

Development of Intercity Travel Demand Models for a Highly Industrialised Regional Corridor



Rohit Rathod, Sunil Parmar, Ashutosh Maurya, and Gaurang Joshi

Abstract To generate cash flow in the economy, it is essential to develop the skillset of people in the country. This is done by taking care of induced travel demand generating year on year since it keeps on increasing with urbanisation. Hence, it is indispensable to provide effective and adequate transport infrastructure at the right time by analysing demand. As a service operator, it is equally important to provide the supply in the form of transport infrastructure like wide road width, flyovers, bridges, bus stops, and railway stations in the country. In the case of the movement of people and goods, the railway comes as the predominant and reliable mode of transport. For this study, the highly industrialised regional corridor covering Surat, Ahmedabad, and Vadodara is considered to develop the intercity passenger demand models and observe its sensitivity. To analyse the demand at the regional level, a direct demand model is developed, and it is found that the demand is going to almost double in 2030. The sensitivity analysis showed that a one percent change in travel time shows higher passenger demand compared to a unit change in travel cost and annual frequency.

Keywords Direct demand modelling · Demand elasticity · Travel demand · Ridge regression · Sensitivity analysis

1 Introduction

The economy of any country is the backbone of its peoples' livelihood. It is essential to make the cash flow in the economy for the survival and growth of any country. This cash flow happens through the movement of people and goods from one place to the other because of the spatial distribution of the resources in the country. For all such valuable economic activities, there is an indispensable and induced need for a transportation system. To boost economic growth, it is important to provide sufficient facilities for the smooth conduct of activities. While focusing on supplying

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the goods and passengers the transport facilities, it is required to know the demand beforehand. Since the activities take place in the physical world, to cater to its demand it is favourable to take decisions for the supply of the transportation system for the future years. In this process, there is a need of modelling the transport demand so that decision makers can be assisted in forming transportation planning decisions. This demand can be generated within the city (Intracity) as well as between the cities (Intercity).

The urban and regional contexts are totally different in the case of transportation systems. Urban travel generally demands a single mode of transportation, mostly road transport, whereas regional travel demands a different pattern with multiple modes of transportation. This further comes with more complexions with a number of modes available for access, egress, and trunk route journey. To analyse and alleviate the complexion of travel demand, it is required to perform the modelling which will support the decisions taken by the decision makers. Again, there is a different modelling approach for urban and regional contexts.

Multimodal inter-regional travel demand models can be made through various approaches. If the behavioural responses are considered at the aggregate level, then a direct demand model and elasticity analysis can be developed. If not considered, then only origin–destination estimation without behaviour theory is made. Furthermore, if disaggregated individual behaviour is considered, then a four-stage model is used. From therein, for analysing trips, the trip-based four-step models and for analysing tours/activity chains, activity-based modelling is done. At the regional level, developing an aggregate model is more sensible considering the complexities in the behavioural responses.

Urban travel demand can be approached by disaggregate modelling where each behavioural measure is analysed. Conventionally, the urban travel demand is modelled through the four-step modelling or sequential modelling which are trip generation, trip distribution, modal choice, and trip assignment. While doing so for regional context, it requires a huge dataset and at such a macrolevel, the homogeneity can be perceived and hence, for regional travel demand aggregate models are used.

In the conventional modelling approach, the estimation of relatively well-defined submodels is necessary which requires disaggregated data of the entire study area. This makes the task complicated at the regional level. Also, there is a challenge of calibrating the gravity model which creates problems with the errors in trip end totals and for those generated poorly from intrazonal trips. This drawback is eliminated in the case of direct demand model where it is calibrated simultaneously for all the three submodels, i.e., trip generation, trip assignment, and mode choice.

2 Literature Survey

Wirasinghe and Kumarage attempted to formulate an aggregate total demand model for estimating the inter-district passenger travel by public transport in Sri Lanka. Limitations of the model proposed were large calibration error, correlation between

socio-economic variables, correlation between impedance variables, inappropriate functional forms, and spatially non-transferable [1]. Ibe modelled an intercity travel demand model for Nigeria. The study found that passenger traffic is closely related to the frequency of vehicle trips, available bus fare, vehicular capacity, distance between origin and destination, and journey time performance of vehicles [2]. A log-linear relationship between travel demand and the explanatory variables was developed.

Woldeamanuel compared the intercity bus service with other competing modes. It concluded that intercity buses are environment-friendly, economically viable, and socially inclusive modes of long-distance travel. Intercity bus provides services to many rural areas which are far apart from the other intercity transit services [3]. Peers and Bevilacqua stated that the separate formulation of models by mode provides the opportunity to achieve the maximum flexibility in the model specification in direct demand modelling [4]. One of the initial formulations for the direct demand models was the Kraft-SARC model which had later on been modified by Mc-Lynn. Filippini and Deb studied 22 Indian states to estimate the log-linear travel demand function using panel data over the period of 1990–2001 [5]. It stated that the population has a positive and significant impact on travel demand. Fouquet studied the behaviour of real income and the price elasticity of demand for aggregate transport [6].

The report of “Transit and Quality Service Manual, third edition” provides the quality of service measure for the transit mode for comfort and convenience as passenger load, reliability, and transit auto travel time. Other factors mentioned were safety, security, and employee interactions with customers. Sinha identified that the key quality of service parameters of public transport is i) Cost, ii) Time, and iii) Quality of attributes of onboard comfort, ease of transfer, and information availability [7]. The report on “Understanding Transport Demands and Elasticities” mentions the elasticity of travel with respect to travel time for various modes and time periods, based on Portland, Oregon, data. It indicates that each 1% increase in AM peak drive-alone travel time reduces vehicle travel by 0.225% and increases demand for shared ride travel by 0.037% and transit by 0.036%. Frank found that transit riders are more sensitive to the change in travel time or waiting time compared to transit fare. A 10% increase in the in-vehicle travel time will reduce the transit demand by 2.3%, whereas a 10% increase in the transit fare will reduce the transit demand by 0.8% only [8].

Gaudry and Wills investigated the different forms of travel demand models that have been part of the different studies. It found that the sequential urban travel demand model is linear whereas the intercity travel demand model is generally of the log-linear form. This states that incorrect form of modelling can lead to erroneous results of the important parameters in the model [9]. Semeyda developed the travel demand forecasting models for low population areas using two different methods, multiple linear regression, and generalised linear modelling (GLM) and then compared them which suggested that the GLM procedure offers a more suitable and accurate approach than linear regression for developing number of trips [10].

Filippini and Deb report that the aggregate transit demand can be estimated from a linear function model, semi-log linear model, log-linear model, and generalised log-linear model. The most common functional form used is the log-linear model



Fig. 1 a Ahmedabad TAZ, b Surat TAZ, and c Vadodara TAZ

because it reduces the number of coefficients to be estimated and the coefficient of the log-linear model directly estimates the elasticity [5].

Yahya carried out the study on modelling the variables when the data shows multi-collinearity and overfit to the testing data. For the stable and efficient estimates of the parameters in the presence of multi-collinearity in the data, it is suggested that the variables should be scaled at unit length or have zero means and unit standard deviation. Studies suggested that it is necessary and desirable to scale the predictor variables in ridge regression modelling when the presence of multi-collinearity is suspected [11].

3 Study Area

The economy of Gujarat state is the third largest in the country with a per capita GDP of 1,57,000. Also, Gujarat has been in the top five contributors to Indian GDP.

Moreover, in this state the corridor of three districts in the central and south regions, Ahmedabad, Vadodara, and Surat, have been taken for this study considering the heavily populated and industrialised corridor. The municipal areas have been delineated based on TAZ in the municipal area. Surat, Ahmedabad, and Vadodara have been divided into 7, 6, and 4 TAZs, respectively, as shown in Fig. 1.

4 Demography

The demographic profile of all three cities is mentioned in Table 1.

Table 1 Demographic profile of all cities

City	Population (2011 census)	Area (Sq. km.)	Decadal growth (2001–2011)
Surat	4,466,826	326.515	55.29%
Ahmedabad	5,577,940	466.000 (2006)	58.46%
Vadodara	1,752,371	230.660	34.16%

4.1 Linkages Between Cities

All three cities are well connected through Rail, Road, and Air Transport. Rail transport is considered for the study and study corridors are mentioned below.

- (1) ST-ADI Rail Corridor
- (2) ST-BRC Rail Corridor
- (3) ADI-BRC Rail Corridor.

5 Data Collection

The following sections are provided for the secondary data collected for the present study.

5.1 Railways Secondary Data

For the current study, secondary data were collected such as for railways; historical passenger travel demand has been collected from the Ministry of Indian Railways (Railway Board), New Delhi, for the past 11 years from January 2009 to December 2019. Railway passenger demand data has been collected for all types of trains (passenger, Mail, Express, superfast, Shatabdi, Special trains, etc.) with 1A, 2A, 3A, CC, EC, FC, SL, and 2S. Later, for ease of analysis and evaluation, the data is segregated into Non-AC and AC classes.

5.2 Population

Historical population data was collected from the official website of Surat Municipal Corporation. The population of municipal areas of all three cities has been listed on a decadal basis from 1901 to 2011. For the construction of Direct Demand Models, the population is estimated from 2011 to 2019.

5.3 Annual Income Per Capita

Annual Income Per Capita has been collected from the national high-speed rail feasibility report. The report has published the annual income per capita of the city for the year 2006.

5.4 Travel Time

Access and Egress Travel time has been collected from the centroid of every zone to the intercity terminal such as railway stations and bus stands with the help of Google Maps. Travel time for the trunk route journey has been taken as per the published schedule of the services.

5.5 Travel Cost

Travel cost has been estimated based on fuel prices. The fuel prices have been collected from the petrol pump.

5.6 Service Frequency

The frequency of the railways has been collected as per the timetable provided by the railway board.

6 Data Analysis

After the data collection, irrespective of the type of data (qualitative or quantitative), analysis may consist of following steps:

1. Describe and summarise the data
2. Identify relationships between variables
3. Compare variables
4. Identify the difference between variables
5. Forecast outcomes.

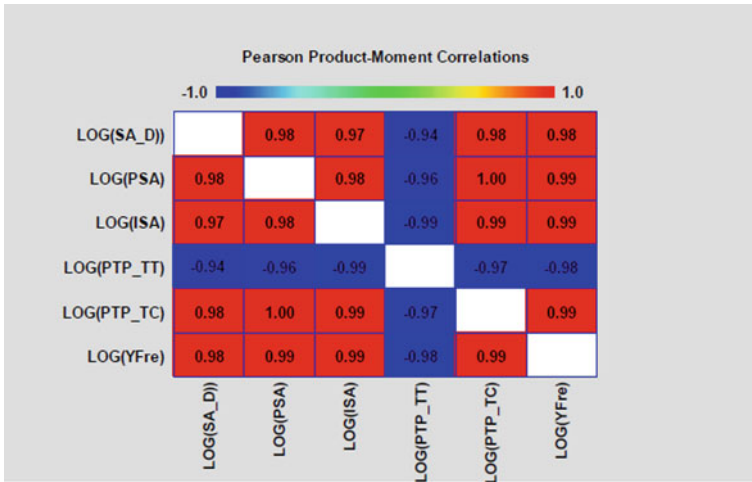


Fig. 2 Multi-collinearity in dataset

6.1 Ridge Regression

To identify the relationships between the variables, the Pearson correlation method was used. But the results showed that it is an overfit model which is shown in Fig. 2 and cannot be used reliably over the forecasting.

Hence, to alleviate the variance in the model, another statistical method called Ridge Regression was used. In this method, it changes the line of least squared fit to ridge regression line that will compromise on the bias but reduces the variance that is needed for the model. It adds an additional term in the least squared fit equation as the product of the lambda value and square of the slope of the line. The lambda value can be obtained by ten-fold cross validation.

6.2 Passenger Demand Analysis

The secondary data obtained from the Ministry of Railway Board gives passenger demand for the last 11 years. The railway passenger demand (RPD) variation over the years is shown in the following figures. Figure 3 shows the overall demand variation, whereas Figs. 4 and 5 are showing demand variation for AC and Non-AC classes, respectively. It can be observed that Surat-Ahmedabad is having the highest demand compared to Surat-Vadodara and Vadodara-Ahmedabad sections.

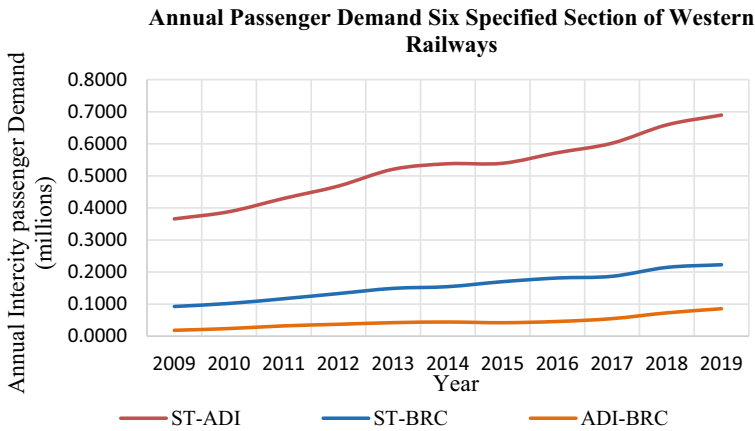


Fig. 3 Railway passenger demand variation from 2009 to 2019

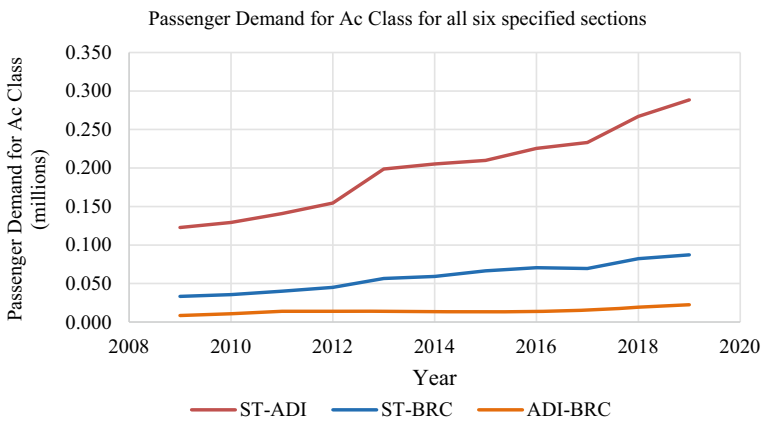


Fig. 4 RPD AC variation from 2009 to 2019

6.3 AC Class Passenger Demand

6.4 Non-AC Passenger Demand

As shown in the above Fig. 5, Non-AC class passenger demand is highest in all sections. The relative demand of Non-AC class passenger demand with respect to AC class passenger demand is shown below:-

- i. ST-ADI—1.71
- ii. ADI-ST—1.86
- iii. ST-BRC—1.70

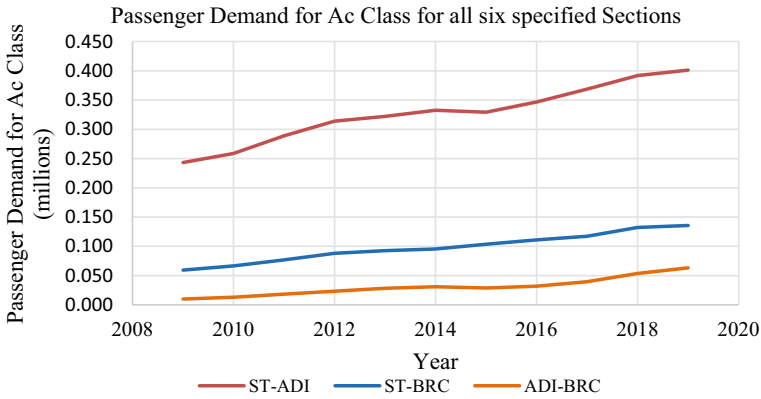


Fig. 5 RPD non-ac variation from 2009 to 2019

- iv. BRC-ST—1.81
- v. ADI-BRC—2.03
- vi. BRC-ADI—1.89.

6.5 Input Variables for Direct Demand Model

For the direct demand model, the intercity demand has been correlated with the product of the population of two cities, product of annual income per capita of two cities, travel time between two cities, travel cost for the chosen mode, and annual frequency of the services for the chosen between two cities. Because of the difficulty in predicting the population of a specific age group who make the intercity trips, the total population is considered for the forecasting.

There can be many measures of income to include in the model: Income distribution, median income, or mean income. Using income groups for the model will be quite unpredictable for forecasting. To forecast median income would require either a projection of the total income distribution or a model relating the median income to some other, more readily forecast, variable such as aggregate personal income. This model will definitely lead to a more complex model than using a mean income. Income can be measured at different scales such as the income of a person, household, or city. The population and annual income per capita are taken in the log scale for the model.

To develop the model, the total travel time is considered for one way. In this study, total travel time considers access time, transfer time, waiting time, trunk route journey time, and egress time. The access and egress travel times for the three cities are mentioned in Table 2.

Table 2 Access and egress travel time in minutes

City	Bus	Car	2W	Auto	Walk
Surat	24	19	18	19	10
Ahmedabad	39	17	16	18	10
Vadodara	25	16	12	15	10

7 Minutes of Walking Time Has Been Considered Based on the 1.2 m/s Pedestrian Speed

Waiting time at different terminal stations has been taken from the feasibility report of national high-speed rail. A waiting time of 24 min is considered for the railway stations. A transfer time of 5 min is considered for the study.

The variation in trunk route journey travel time in minutes is shown in Fig. 6 for the past 11 years. It shows that over the years the travel time is decreased for Surat to Ahmedabad more than the other sections.

In this study, the travel cost is considered as access travel cost, trunk route travel, and egress travel cost. Access and egress travel cost has been estimated from the fuel prices in the city. The trunk route travel cost is available through secondary data, and it is given in terms of average travel cost per passenger. It was found that the travel cost has increased drastically for the railways over the years.

As per the transit capacity quality of the service manual, the service frequency was consistently reported as the top factor influencing overall trip satisfaction. It is also taken from the secondary data provided. This shows that over the years, the frequency has increased with increased demand.

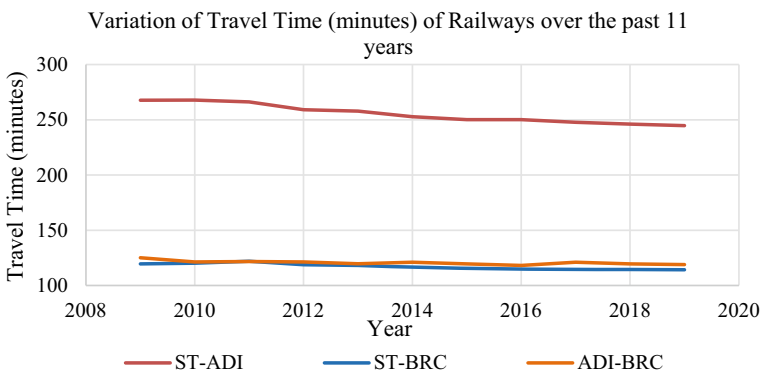


Fig. 6 Variation of travel time (minutes) for rail corridors

8 Passenger Demand Modelling

Direct Demand Models have been constructed for the different corridors by using the five variables as explanatory variables and the passenger demand as the response variable. The following types of direct demand models have been constructed:

1. Railway models without access and egress consideration for all three sections (RPDM—XEA)
2. Railway AC models without access and egress consideration for all three sections (RPDM AC—XEA)
3. Railway Non-AC models without access and egress consideration for all three sections (RPDM NAC—XEA)
4. Railway AC models with access and egress consideration for all three sections (RPDM AC—WEA)
5. Railway Non-AC models with access and egress consideration for all three sections (RPDM NAC—WEA).

8.1 RPDM—XEA

Table 3 shows the coefficients for every explanatory variable used in the model. The coefficients for the product of population, product of income per capita, average travel cost, and annual frequency are positive because of having a positive correlation with annual passenger demand, whereas the coefficient of travel time is negative, because of the negative correlation with annual passenger demand. The model has been constructed based on the log-linear model hence the coefficient itself shows the elasticity value of that variable.

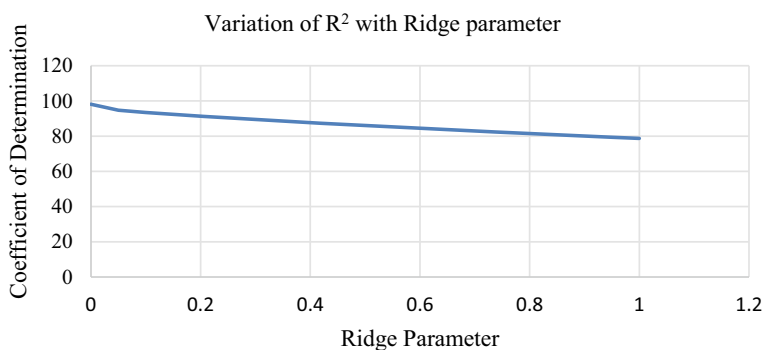
For intercity travel, the elasticity value of travel cost is positive. Mathematically, it represents that by increasing the travel cost the travelling demand will get increased, which never justifies the behaviour of transit users. Generally, the user responds to the travel cost when it exceeds his travel expenditure limit. In the case of railways, there are 30 types of trains which are running with multiple classes with different

Table 3 RPDM—XEA

Section	RP	LOG(PSA)	LOG(ISA)	LOG(R_ TT)	LOG(R_ TC)	LOG(R_ YFre)	Constant
ST-ADI	0.1	0.193	0.059	-0.473	0.061	0.242	2.467
	RP	LOG(PSB)	LOG(ISB)	LOG(R_ TT)	LOG(R_ TC)	LOG(R_ YFre)	CONSTANT
ST-BRC	0.25	0.327	0.065	-1.144	0.199	0.404	0.439
	RP	LOG(PAB)	LOG(IAB)	LOG(R_ TT)	LOG(R_ TC)	LOG(R_ YFre)	CONSTANT
ADI-BRC	0.55	0.537	0.094	-0.429	0.030	0.457	-4.461

Table 4 RPDM—XEA performance statistics

Corridor	RP	MSE	MAE	MAPE	ME	MPE	R ²
ST-ADI	0.10	0.000	0.009	0.154	0.000	-0.001	95.035
ST-BRC	0.25	0.001	0.011	0.201	0.000	-0.002	92.667
ADI-BRC	0.55	0.008	0.038	0.793	0.000	-0.019	73.552

**Fig. 7** Variation of R² value with the ridge parameter

travel costs. Hence, If the travel cost increases for the railways, then the passengers will shift to the other classes which will not show a decrease in demand.

Table 4 shows the residual analysis results for the above model.

Likewise, the models for the AC class and Non-AC class were developed without considering access and egress time. And similar results were obtained.

8.2 Ridge Parameter

It was found that with the increase of the ridge parameter, there was a higher error observed in the model in terms of R² value. The relationship between the R² value and the ridge parameter is shown in Fig. 7. Hence, it is necessary to find the appropriate value of the ridge parameter for the optimum results of the model.

8.3 RPDM AC—WEA

This section describes the direct demand model of railway passenger demand considering access and egress modes. Access and egress modes have been kept in 4 categories. Private car and 2W have been mentioned as Private mode, BRTS and City Bus are considered as Buses, Cab and Auto are categorised as Auto, and Walk has

been taken as Non-motorised Transport. A total of 16 possible mode chains have been taken in the model as PTP, PTB, PTA, PTN, BTP, BTB, BTA, BTN, ATP, ATB, ATA, ATN, NTP, NTB, NTA, and NTN where P = Private Mode, T = Train, B = Bus, A = Auto, and N = Non-motorised Transport.

Hence, PTP indicates a mode chain for a passenger as follows:

First Alphabet: It denotes the access mode in the origin city.

Second Alphabet: It denotes the trunk route mode between the cities.

Third Alphabet: It denotes the egress mode in the destination city.

8.3.1 ST-ADI Rail Corridor

This model considers the access and egress modes with AC class in the trip and the regression coefficient for all explanatory variables used in the model which are shown in Table 5. These coefficients show the elasticity value in that particular variable.

The performance measures of this model are shown in Table 6.

In this way, models for other corridors ST-BRC and ADI-BRC were developed. And similar results were found.

Table 5 RPDM AC—WEA ST-ADI

Mode chain	RP	LOG (PSA)	LOG (ISA)	LOG (TT)	LOG (TC)	LOG (Y_Fre)	CONSTANT
PTP	0.15	0.222	0.084	-0.919	0.333	0.238	1.275
PTB	0.15	0.224	0.084	-0.929	0.327	0.242	0.876
PTA	0.15	0.221	0.082	-0.967	0.358	0.235	0.581
PTN	0.1	0.230	0.095	-0.609	0.333	0.217	0.293
BTP	0.15	0.222	0.083	-1.019	0.320	0.238	0.935
BTB	0.15	0.222	0.083	-1.047	0.315	0.239	0.616
BTA	0.15	0.219	0.082	-1.080	0.345	0.233	0.308
BTN	0.1	0.228	0.094	-0.758	0.319	0.213	0.126
ATP	0.2	0.215	0.077	-1.148	0.349	0.247	0.345
ATB	0.2	0.215	0.077	-1.199	0.345	0.247	0.099
ATA	0.25	0.210	0.072	-1.333	0.356	0.250	0.125
ATN	0.2	0.214	0.076	-1.249	0.332	0.245	0.624
NTP	0.2	0.218	0.078	-1.109	0.304	0.252	0.788
NTB	0.2	0.218	0.078	-1.145	0.300	0.254	0.491
NTA	0.2	0.216	0.077	-1.156	0.328	0.248	0.120
NTN	0.15	0.222	0.084	-0.973	0.300	0.241	0.322

Table 6 RPDM AC—WEA ST-ADI performance statistics

Mode chain	MSE	MAE	MAPE	ME	MPE	R ²
PTP	0.001	0.015	0.316	0.000	−0.003	93.110
PTB	0.001	0.015	0.350	0.000	−0.003	93.069
PTA	0.001	0.015	0.365	0.000	−0.004	93.201
PTN	0.001	0.015	0.308	0.000	−0.002	94.175
BTP	0.001	0.015	0.366	0.000	−0.004	93.119
BTB	0.001	0.015	0.411	0.000	−0.004	93.088
BTA	0.001	0.015	0.435	0.000	−0.005	93.222
BTN	0.001	0.015	0.357	0.000	−0.003	94.186
ATP	0.001	0.015	0.474	0.000	−0.007	92.176
ATB	0.001	0.016	0.552	0.000	−0.009	92.148
ATA	0.001	0.015	0.622	0.000	−0.013	91.327
ATN	0.001	0.015	0.485	0.000	−0.007	92.199
NTP	0.001	0.016	0.431	0.000	−0.005	92.040
NTB	0.001	0.016	0.491	0.000	−0.007	92.006
NTA	0.001	0.015	0.528	0.000	−0.008	92.149
NTN	0.001	0.015	0.425	0.000	−0.005	93.051

8.4 RPDM NAC—WEA

This model considers Non-AC class of railway and includes access and egress modes of travel. The results and performance measures are shown for each corridor considered in this study in the subsequent tables below.

8.4.1 ST-ADI Rail Corridor

Tables 7 and 8 are showing the model results in terms of coefficients of ridge regression and the performance measures.

In a similar manner, models for other corridors were developed. And satisfactory results were obtained.

9 Sensitivity Analysis

The sensitivity analysis based on the elasticity values of the level of service parameters used in the model was carried out. The following Table 9 shows the percentage change in the passenger demand for railways with respect to the unit change of LOS parameters while keeping other factors constant.

Table 7 RPDM NAC—WEA ST-ADI

Mode chain	RP	LOG (PSA)	LOG (ISA)	LOG (TT)	LOG (TC)	LOG (YFre)	CONSTANT
PTP	0.10	0.122	0.025	-0.056	0.150	0.203	2.009
PTB	0.10	0.125	0.025	-0.126	0.133	0.204	1.783
PTA	0.10	0.109	0.022	-0.079	0.226	0.183	1.400
PTN	0.10	0.127	0.026	-0.103	0.120	0.208	2.049
BTP	0.10	0.123	0.025	-0.065	0.141	0.203	1.409
BTB	0.10	0.125	0.025	-0.139	0.125	0.204	1.188
BTA	0.10	0.109	0.022	-0.084	0.215	0.184	0.793
BTN	0.10	0.128	0.026	-0.114	0.112	0.208	1.449
ATP	0.15	0.105	0.023	-0.231	0.213	0.168	1.103
ATB	0.10	0.108	0.022	-0.035	0.228	0.183	0.083
ATA	0.10	0.098	0.021	-0.057	0.300	0.169	-0.216
ATN	0.10	0.109	0.023	-0.013	0.215	0.186	0.373
NTP	0.15	0.118	0.026	-0.244	0.126	0.185	1.570
NTB	0.10	0.128	0.026	-0.070	0.114	0.210	0.512
NTA	0.10	0.111	0.023	-0.024	0.203	0.189	0.163
NTN	0.10	0.131	0.027	-0.045	0.102	0.214	0.768

Table 8 RPDM NAC—WEA ST-ADI performance statistics

Mode chain	MSE	MAE	MAPE	ME	MPE	R ²
PTP	0.000	0.007	0.132	0.000	0.000	93.860
PTB	0.000	0.007	0.142	0.000	-0.001	93.750
PTA	0.000	0.006	0.141	0.000	-0.001	94.460
PTN	0.000	0.007	0.132	0.000	0.000	94.460
BTP	0.000	0.006	0.147	0.000	-0.001	93.840
BTB	0.000	0.007	0.165	0.000	-0.001	93.840
BTA	0.000	0.006	0.167	0.000	-0.001	94.430
BTN	0.000	0.007	0.152	0.000	-0.001	93.660
ATP	0.000	0.006	0.179	0.000	-0.001	93.500
ATB	0.000	0.006	0.194	0.000	-0.001	94.650
ATA	0.000	0.005	0.192	0.000	-0.001	95.230
ATN	0.000	0.006	0.176	0.000	-0.001	94.440
NTP	0.000	0.006	0.165	0.000	-0.001	92.650
NTB	0.000	0.007	0.187	0.000	-0.001	93.650
NTA	0.000	0.006	0.192	0.000	-0.001	93.650
NTN	0.000	0.007	0.171	0.000	-0.001	93.650

Table 9 Railway passenger demand sensitivity analysis

Additional railway passenger demand due to			
Corridor	–1% change in travel time (min)	1% change in average travel cost (Rupees)	1% change in annual frequency
ST-ADI	4452	1424	1365
ST-BRC	2494	553	865
ADI-BRC	1085	188	271

The results show that the reduction in travel time shows higher passenger demand compared to a unit change in travel cost and annual frequency. Hence, passengers are more sensitive to travel time during the travel compared to the other two parameters.

10 Scenario Analysis

After the construction of the above models, attempts were made to check the future demand with the three scenarios with the different combinations of three parameters, i.e., travel time, travel cost, and annual frequency.

Three scenarios related to all LOS parameters were generated as Business As Usual (BAU), Scenario-1 (S-1), and Scenario-2 (S-2).

The different combinations of these parameters with different scenario analysis combinations are shown below.

- (1) (BAU_TT) and (BAU_TC) and (BAU_Fre)
- (2) (S1_TT) and (S1_TC)
- (3) (S1_TT) and (S1_Fre)
- (4) (S1_TC) and (S1_Fre)
- (5) (S1_TT) and (S1_TC) and (S1_Fre)
- (6) (S2_TT) and (S2_TC)
- 7) (S2_TT) and (S2_Fre)
- (8) (S2_TC) and (S2_Fre)
- (9) (S2_TT) and (S2_TC) and (S2_Fre)

where

BAU_TT = Business as Usual for Travel Time.

BAU_TC = Business as Usual for Travel Cost.

BAU_Fre = Business as Usual for Annual Frequency.

S1_TT = Scenario—1 for Travel Time.

S1_TC = Scenario—1 for Travel Cost.

S1_Fre = Scenario—1 for Annual Frequency.

S2_TT = Scenario—2 for Travel Time.

S2_TC = Scenario—2 for Travel Cost.

S2_Fre = Scenario—2 for Annual Frequency.

Business As Usual: This scenario shows a do-nothing case where only the historical trends are observed.

S1_TT: In this scenario, the speed of trains increases by 15% and 25% for the years 2025 and 2030, respectively.

S2_TT: Speed has been changed by 20% and 30% for the years 2025 and 2030, respectively.

S1_TC: (BAU-10%): This scenario considers there will not be any investment towards the new trains with new technology, and the travel cost will change due to the change in the source of energy with renewable energy so the cost might increase with decreased rate than the BAU.

S2_TC: (BAU + 10%): It considers new investment towards new technology trains with better comfort and convenience, with renewable energy sources hence increasing the cost of travel at a greater rate than BAU, considered for the years 2025 and 2030.

S1_Fre: (BAU-10%): Since the semi-high-speed train has been planned in the same corridor, it will attract passengers from railways as well as from buses hence these may experience an increase in frequency with a lower rate than BAU, considered for the years 2025 and 2030.

S2_Fre: (BAU + 10%): If some new technology train has been operated through Indian railways with an affordable price than semi-high-speed rail, then it might see some increase in demand, and hence increase in frequency with a greater rate than BAU, considered for the years 2025 and 2030.

Table 10 shows the different scenarios of LOS parameters for the years 2025 and 2030.

Table 11 suggests that scenarios S1_TT and S1_TC and S1_TT and S1_Fre have resulted in almost the same percentage change in demand for all three study corridors. Similarly, S2_TT and S2_TC, S2_TT and S2_Fre, and S2_TT and S2_TC and S2_Fre have also resulted in almost equal percentage increase in demand.

The similar analysis was carried out for the year 2030 and results are shown in Tables 12 and 13.

The above table suggests that scenario S1_TT and S1_TC and S1_TT and S1_Fre have resulted in almost the same percentage change in demand for all three study corridors. Similarly, S2_TT and S2_TC, S2_TT and S2_Fre, and S2_TT and S2_TC and S2_Fre have also resulted in almost equal percentage increase in demand. As most of the scenarios resulted in around a 100% increment, this indicates that in the next 10 years the passenger demand may get doubled.

Table 10 Scenario analysis for RPD for the year 2025

		ST-ADI	ST-BRC	ADI-BRC
Travel time (based on speed)	BAU	-5.589%	-2.564%	-3.268%
	Scenario 1	-13.043%	-13.043%	13.043%
	Scenario 2	-16.667%	-16.667%	16.667%
		Scenario 1: 15% speed increment		Scenario 2: 20% speed increment
Average travel cost	BAU	27.781%	22.066%	20.284%
	Scenario 1	17.781%	12.066%	10.284%
	Scenario 2	37.781%	32.066%	30.284%
		Scenario 1 = BAU - 10%		Scenario 2 = BAU + 10%
Annual frequency	BAU	23.279%	21.005%	27.284%
	Scenario 1	13.279%	11.005%	17.284%
	Scenario 2	33.279%	31.005%	37.284%

11 Conclusion

Direct Demand Models have been constructed for the 5 different combinations with and without consideration of access and egress modes. Four different modes have been considered in the cities for access and egress to and from the intercity terminal in the cities. The elasticity values are found less than the unity for most of the cases which shows the inelastic nature of the railway passenger demand. As mentioned in previous studies that travel time and travel cost generally show negative elasticity values for the change in demand but in this study, it is found that travel cost is having positive elastic value. This indicates that there is no decrease in passenger demand with travel cost increased. This is justified by the thought that whenever the travel cost exceeds the travel expenditure of an individual, he will shift the class (AC to Non-AC) of the train journey rather than shifting to other modes.

Scenario Analysis has shown that in 2025, the passenger demand will get increased by around 40% whereas by the year 2030, this demand will be nearly doubled. It can be observed that scenarios S1_TT and S1_TC and S1_TT and S1_Fre have resulted in almost the same percentage change in demand for all three study corridors. Similarly, S2_TT and S2_TC, S2_TT and S2_Fre, and S2_TT and S2_TC and S2_Fre have also resulted in almost equal percentage increase in demand.

Table 11 Change in passenger demand for the year 2025 based on scenario analysis

Corridor	BAU_TT & BAU_TC & BAU_Fre	S1_TT & S1_TC	S2_TT & S2_TC	S1_TT & S1_Fre	S2_TT & S2_Fre	S1_TC & S1_Fre	S2_TC & S2_Fre	S1_TT & S1_TC & S1_Fre	S2_TT & S2_TC & S2_Fre
ST-ADI	27.397%	32.103%	40.254%	32.114%	40.237%	23.190%	31.409%	29.909%	42.436%
ST-BRC	40.861%	56.629%	71.107%	54.722%	73.045%	33.362%	48.139%	51.472%	76.463%
ADI-BRC	16.728%	31.071%	43.487%	30.186%	44.401%	11.604%	21.664%	27.728%	46.955%

Table 12 Scenario analysis for RPD for the year 2030

		ST-ADI	ST-BRC	ADI-BRC
Travel time (based on speed)	BAU	-8.597%	-4.533%	-4.982%
	Scenario 1	-20.00%	-20.00%	-20.00%
	Scenario 2	-23.08%	-23.08%	-23.08%
		Scenario 1: 25% speed Increment		Scenario 2: 30% speed increment
Average Travel Cost	BAU	60.206%	51.813%	60.009%
	Scenario 1	50.206%	41.813%	50.009%
	Scenario 2	70.206%	61.813%	70.009%
		Scenario 1 = BAU - 10%		Scenario 2 = BAU + 10%
Annual Frequency	BAU	68.233%	34.345%	79.647%
	Scenario 1	58.233%	24.345%	69.647%
	Scenario 2	78.233%	44.345%	89.647%
		Scenario 1 = BAU - 10%		Scenario 2 = BAU + 10%

Table 13 Change in passenger demand for the year 2030 based on scenario analysis

Corridor	BAU_ TT & BAU_ TC & BAU_ Fre	S1_TT & S1_TC	S2_TT & S2_TC	S1_TT & S1_Fre	S2_TT & S2_Fre	S1_TC & S1_Fre	S2_TC & S2_Fre	S1_TT & S1_TC & S1_Fre	S2_TT & S2_TC & S2_Fre
ST-ADI	62.889%	75.176%	84.367%	75.382%	84.170%	58.796%	66.835%	73.063%	86.487%
ST-BRC	90.643%	128.441%	146.641%	125.468%	149.624%	81.900%	99.161%	100.086%	153.610%
ADI-BRC	71.836%	110.672%	127.571%	109.848%	128.436%	66.382%	77.142%	72.108%	131.497%

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