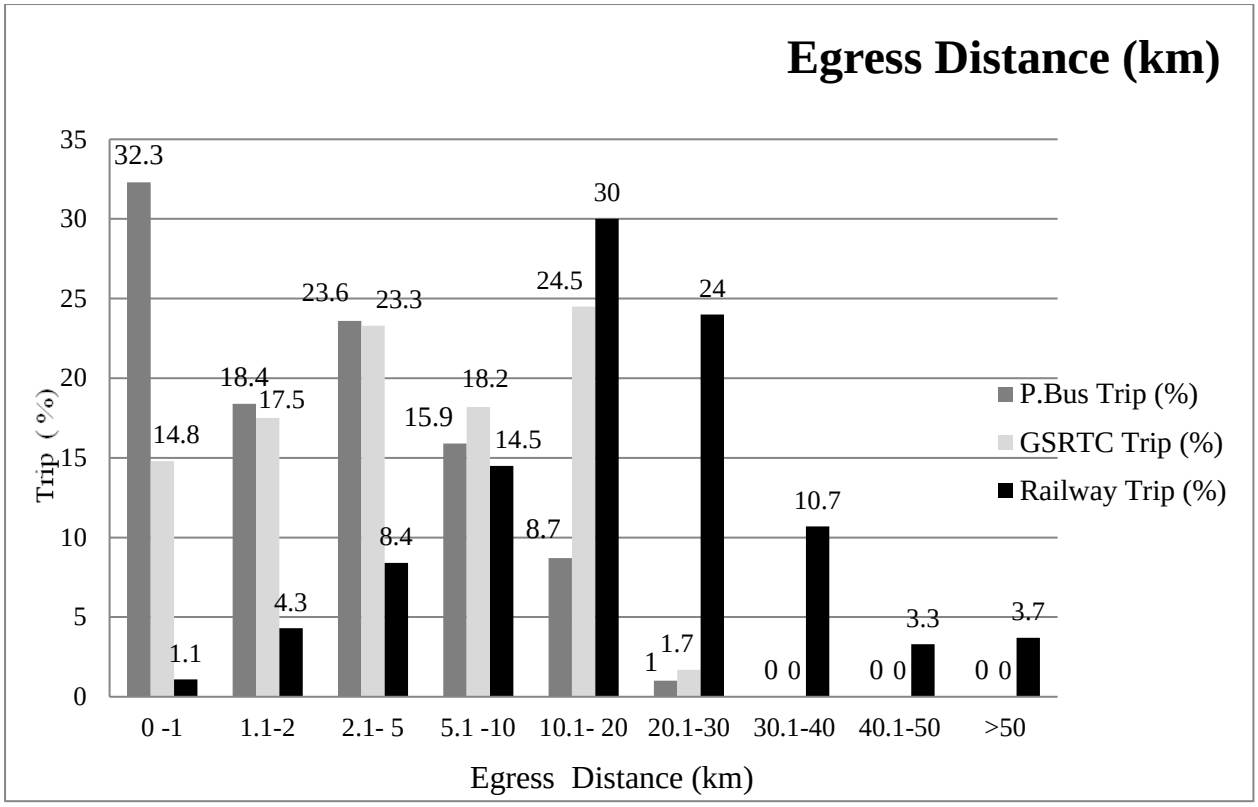

Fig. 3. Distribution of egress distance (km)

Respondents were asked to rate the quality of service offered by the modes as per their perception. It is presented in figure 4. Mode-wise classification of governing parameters perceived by the respondents for the mode selection is presented in figure 5.

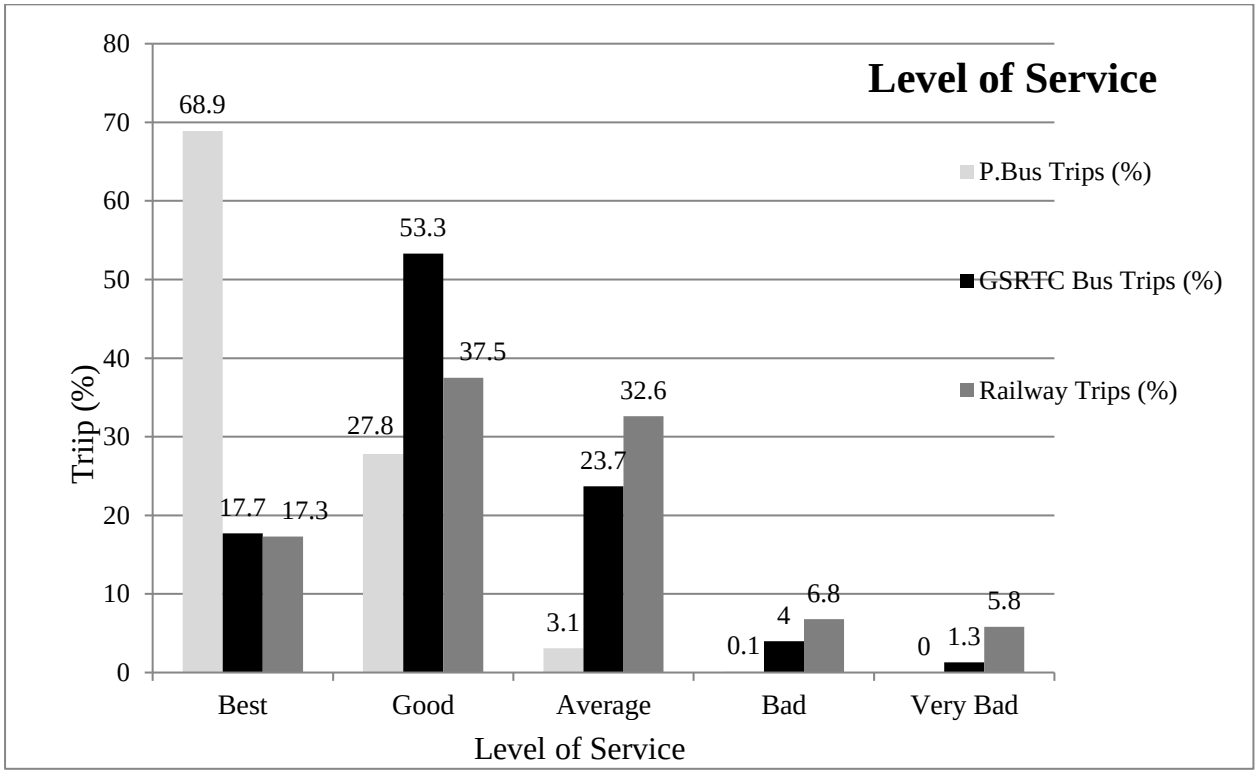

Fig. 4. Level of service perceived by travelers

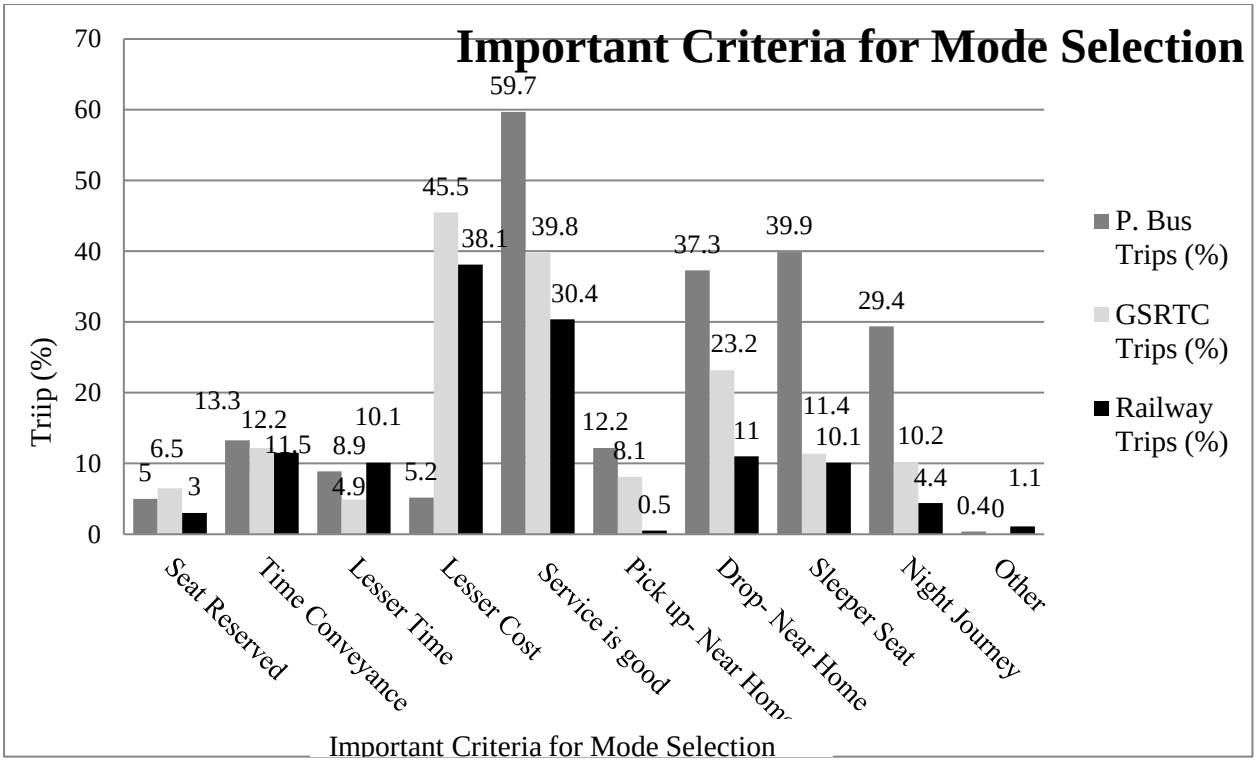

Fig. 5. Important criteria for mode selection

Better service level is an important criterion for the pbus mode selection. Because of higher travel costs of pbus mode, lower travel cost is an important governing criterion for the gbus and train travelers. The travelers for whom less ingress and egress distance were more important; they preferred pbus due to its well-distributed network in the study area. A variable representing the availability of night journeys was important for pbus users as the majority of all private buses run during the night in the study area. Service availability variables based on the number of buses and trains that run between Surat and destination taluka are derived.

6.4 Model Development

Based on the analyses of prior work concerned with mode choice modeling, choice variables for the model were selected. The variables' code and definition are presented in Appendix II.

Three main inter-regional public transportation modes have been considered, i.e. privately operated bus (pb), GSRTC bus (gb), and railway/train (tr) with reference to descriptive data analysis for modeling. The analysis includes calibration and estimation of the utility functions for the different models and then choosing the best model. The model with a logical sign, maximum log-likelihood value and, maximum goodness of fit index (ρ^2) value was considered as the most suitable model. The first trial model includes total travel time (T)

and total travel cost (C) as generic variables. The private bus mode was considered as a base mode. The utilities for different modes are presented in Eqs. (1a) to (1c) for the first trial model.

$$U_{pb} = \beta_1(T) + \beta_2(C) \quad (1a)$$

$$U_{gb} = \beta_G + \beta_1(T) + \beta_2(C) \quad (1b)$$

$$U_{tr} = \beta_T + \beta_1(T) + \beta_2(C) \quad (1c)$$

The significance of variables was checked and the non-significant variables were eliminated based on the logical sign, p-value, and likelihood ratio test. Expected influencing variables were added in their various forms and their statistical parameters were checked through NLOGIT software. Mcfadden's Pseudo R^2; ρ_c^2 and $\bar{\rho}_c^2$ are considered as goodness-to-fit measures for the model. The model was further refined by adding/removing different variables. The McFadden R^2, p-values, and Likelihood Ratio Test Statistics (LRTS) were used as evaluation criteria. Estimation results of the final model among all trial models developed during refinement are presented in Table 4. The correlation matrix has been used to check the correlation between input variables used in the model. The model estimation results and the final utilities for different modes are presented in Eqs. (2a) to (2c) respectively.

Table 4. Model Estimation

Variable	Final Model		
	Estimated coefficient	Significance	Exp (β)
Constant (tr)	0.3459	0.1913	1.41
Constant (gb)	-1.1633	0	0.31
Waiting Time at Egress (WD)	-0.0373	0	0.96
Egress Distance (DD)	-0.0347	0	0.97
Level Of Service (LS)	0.7966	0	2.22
Egress Cost/ Income (OVCD/Inc)	-0.0340	0.0037	0.97
TW/EM (tr)	-0.2387	0.0788	0.79
TW/EM (gb)	-0.3079	0.0452	0.74
Lesser Egress Distance RD (tr)	-0.7516	0.0002	0.47
Lesser Travel Cost RC (tr)	2.639	0	14
Lesser Travel Cost RC (gb)	2.8247	0	16.86
Night journey RN (pb)	1.1217	0.0001	3.07
Sleeper seat availability RSL (pb)	1.5665	0	4.79
Service Accessibility S(tr)	0.0408	0.0022	1.04
Urban Destination UR (gb)	2.3364	0	10.34
LL(0)	-2201.619		
LL(C)	-1644.212		
LL(θ)	-1068.041		

ρ_0^2	0.515
$\bar{\rho}_0^2$	0.513
ρ_c^2	0.3504
$\bar{\rho}_c^2$	0.3480

$$U_{pb} = -0.0347\ DD - 0.0373\ WD - 0.0340\ \ OVCD/IN + 0.7966\ LS + 1.5665\ RSL(pb) + 1.1217\ RN(pb) \quad (2a)$$

$$U_{tr} = 0.3459 - 0.0347\ DD - 0.0373\ WD - 0.0340\ {}^{OVCD}/_{IN} + 0.7966\ LS - \ 0.2387\ {}^{TW}/_{EM(tr)} - 0.7516\ RD(tr)+) 2.6390\ RC(tr) + 0.0408\ S(tr) \quad (2b)$$

$$U_{gb} = -1.1633 - 0.0347\ DD - 0.0373\ WD - 0.0340\ \ OVCD/IN + 0.7966\ LS - 0.3079\ \ TW/EM(gb) + 2.8247\ RC(gb) + 2.3364\ UR(gb) \quad (2c)$$

The developed model was tested by using 212 trip data. The log-likelihood value for the fitted model was -98 against the log-likelihood value of the intercept-only model as -200. Also, the McFadden ρ^2 value for the testing data was 0.54 satisfactory for the logistic model.

6.5 Model Analysis

It is worthwhile to know the extent to which the mode selection probability changes in response to changes in the value of important attributes. An elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in an attribute of the alternative. The elasticity for important attributes in the final model has been obtained. An arc elasticity, obtained with the probability-weighted sample enumeration method which was recommended by Hensher et al. (2005). Direct and cross elasticities were calculated for egress distance, waiting time, egress travel cost per average of income level (OVCD/Inc), and the number of two-wheelers per number of earning members in the household are presented in Table 5.

Table 5. The elasticity of important variables in the model

Attribute (Alternative)	Direct Elasticity (DE) and Cross Elasticity (CE)		
	pbus	Gbus	train
DD (gbus)	0.018 (CE)	-0.157(DE)	0.037 (CE)
DD (train)	0.064 (CE)	0.122 (CE)	-0.334 (DE)
WD (pbus)	-0.043 (DE)	0.092 (CE)	0.105 (CE)
WD (gbus)	0.019 (CE)	-0.017 (DE)	0.043 (CE)
WD (train)	0.047 (CE)	0.094 (CE)	-0.239 (DE)
OVCD/Inc (pbus)	-0.019 (DE)	0.039 (CE)	0.046 (CE)
OVCD/Inc (gbus)	0.009 (CE)	-0.075 (DE)	0.017 (CE)
OVCD/Inc (train)	0.023 (CE)	0.045 (CE)	-0.116 (DE)
TW/EM (gbus)	0.023 (CE)	-0.171 (DE)	0.047 (CE)
TW/EM (train)	0.025 (CE)	0.052 (CE)	-0.117 (DE)

If the egress parameter DD increased by 1% for gbus and train mode, the probability of choosing the gbus and train mode would be reduced by 0.16 % and 0.33 % respectively. The direct elasticity of WD and OVCD/Inc for the train mode was higher than the alternative modes. It reflects that there might be a more reduction in the probability of choosing the train mode with an increase in egress waiting time and egress cost.

As the elasticity of the categorically coded data is not meaningful, sensitivity testing for various scenarios was carried out. To study the variation in mode choice with reference to improvement in the Level of Service (LS) variable for gbus and train were obtained and presented in Table 6 and Table 7. The rise in the probability of choosing gbus and train mode were 13.1% and 20.1% respectively with the improvement in the level of service perceived by the travelers.

Table 6. Sensitivity testing of attribute LS on gbus mode

Change in Attribute	Affected Mode	Base		Scenario		Scenario- Base	
		% Share	Number of Trips	% Share	Number of Trips	Change in % Share	Change in Number of Trips
3 to 4	pbus	73.66	1476	68.11	1365	-5.55	-111
	gbus	5.88	118	14.68	294	8.79	176
	train	20.456	410	17.22	345	-3.24	-65
4 to 5	pbus	68.11	1365	65.24	1307	-2.87	-58
	gbus	14.68	294	18.96	380	4.28	86
	train	17.22	345	15.80	317	-1.41	-28
3 to 5	pbus	73.66	1476	65.24	1307	-8.42	-169
	gbus	5.88	118	18.96	380	13.08	262
	train	20.456	410	15.80	317	-4.66	-93

Table 7. Sensitivity testing of attribute LS on train mode

Change in Attribute	Affected Mode	Base		Scenario		Scenario- Base	
		% Share	Number of Trips	% Share	Number of Trips	Change in % Share	Change in Number of Trips
3 to 4	pbus	73.72	1477	67.33	1349	-6.39	-128
	gbus	13.87	278	11.47	230	-2.40	-48
	train	12.42	249	21.20	425	8.78	176
4 to 5	pbus	67.33	1349	58.56	1174	-8.77	-175
	gbus	11.47	230	8.86	178	-2.60	-52
	train	21.20	425	32.57	653	11.37	228
3 to 5	pbus	73.72	1477	58.56	1174	-15.16	-303
	gbus	13.87	278	8.86	178	-5.00	-100
	train	12.42	249	32.57	653	20.16	404

To understand the influence of the types of the destination region (urban/rural), the binary variable UR for gbus was simulated. It reveals that there is a 27.5 % rise in the probability of choosing gbus if the change in destination from rural to urban as presented in Table 8.

1. Table 8. Sensitivity testing of attribute UR on gbus mode

Change in Attribute	Affected Mode	Base		Scenario		Scenario- Base	
		% Share	Number of Trips	% Share	Number of Trips	Change in % Share	Change in Number of Trips
0 to 1	pbus	71.88	1440	52.64	1055	-19.24	-385
	gbus	8.30	166	35.776	717	27.47	551
	train	19.82	397	11.59	232	-8.23	-165

6.6 ANN Model

Multilayer feed-forward neural network with single hidden layer was developed with backpropagation Levenberg-Marquardt algorithm. Initially, input variables of the MNL model were used after normalization between 0 and 1. The nodes in the input layer were 11. After the number of trials, 35 hidden nodes were observed as an optimum number to avoid overfitting. The coefficient of correlation (r) value, used to measure the correlation between actual and predicted output in training, validation, and testing are 0.85, 0.76, and 0.75 respectively. However, the correctly classified percentage shown in table 9 reveals that the ANN model needs improvement to serve the aim.

Table 9: Correctly Classified mode (%)

Sr	Mode	Correctly classified (%)
1	Train	51.51
2	Gbus	82.93
3	Pbus	87.44
	Aggregate	80.34

The mode selection process of decision-makers is highly influenced by the difference in attributes (Koppelman and Bhat, 2006). Therefore, the difference of the generic variables such as egress distance, waiting time at egress, egress cost/income were added to the model to make it more realistic. The revised ANN model has been developed with 19 input variables as input nodes. The most efficient model has been selected based on the results of the various trials with

the varying number of hidden nodes as presented in table 10 in figure 6. Percentage of the correctly classified modes are tabulated in table 11 for all the trials.

Table 10: Network sensitivity analysis

No. of Hidden nodes	Coefficient of Correlation (R)			
	Training	Validation	Testing	Total
5	0.8328	0.8066	0.7717	0.8175
10	0.8646	0.7816	0.8103	0.8424
15	0.9079	0.8282	0.754	0.873
20	0.8786	0.8233	0.8527	0.8659
25	0.9398	0.8653	0.8254	0.9105
30	0.8858	0.8601	0.8199	0.8725
35	0.9099	0.7861	0.8556	0.8845
40	0.9048	0.8246	0.7756	0.871
45	0.9514	0.8413	0.7671	0.9058

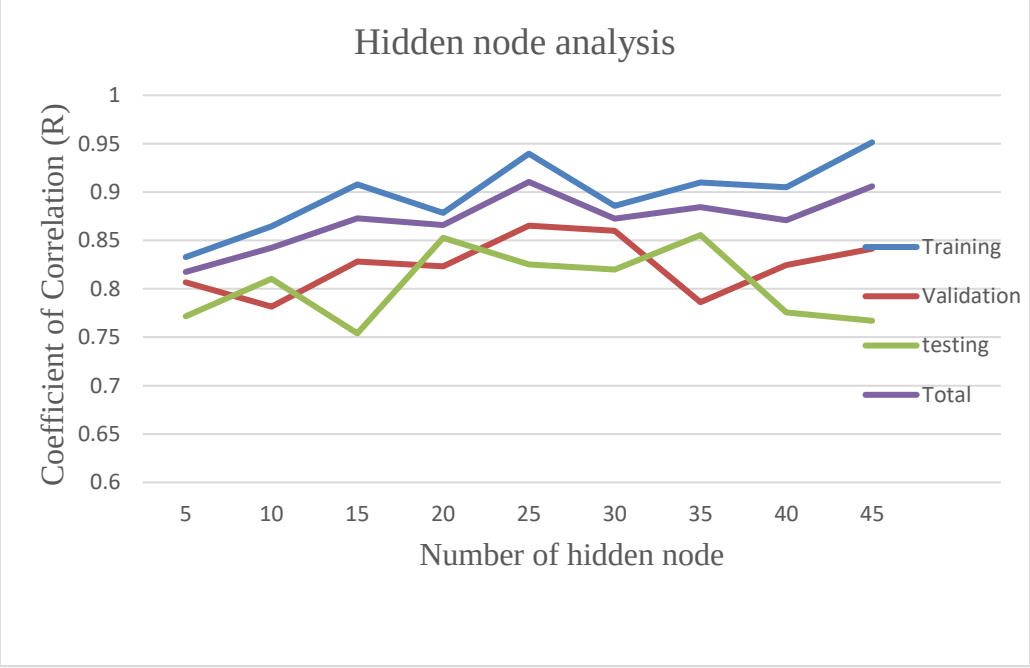

Figure 6: Hidden Node Analysis

The model with 35 hidden nodes has a maximum r value in testing. However, considering the prediction accuracy of modes as shown in Table 11 the model with 25 hidden nodes is considered the best model. It has r value in training, validation, and testing as 0.9398, 0.8653, and 0.8254 respectively.

Table 11: Prediction success rate

No. of Hidden nodes	Prediction success (%)			
	Train	Gbus	Pbus	Total
5	52.05	69.92	88.73	79.74
10	52.05	73.98	89.66	80.89
15	74.79	81.71	91.1	86.98
20	60.27	85.77	87.72	82.49
25	84.93	82.52	93.4	90.52
30	64.11	84.55	88.73	83.73
35	66.03	83.74	90.6	85.28
40	59.45	85.77	89.38	83.48
45	83.01	81.3	93.68	90.22
50	62.19	85.37	89.52	84.03

The cross-classification data presented in table 12 indicates that the revised ANN model has a higher prediction capacity than the previous ANN model.

Table 12: Prediction success table

		Predicted output		
		Train	Gbus	Pbus
Actual output	Train	84.9	14.5	0.5
	Gbus	10.6	82.5	6.9
	Pbus	0.3	6.3	93.4

The performance of ANN is good in predicting the observed choice. However, it suffers from the lack of methods for the interpretation of the significance of input variables. This black box image of the neural network is revealed by finding the effect of the variables on the output. For this purpose, a relative variation in the output with respect to varying the input value by its standard deviation from the mean was determined by keeping all other variables at their mean value. The procedure was repeated for all variables. It is found that level of service, egress distance, type of destination, egress waiting time as well as sleeping seat availability and night journey as governing parameters are having more relative importance (RI) which is shown in figure 7. The importance of these variables has been observed in the MNL model also.

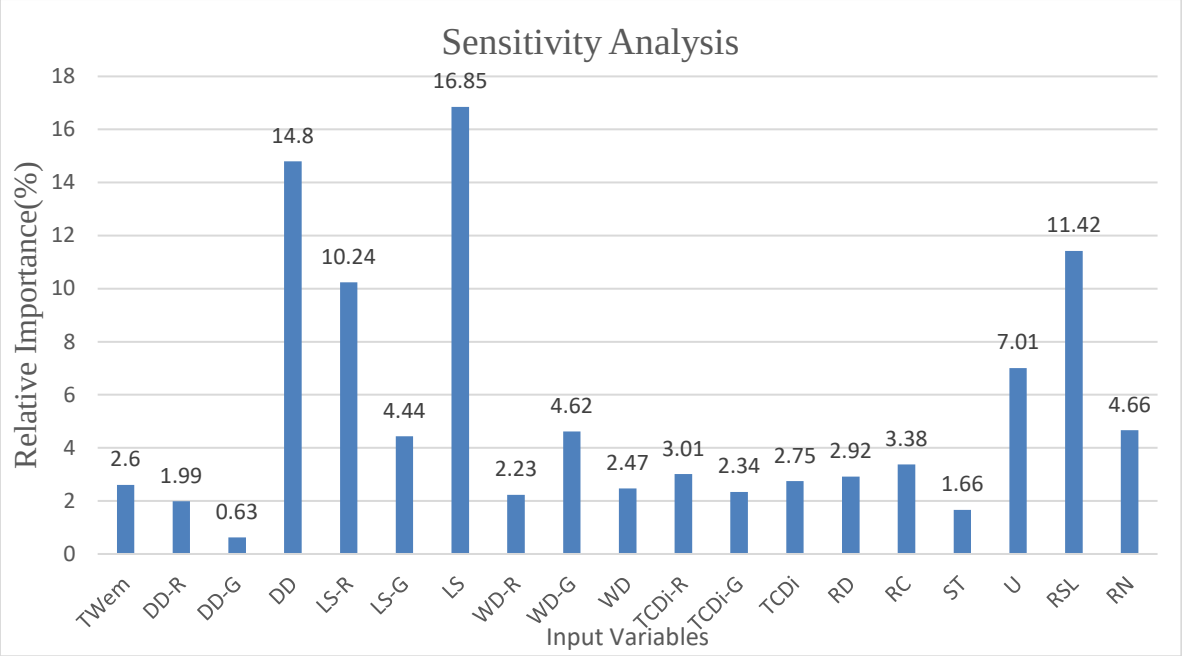

Figure 7: Sensitivity analysis of input variables

7. Achievements with respect to objectives

- To achieve the first objective i.e. to understand the travel pattern in the study area, all available alternatives have been identified and among them, passenger trips were focused. Data of private buses, GSRTC buses, and railway frequency were collected and analyzed. Moreover, travel time, travel cost, and route for selected mode have been compared. A detailed survey was carried out after the pilot survey. The importance of various factors was perceived through the analysis of the collected data.
- To achieve the second objective i.e. to develop a model to predict mode choice in the study area, the MNL model has been developed. For the model building, 2004 trip data were used. The final model was developed by several trials with varying influencing factors. Each variable and model was checked for statistical significance. The model has been validated from 212 external trip data. ANN models have been developed with the same input as well as revised input.
- The third objective- to understand the influence of the various parameters in the model was achieved during the model refinement process and with the help of the final model. The influence of variables has been understood by their sign, significance level, and value. The same has been supported by ANN model analysis.
- The fourth objective i.e. to suggest improvement in the transportation facilities is achieved by some conclusion derived from β of the utility functions. Also, elasticities of a few

variables were calculated to check the relative change in the probability of the particular mode selection. Moreover, to check the importance of category-coded variables such as service level, sensitivity testing has been carried out. With the help of these analyses, some suggestions to attract travelers toward GSRTC bus and railway mode have been derived.

8. Conclusion

The result expected from developing the inter-regional mode choice model for the passenger trip between Surat city and Bhavnagar region of Gujarat state may help the authorities and public transport agencies to make marginal decisions. Several conclusions derived from this study are as follows:

- In the final MNL model, all the parameters have expected signs and are found significant at a 95 percent confidence level. The best-fitted ANN model is found with 25 hidden nodes.
- A comparison of the prediction result of all models shows that the performance of the ANN model with revised input is better than other models. The prediction success rate of the revised ANN model increased to 90.52 % compared with 70.11 % of the MNL model. The performance of the ANN model could be increased by adding input variables representing the difference in attributes.
- The MNL model indicates that vehicle ownership, egress distance, waiting time at egress, transport service availability, type of destination (Urban/rural), facility/service level offered by the mode have impacted the mode choice decision. All these variables except vehicle ownership and transport service availability have been found important in the ANN model analysis also.
- Additionally, travelers are asked regarding their governing parameters for the mode choice. It is observed that lesser egress distance, lesser egress cost, availability of night journey, reserved sleeping seat availability are found important parameters for the mode selection.
- Governing binary parameters, availability for night journey and reserved sleeping seat for the private bus have a strong positive effect with β 1.12 and 1.567 reflect the few reasons for private bus popularity. Sensitivity analysis of the ANN model also reveals the very high importance of these parameters with RI of 4.66 % and 11.42 % respectively. Therefore, railway and GSRTC modes may change their timing for attracting more travelers.

- Vehicle ownerships (TW/EM) in the household have a negative effect on choosing GSRTC and Railway mode compared with the private bus having a comparatively higher fare structure. This reflects that travelers with higher vehicle ownership (indirectly higher income) prefer costly travel modes.
- Travel time parameters have no proper effect on the mode choice decision might be due to the overnight journey. Minor travel time saving is not governing criteria when a sleeping facility is available during an overnight journey. The effect of egress travel time is indirectly considered in the egress distance parameter, which has a proper negative sign with a 95 percent confidence level.
- The private bus popularity reveals that the effect of travel cost is dominated by better service level offered and favorable egress parameters.
- The level of service offered has a strong positive effect (β=0.7965) on choosing the mode. The same has been agreed by ANN model analysis also, with 16.85 % RI. The level of service of the modes is ranked based on regularity, fare structure, travel time, vehicle condition, etc. perceived by travelers. The probability of choosing the less ranked modes gbus and train can increase up to 13.1 % and 20.2 % respectively with the improvement in the level of service.
- Destination in an urban area has a strong positive effect (β=2.3371) on choosing GSRTC bus reflects its uneven distribution network in the rural region. There is a 27.5 % rise in the probability of choosing gbus if a change in destination variable UR changed from 0 to 1. It may be the scope for the GSRTC to attract the passengers having a destination in the rural region by providing the proper connectivity in the rural area.

9. Copies of papers published and a list of all publications arising from the thesis

- Ramanuj, P. S. and Varia, H. R. (2018). Mode Choice Analysis: Fundamental and Models. *Trends in Transport Engineering and Applications*, 7-13.
- Ramanuj, P. S. and Varia H. R. (2018). Application of Soft Computing Techniques in Mode Choice. Pramana Research Journal, Vol. 8, Issue 11, 357-365.

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Appendix 1

Survey Form Form No.: J/

Information provided by you will be used only for the research work of the student. This information is useful to improve usefulness of the transportation system joining Surat with Bhavnagar, Amreli and Botad. You are please to provide reliable information by sparing you valuable time.

Part 1- Passenger's Information

1.	Area in which you living?	Area: ☐ Nana Varachha ☐ Mota varachha ☐ Katargam ☐ Karodra
		☐ Ved Road ☐ Amroli ☐ Adajan ☐ Rander ☐ Other:_____
	Name of Society	:_____ 2 Your Age: ___ ☐ Male ☐ Female
3.	Occupation:	☐ Student ☐ Govt. Servant ☐ Private Job ☐ Self Employed
		☐ House Wife ☐ Diamond Industry ☐ Retired ☐ Other (_____)
4.	Total Household Income(Monthly)Rs	☐ Less than 10,000 ☐ 10,001 to 20,000
		☐ 20,001/- to 30,000/- ☐ 30,001 to 50,000 ☐ 50,001 to 1,00,000/- ☐ Greater than 1,00,000
5.	No. of Person in Household: ___	No. of Earning Members: ___
6.	No. of Two Wheelers in Household(HH): ___	No. of Car in HH: ___
Part 1 B	7. Distance of following places from your House in Surat (Useful for Native Journey)	
	Dist. Of GSRTC Bus Station/ Nearby Pick-up point:_____KM	Dist. Of Private Bus Office / Nearby Pick-up point: _____KM
8.	Distance of Following places from your House in Native (Useful for trip between Surat and Native) KM:	
	Dist. Of GSRTC Bus Station/ Drop point: ___	Dist. Of Private Bus Office / Drop point: ___ Railway Station: ___
9.	Name of your Village/ City in Native:_____	10. No. of native's Visit during Last year:_____

Part 2- Trip Information (1 Year)

			Trip 1	Trip 2	Trip 3	Trip 4	Trip 5
1.	Trip Date/ Month:						
2.	Main Trip Mode (√ Please Tick)	Private Bus					
		GSRTC Bus					
		Railway					
		Car					
		Railway upto Baroda, Private bus from Baroda					
		Railway upto Baroda, GSRTC bus from Baroda					
		Plane					
		Ghogha- Dahej Ferry Boat					
		Other (Write vehicle Name)					
3.	Trip Cost(Train/ Bus/ Ferry Boat fare)						
	Travelled in sleeping Seat? (√/×):						
	Waiting Time to pick up a Bus/ Train(at station/ pick-up) Minute:						
4.	Trip Purpose: (√ Tick)	Social					
		Festival Celebration					
		Business					
		Recreational					
		Other (Write purpose)					
5.	No. of Group Member traveling with you:						
6.	Stay Duration(days):						
7.	Journey Time(HH:MM)	Start Time (from your House):					
		End Time:					
8.	Journey Details -between your house to pick up Bus/ Train						
	8.1 Vehicle Used (√ Please Tick)	Auto					
		City Bus					
		Commuted by Two Wheeler					
		Commuted by Car					
		Walk					
		Other (Please Write name)					
	8.2 Journey Time(Minute):						
	8.3 Journey Expenditure (Rs.)						
	8.4 Waiting Time (Minute):						
9.	Journey Details- Between Drop Point to Your home in Native						
	9.1 Name of Drop/ Destination Point						
	9.2 Vehicle Used (√ Please Tick))	Auto					

1

			Trip 1	Trip 2	Trip 3	Trip 4	Trip 5
		Tempo					
		Bus					
		Picked up by Two Wheeler					
		Picked up by Cay					
		Walk					
		Other (Please Write name)					
	9.3	Journey Time(Minute):					
	9.4	Journey Expenditure(Rs.)					
	9.5	Waiting Time (Minute):					
10.	Fill the following Details (Point -10), if travelled by Dahej- Ghogha ferry boat						
	10.1	Details of Journey between Surat to Dahej – Vehicle Used					
		Travel Time(HH:MM)					
		Travel Expenditure(Rs)					
	10.2	Waiting Time at Dahej (Minute):					
	10.3	Details of Journey beween Ghogha to your home (native) – Vehicle Used					
		Travel Time(HH:MM)					
		Travel Expenditure(Rs)					
	10.4	Waiting Time at Ghogha(Minute):					
11.	Reasons of Selecting Vehicle, selected by you (✓ Please Tick)						
		Reserved Seat					
		Convenient Journey start/End Time					
		Less Travel Time					
		Less Travel Cost					
		Better Service					
		Pick up point near to home					
		Drop point near to home in native					
		Sleeper seat					
		Night Journey					
		Other (_____) Write Details					
12.	Did you return journey by same vehicle type? (Y/N)						
		If No, Details of Vehicle					

13. Journey Details- Between Drop Point to Your home in Native(Write the Provisional journey details for the mode didn't use out of Train/ GSRTC Bus/ Private Bus during the year)	If Travelled by GSRTC Bus....	If travelled by Train....	If Travelled by Private Bus....
Name of Drop point			
Vehicle can be used from the drop point			
If more than one vehicles need to be used: Give Details			
Tentative Travel time (Minute)			
Tentative trip Expenditure (Rs.):			
Tentative Waiting Time (minute):			

14. Rate the following Transport Service, useful for the traveling between Surat to Native as per Service Offered (✓ Please tick)		Excellent	Good	Average	Poor	Very Bad
1.	GSRTC Bus Service					
2.	Private Bus Service					
3.	Train Service					
4.	Ghogha - Dahej Ferry (Tick only if Travelled by Ferry Boat)					

Part 3 –Future Trips Selection

1.	Will you Travelled by Railway if reservation is available?	☐ Yes ☐ No {Reason if 'No' :_____}
2.	Will you travelled by Railway if train timings are convenient for night journey? ☐ Yes ☐ No {Reason if 'No' :_____}	
3.	Will you travelled by GSRTC if bus stops are within 1 KM from your home ? ☐ Yes ☐ No {Reason if 'No' :_____}	

4. Will you travelled through Ro Ro ferry service in the following condition?			5. Remarks
Travel Time Saving :	15 %	Yes ☐	
Raise in Travel Cost:	80 %	No ☐	
Frequency of Ro Ro Ferry service per day:	2		

Appendix 1I

Variable code and definition

Sr.	Parameter	Variable Code	Definition
1	Age	AG	1, if ≤ 20; 2, if 21 - 39; 3, if 40 - 59; 4, if ≥ 60
2	Gender	GND	1, if male; 2, if female
3	Occupation	OCC	1= Self-employed; 2 = Diamond industry; 3 = Private Service; 4 = House wife; 5 = Other; 6 = Retired; 7 = Student
4	Income Level	IN	1: < 10000; 2: 10001-20000; 3: 20001 - 30000; 4: 30001 – 50000; 5: 50001 - 100000; 6: > 100000.
5	Average Income	INC	Average of income group. Unit Indian Rupees.
6	No. of TW	TW	Number of Two-wheelers in Household. Discrete Value
7	Member in Household	HH	Number of Members in Household. Discrete Value
8	Earning Member	EM	Number of Earning Members in Household. Discrete Value
9	Car Ownership	CW	Number of Cars in Household. Discrete Value
10	Out-of-Vehicle Distance	DST	Continuous. Unit –kilometer
11	Egress Distance	DD	Continuous. Unit –kilometer
12	Total Travel Time	T	Continuous. Unit – Hours
13	Total Travel Cost	C	Continuous. Unit Indian Rupees.
14	Main Mode Travel Time	IVT	Continuous. Unit – Hours
15	Total Egress time	WTD	Continuous. Unit – Minutes.
16	Main mode Cost	IVC	Continuous. Unit Indian Rupees.
17	Egress Cost	OVCD	Continuous. Unit Indian Rupees.
18	Waiting time at Egress	WD	Continuous. Unit – Minutes.
19	Level of Service	LS	Discrete: 1: Very Bad; 2: Bad; 3: Average; 4: Good; 5: Best
20	Lesser Egress Distance	RD	Governing criteria for Mode Selection - Lesser Egress Distance (1 if yes, 0 otherwise)
21	Lesser Travel Cost	RC	Governing criteria for Mode Selection - Lesser Travel Cost (1 if yes, 0 otherwise)
22	Service Availability	S	Index based on Frequency of mode availability between origin and destination Taluka.

23	Night Journey	RN	Governing criteria for Mode Selection - Night Journey (1 if yes, 0 otherwise)
24	Better Service/ Facility	RS	Governing criteria for Mode Selection - Better Service availability in a journey (1 if yes, 0 otherwise)
25	Sleeper Seat Availability	RSL	Governing criteria for Mode Selection - Sleeper Seat availability in a journey (1 if yes, 0 otherwise)
26	Urban Destination	UR	Destination is in Urban (1 if yes, 0 otherwise)
27	Peak Month	PM	Trip in the peak period (1 if yes, 0 otherwise)
	Mode Selected	MOD	1: Private bus (pb/pbus); 2: GSRTC Bus (gb/gbus); 3: Railway (tr)