EVALUATION OF DEVELOPMENT SCENARIOS TOWARDS SUSTAINABLE URBAN TRANSPORTATION: A CASESTUDY OF PUNE

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ABSTRACT

As cities grow exponentially, an effective and sustainable urban transport system for people and goods is a prerequisite for sustainable economic growth. Motor vehicle ownership is growing faster than population, with growth continuing to accelerate even during the height of the economic crisis. However, urban transport systems in most cities are underdeveloped and their transport capacity is insufficient. Literature indicates that the geographic distribution of jobs and population is more crucial in creating drastic changes in travel pattern. Broader definition of sustainability which tends to favour integrated solutions, including improved travel choices, economic incentives, land use changes as well as technological innovation has been studied. Planning for sustainable urban development focuses on improvements in all of these characteristics of the functioning of cities. Land Use initiatives represent a potentially effective tool for coping with the kinds of mobility patterns. An integrated evaluation framework is suggested to incorporate a wide range of sustainability issues into the design process.

Pune Metropolitan Area is taken as the study area. The development plan for 2007-2027 is prepared by Municipal Corporation. This work evaluates the impacts of various development scenarios proposed in the development plan on the Transportation infrastructure. The evaluation will be carried out considering the concepts of sustainability by employing the conventional Transportation planning model. Equity issues are addressed in the study by segregating the population into three groups namely: Car owning group, Two-wheeler owning group and no vehicle group based on vehicle ownership. The sustainability indices will be arrived at by incorporating the measures namely development controls, densities, Pollution load and travel impacts.

Key Words: Sustainable urban transportation, land-use, development scenarios, sustainability indices.

1 INTRODUCTION

Many cities in Asian countries are growing by leaps and bounds both physically and demographically. The rapid growth of cities is putting tremendous pressure on urban infrastructure—including housing, transportation, power supply, water supply, and sewerage systems. Transport, which is demand-driven, plays a very important role in the overall growth of the economy. Despite having direct influence on economic growth, transport systems in many cities in Asia—especially in India—require much higher levels of attention in terms of their growth and sustainability.

In view of the high growth rates of personalized vehicles—and their multidimensional effects on ecology, travel quality, environment, safety, and public health—it is important for planners to take suitable short and long-term remedial measures. Given this situation, it would be useful to identify a set of objective indicators that would reasonably reflect whether the urban transport system is heading towards sustainability. ”Sustainable Transport” came up as an accident follow-up to the earlier term Sustainable development whose origins were the 1987 Brundtland Commission. Later in 1990’s Organisation for Economic Cooperation and Development (OECD) began to chart a path towards Environmentally Sustainable Transport (EST). With the growing index of urban population everywhere, growing transport problems associated with rising levels of Low Occupancy Vehicles(LOV), passenger car use is on the increase; necessitating a call for the sustainable transport paradigm.

Thorough discussions on developing scenarios for evaluating sustainable urban transportation can be found in Christopher Pettit (2001) where they have analysed trends scenario, maximizing employment opportunities and sustainable development scenario for the Growth of Hervey Bay region. In the same direction Black et al. (2002) proposed a framework that links definitions and objectives for sustainability with appropriate performance indicators and analytical techniques. Henrik Gudmundsson (2002) presented a more thorough review on a number of current indicator systems in terms of their support to more sustainable transport policies so as to provide input to planning for sustainable transport in Denmark. The study addressed: 1) how is environmental sustainability reflected in the various indicator frameworks in use? And 2) in what way are the indicator systems linked to decision making. Todd Litman (2006) attempted to develop Indicators for Comprehensive and Sustainable Transport Planning. The framework described the selection of sustainable transportation indicators by category and Reference units to compare impacts, such as per mile, per trip, per vehicle-year, per capita, and per dollar.

Kari Lautso et al. (1999) used SPARTACUS system for assessing policy options in three cities: Helsinki, Bilbao, and Naples. The policy elements represent different pricing, regulatory, land use, transport planning, and investment measures. The study has shown that the level of sustainability can be increased in the test cities in cost-effective way by using a variety of policies, especially pricing and regulatory policies and their combinations. Peng and Lu (2007) described GIS spatial analysis technique to analyze the average characteristics of general density, urban densities and their spatial difference. From the study it can be concluded that different urban densities have certain effect on different travel demand, and within certain threshold, there is an obvious monotonous relationship between urban density and travel demand. Hunt J D et al. (2007) developed a state-wide land use transport model for Alberta based on the framework of PECAS, which represents Production, Exchange and Commodity Allocation System. The model provided the “skims” which certain influences on exchange locations, and thus further influence on technology choices and location choices of individual activities through the nested logit model structure.

Jianhu Zheng (2008) presented how congestion pricing can contribute to economic growth, environmental protection and social justice. From the results by converting all the savings in travel time resulting from decreased congestion to monetary units, it can be concluded that the reduction of congestion will promote sustainable economic development.

With this background, Pune, the seventh largest industrial city in India and the second most important city in Maharashtra after Mumbai is taken as the study area (Figure 2.1). Over the past three decades, Pune has witnessed remarkable development, particularly along the Mumbai-Pune highway (NH-4)/Mumbai-Pune expressway, and in most regions in the hinterland. Pune Metropolitan Area (PMA) includes Pune Municipal Corporation Area (PMC), the Pimpri-Chinchwad Municipal Corporation (PCMC) and the Cantonment Boards of Pune and Khadki. The objective is to evaluate the impacts of various development scenarios proposed in the development plan on the Transportation infrastructure. The evaluation is carried out considering the concepts of sustainability by employing the conventional Transportation planning model.

The details of the model data and methodology are provided in the next section. The subsequent part of the paper explains the model structure. The scenarios considered are presented in the next section. The conclusions and discussions are presented at the end.

2 DATA SET AND METHODOLOGY

While the focus is on Pune Metropolitan region, the study area included a much larger area taking into accounting all areas that have an influence on Pune’s traffic. This study hence extends itself to the Pune Metropolitan Region PMR that includes Pimpri Chinchwad and all surrounding villages, Pune cantonment and khadki Cantonment.

The Pune Metropolitan region (PMR) spreads over an area of 1,340 sq. km. The 2001 Census of India estimated that the Pune and Pimpri-Chinchwad urban areas had populations of 25,38,473 and 10,12,472 respectively. Over the period from 1991–2001, the population of the state grew by 22.57 percent, whereas the population of the Pune MA increased by 65.19 percent. The population density (persons per sq km) for Pune MA was 9,873 in 2001. Average household size in Pune city is about 4.36 persons per household. 55 percent of households own a two wheeler. The map in Fig 2.2 shows the study area.

Table 2.1: Population Growth in Study Area

	PMC	PCMC	Pune Cantonment	Khadki Cantonment
1961	595762	46031	65838	58496
1971	856105	83542	69451	65497
1981	1203351	220966	85986	80835
1991	1566651	517083	82139	78323
2001	2328349	1083967	80191	77473

Figure 2.1 Location of Pune

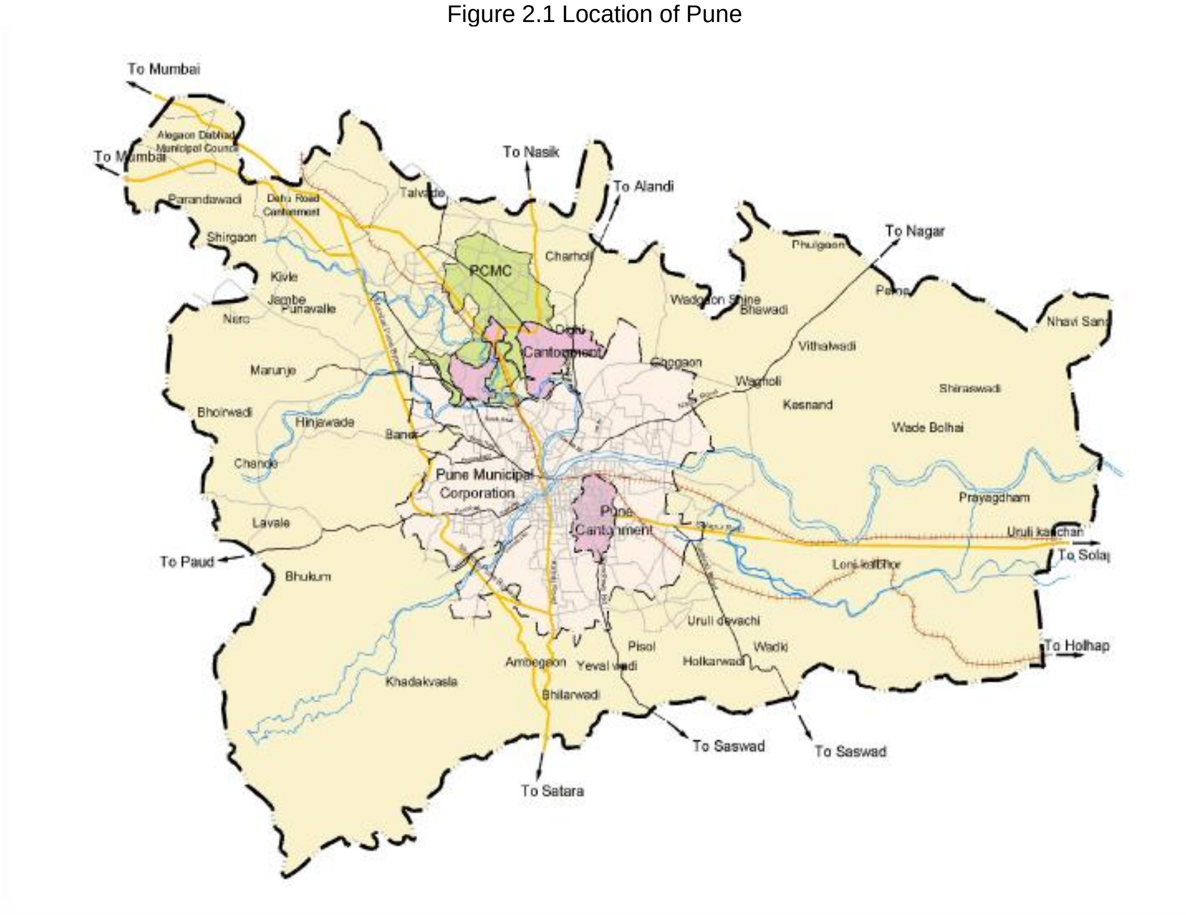


Figure 2.2 Study Area

2.1 Delineation

2.1.1 Traffic Zones

The zoning system of the study has been adopted based on the City Development Plan (2007-2027) comprising 144 zones in the PMC area, 105 zones in PCMC area and 16 zones in hinjewadi. Pune and Khadki cantonments have been considered as two zones. In addition to 267 internal zones, 13 external zones are considered. These external zones represent the catchment of external transport links feeding into the city. The zonal network is shown in figure 2.3

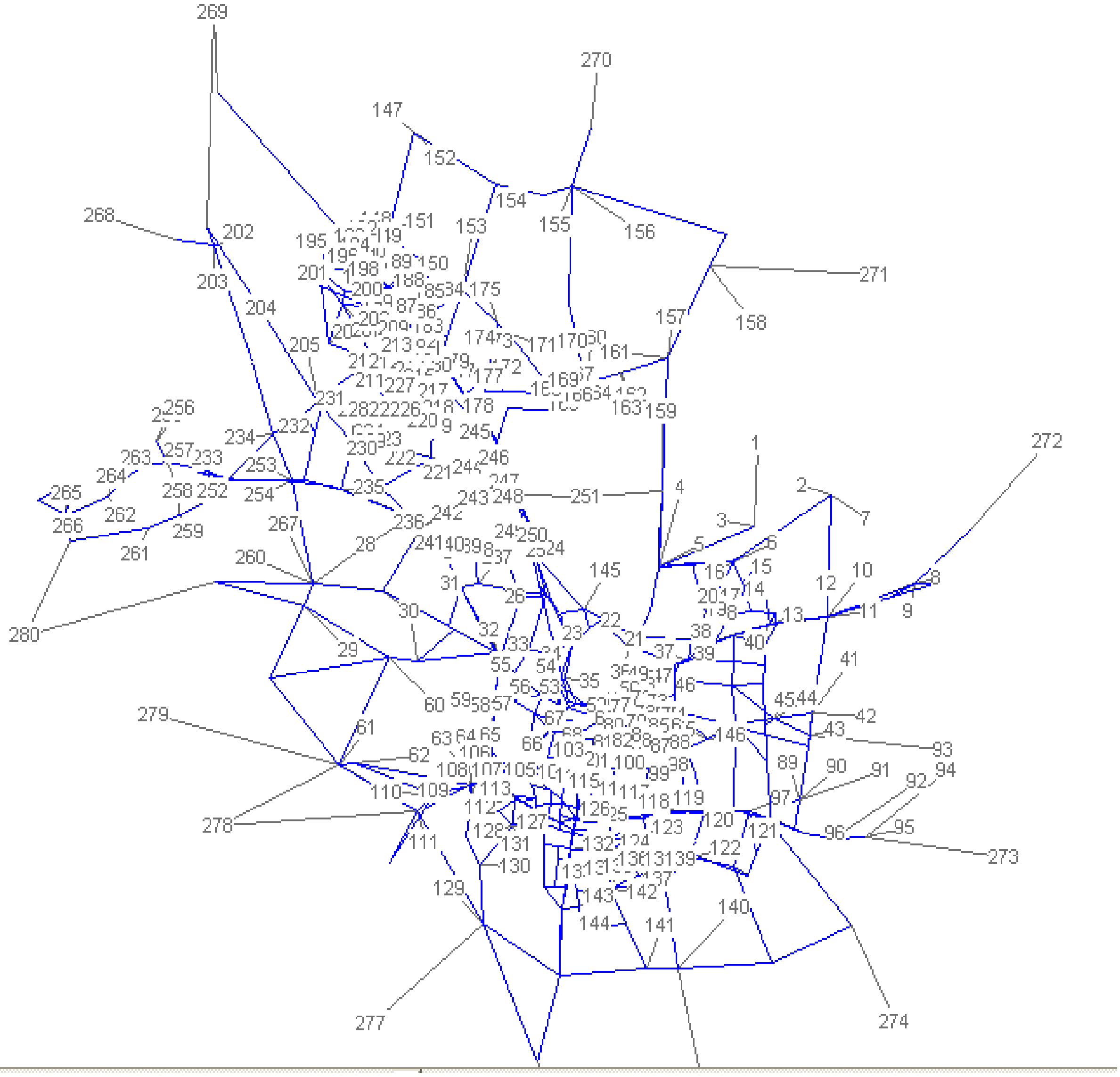


Figure 2.3: Study Area Zonal Map

2.1.2 Screen-lines and Cordon-Lines

Two screen lines, one along the existing railway line and other along Mula – Mutha River are adopted. The boundary of the study area as shown in Fig 2.2 is the outer cordon line. Figure 2.4 shows the location of these screen lines and the external cordon.

Figure 2.4: Location of Screen Lines and the External Cordon

2.2 Planning Period

2008 is taken as base year and since estimates of traffic are required over a 20 - 30 year period, therefore the horizon year is kept as 2031. The model will give traffic estimates for 2011 and 2021.

2.3 Vehicle Ownership

The total registered vehicle population (public transport and personalized vehicles) in Pune city in 2002 was 658,313, out of which 537,956 were personalised vehicles such as two-wheelers, cars, and jeeps. Two- wheelers constitute the highest among these vehicles (491,747, or 74.6 percent of total vehicles), followed by cars (63,489, or 9.6 percent of total vehicles) in 2002. Growth of vehicles is about 8 percent per annum as shown in figure 2.5

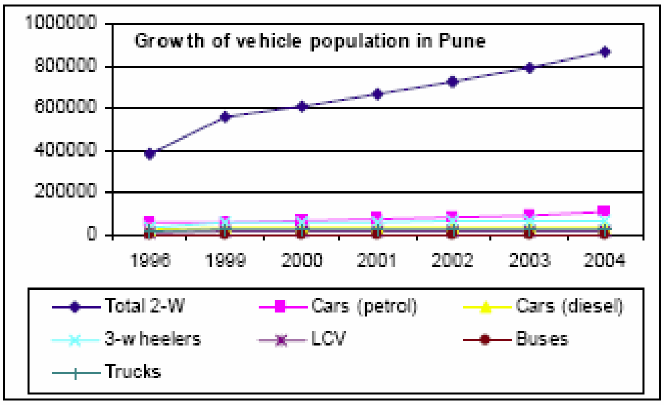


Figure 2.5: Growth of vehicles in Pune

(Source: RTO Pune)

This decreased patronage for public transport and increase in number of 2-wheelers in Pune is due to the flexibility and affordability of personalized vehicles.

2.4 Network Development

Transport network developed for the model comprises of two components,

• Highway Network for vehicles

• Transit Network for public transport system i.e. buses, rail and any new public transportation system.

2.4.1 Highway Network

13 different types of road links have been adopted for the study. All these links types are appropriately recorded while coding the road network and preparing the link list for basic network for study area. Table 3.1 shows the different types of road links with their link characteristics and parameters of the speed flow functions. Since only the strategic network is considered for planning purpose the length of road network coded is 922 km. Coded highway network with existing Sub Urban Railway and proposed BRT, Metro and monorail alignments is shown in figure 2.6

Table 3.1 Different types of links in network and their characteristics

Link Type	**No. of lanes**	**Divided/ Undivided**	**Type of flow**	**Capacity Per Dirn. (PCU/hr)**	**Free Flow speed (km/h)**	**Speed at Cap. (km/h)**
1	One Lane	Undivided	One-way	1650	30	15
2	Two Lane	Undivided	One-way	3200	40	15
3	Three Lane	Undivided	One-way	4350	40	15
4	Four Lane	Undivided	One-way	5300	50	18
5	Five Lane	Undivided	One-way	6200	50	18
10	One Lane	Undivided	Two-way	600	25	12
11	Two Lane	Undivided	Two-way	1100	35	15
12	Three Lane	Undivided	Two-way	1500	35	15
13	Four Lane	Undivided	Two-way	2150	40	18
17	Four Lane	Divided	Two-way	2600	50	18
18	Six Lane	Divided	Two-way	3800	50	18
19	Eight Lane	Divided	Two-way	6200	55	20
31*	Four Lane	Divided	Two-way	2600	80	25

* High Speed Design

2.4.2 Public Transport Network

The network developed for public transport consists of all road links, suburban rail links, BRT links and future metro links along with the routes coded on them. The fare tables currently in force are appropriately coded in routes file. Total of 288 bus routes are coded.

The types of transit links coded on the network are shown in Table 3.2.

Table 3.2 Description of Other Links Used in the Network

Link Type	**Description**
21	Highway Node to Transit Stop
22	Road Node to Zone Centroid Connection
25	Suburban Rail Links
26	BRT Links
27	Metro Links
28	Monorail Links

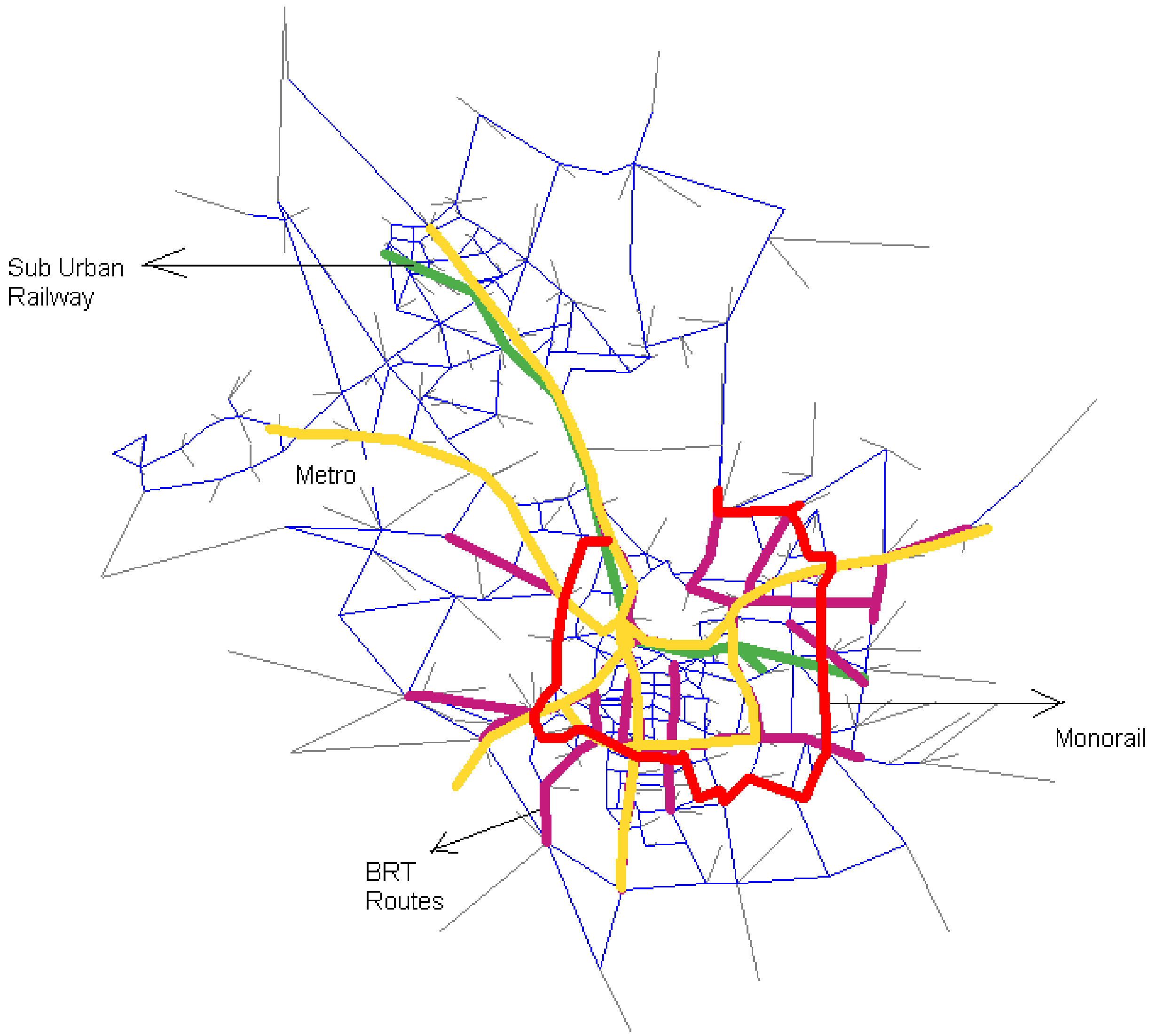


Figure 2.6: Highway Network with existing Sub Urban Railway and proposed BRT, Metro and monorail alignments

3 MODEL STRUCTURE

To address equity issues, population in the study area has been divided into three groups. This is done on the basis of vehicle ownership as Car Owning Group, Two Wheeler owning group and no vehicle group.

The methodology adopted for forecasting traffic volume consists of the following four steps.

1. Generation and Validation of base year OD Matrices
2. Development of Travel Demand Model for base year
3. Horizon year Travel Demand Forecasts
4. Developing indicators.

3.1 Generation of Base Year OD Matrices and Travel Pattern

This process starts with the Home Interview Survey (HIS) data as input. The data collected from HIS is checked for bias and the necessary bias correction is applied and expansion factors are computed. Thus the expanded partial OD matrices for all the three groups are obtained. OD surveys conducted at outer cordon are pooled in to get the OD matrices with all trips. The matrices are loaded on to the network and the assigned values are compared with the ground counts to validate the Matrices.

3.2 Development of Travel Demand Model

Planning variables based on old zonal system as per previous planning study (91 internal zones) are available. Hence equivalencies between old and new zonal systems (267 internal zones) are established. Based on old zonal system, increments of population in each zone are found and the aggregated population is apportioned based on the proportions obtained. Employment is distributed by obtaining the equivalencies between old and new zonal systems based on area and density.

Using the planning variables and validated total O-D matrix for base year (2008), trip end models and Gravity model for all 3 groups are calibrated for total internal passenger travel. The revised skims obtained after successive modal split and traffic assignments will be used to calibrate the gravity model.

A Multi-Nomial logit modal split model is devised, to determine the modal share. The model is mainly based on the transport system attributes. The cost skims are obtained from the assignment are used to calibrate the mode choice model. The *Public transport matrix* includes the person trips performed by Public Transport (Bus, IPT and Train) while the *Private vehicle matrix* includes person trips by car and two-wheeler.

The peak hour public transport passenger matrix is assigned to the public transport network, which includes a) Bus b) Intermediate Public Transport (IPT) routes on the road network and c) Rail network with all the existing links. The public transport assignment is based on generalized time, which is a combination of In-Vehicle Travel Time (IVTT), Waiting Time (WT), No of Transfers (TR), Fare and Discomfort in time units. The parameters of this generalized time are obtained from Stated Preference Survey. The public transport assignment is done by assigning no vehicle group first on to the network, and then the 2-Wheeler owning group on to the network which is preloaded with no vehicle group and finally the Car owning group is assigned. Hence a multi-class user assignment is attempted.

The public transport assignment is also required to assign the trips as per the observed modal shares. In order to achieve this, the parameters of the generalized time were fixed based on the values obtained from the analysis of stated preference surveys. After performing the public transport assignment, the assigned flows across the screen lines are compared with the observed flows.

Highway assignment is carried out for peak hour, preloading the highway network with peak hour public transport and commercial vehicle flows. The daily public transport loadings are factored by the peak hour flow to daily flow ratios to obtain the peak hour public transport flows. These are converted to PCU's by using appropriate passenger–to-PCU conversion factors. These peak-hour public transport (bus and IPT) and commercial vehicle flows in terms of PCU's are preloaded on to the highway network before loading the private vehicle passenger OD matrices.

The private vehicle passenger matrices are converted into peak hour PCU units, by using appropriate regional peak hour ratios and passenger-PCU conversion factors, based on observed occupancies at screen lines. A user equilibrium procedure based on generalized cost (sum of vehicle operating cost and time cost) is used in loading private vehicle matrices.

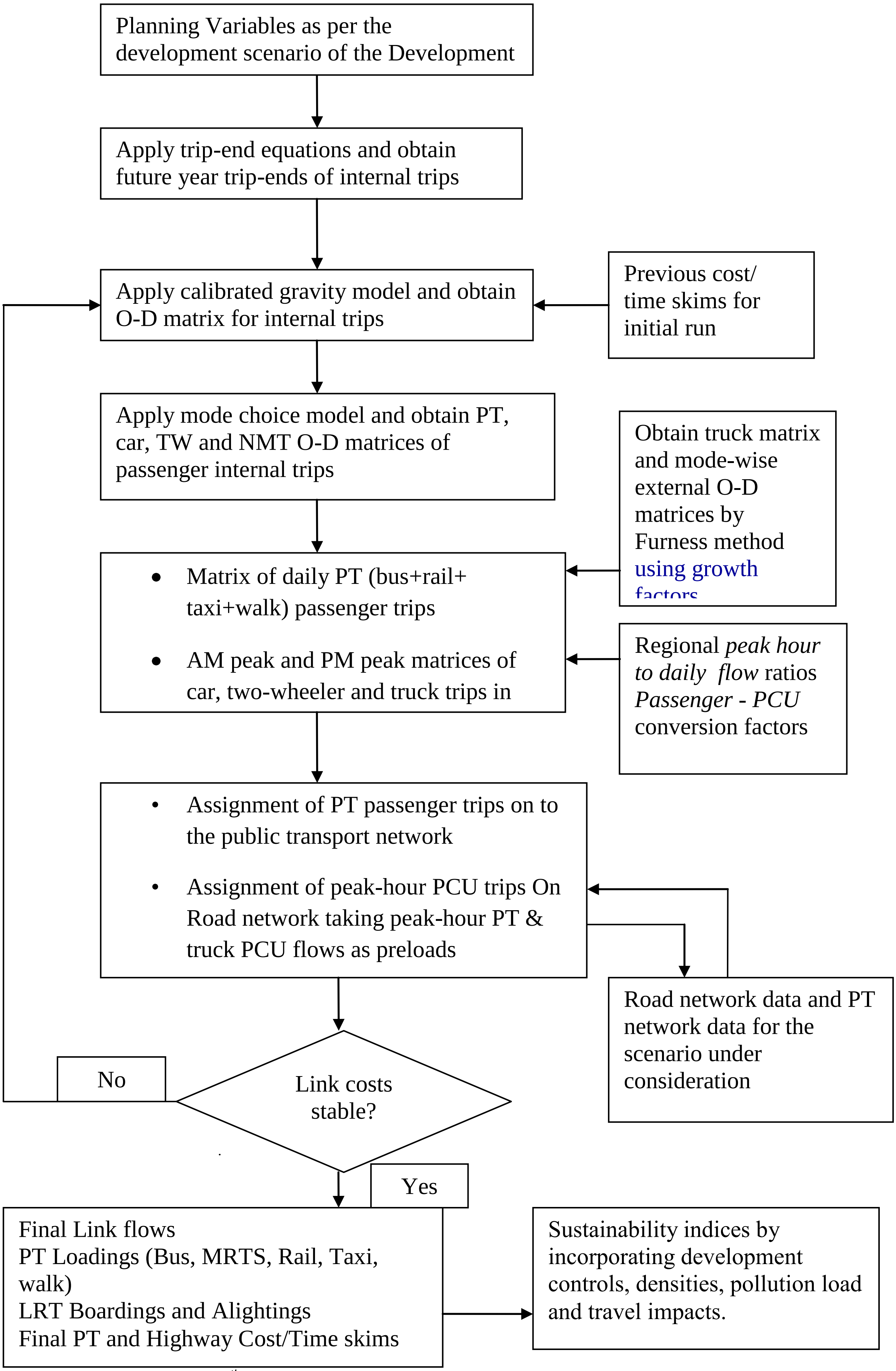
The public transport network is revised with the speeds obtained after assigning the private trips. The assignment of public transport trips is performed on the revised network, and the next iteration of private traffic assignment is carried out by taking the bus, taxi, auto and truck flows as preloads. This iterative process between PT and private vehicle traffic assignment is repeated until there is no appreciable change in the link loadings and link costs.

Three skims namely the highway time, highway travel cost and highway distance are obtained from the loaded network. The skims obtained are used for calibrating the gravity model and the modal split-model. The process of distribution, modal split and assignment is repeated till the OD matrices become stable.

3.3 Horizon Year Travel Demand Forecasts

The developed Travel Demand Model is used to forecast the Horizon Year loadings for each mode on all the links. Future forecasts are done for the Horizon years 2011, 2021 and 2031. Planning variables are forecasted for Horizon years based on demographics. The planning variables of horizon year form the input to the Travel demand model along with the future highway and proposed metro corridors. Trip ends are estimated and are fed into the calibrated gravity model along with base year highway skims. The distributed PA matrix so obtained is fed into the Mode split model and mode wise PA matrices are estimated. This forms the internal portion of the PA matrix. The external passenger PA portion as well as Commercial vehicle trips are estimated by Furness method (by taking 3% and 2% growth rate respectively) and added to the horizon year internal matrices. The combined PA matrix is converted into OD matrix and is loaded on to the PT and highway networks.

Skims obtained from this assignment process are updated in the gravity model and redistribution of trips is done. Mode wise OD matrices are estimated by the updated skims. The final matrices thus produced are loaded on to the network and the cycle is continued till the skims are stable. The procedure is displayed in Figure3.1.


Planning Variables as per the development scenario of the Development
Apply trip-end equations and obtain future year trip-ends of internal trips
Apply calibrated gravity model and obtain O-D matrix for internal trips
Previous cost/ time skims for initial run
Apply mode choice model and obtain PT, car, TW and NMT O-D matrices of passenger internal trips
Obtain truck matrix and mode-wise external O-D matrices by Furness method using growth factors
Matrix of daily PT (bus+rail+ taxi+walk) passenger trips
AM peak and PM peak matrices of car, two-wheeler and truck trips in
Regional peak hour to daily flow ratios Passenger - PCU conversion factors
Assignment of PT passenger trips on to the public transport network
Assignment of peak-hour PCU trips On Road network taking peak-hour PT & truck PCU flows as preloads
Road network data and PT network data for the scenario under consideration
No
Link costs stable?
Yes
Final Link flows
PT Loadings (Bus, MRTS, Rail, Taxi, walk)
LRT Boardings and Alightings
Final PT and Highway Cost/Time skims
Sustainability indices by incorporating development controls, densities, pollution load and travel impacts.

4 Analysis and Results

4.1 Trip Generation Models

The Productions (P) and Attractions (A) of internal passenger trips by all modes for the base year (2008) are calculated from the validated P to A matrices. Trip generation models are developed using stepwise multiple linear regression technique. The calibrated trip end equations for different income groups are presented below.

Table 4.1: Trip Production Models for various categories

Category	Model	R^2	$(t_{stat})_{POP}$	$(t_{stat})_{VEH}$
Car Owning Group	0.289 x POP + 0.939 x VEH	0.957	2.51	5.21
Two Wheeler Owning Group	0.689 x POP + 0.66 x TW	0.88	6.18	2.37
No Vehicle Group	0.987 x POP	0.949	9.85	

Where,
POP: population
TW: number of Two Wheelers
VEH: vehicle ownership

Table 4.2: Trip Attraction Models for various categories

Category	Model	R^2	$(t_{stat})_{EMP}$	$(t_{stat})_{STEN}$
Car Owning Group	1.995 x EMP+1.72 x STEN	0.695	19.28	2.72
Two Wheeler Owning Group	1.97 x EMP+0.55 x STEN	0.80	18.69	1.87
No Vehicle Group	1.90 x EMP	0.639	8.58	

Where,
EMP: Employment
STEN: student enrollment

4.2 Trip Distribution Model

A Gravity Trip Distribution model of the following form is calibrated for distributing the total internal passenger trips.

$$T_{ij} = A_i O_i B_j D_j F_{ij}$$

Where,

$$A_i = \frac{1}{\sum_j B_j D_j F_{ij}}$$

$$B_j = \frac{1}{\sum_i A_i O_i F_{ij}}$$

F_{ij} = the deterrence function

$$= \left(C_{ij}\right)^{\alpha} \exp\left(\beta C_{ij}\right)$$

C_{ij} = Highway travel time from i to j

T_{ij} = Number of trips between zones i and j.

α = Calibration parameter – power function

β = Calibration parameter – exponential function
Following Gravity Model parameters for trip distribution were obtained.

S.No	Class	α	β
1	Car owning Group	-2.09557	-0.0001819
2	Two Wheeler Group	-1.07986	-0.0236587
3	No vehicle Group	-0.897392	-0.0255572

The observed and Modeled Trip length Frequency Distributions are displayed in Figure 4.1. It can be seen that the Gravity model is very closely representing the observed trip length frequency.

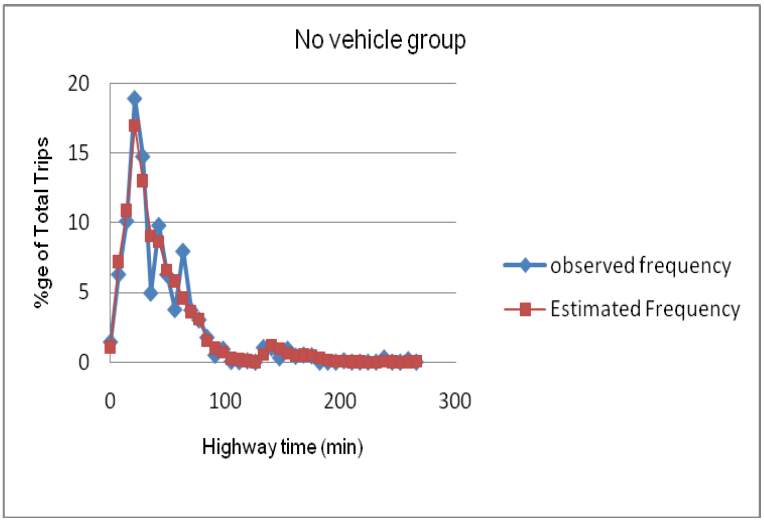


Figure 4.1 (a): Trip Length Frequency Distributions corresponding to no vehicle group

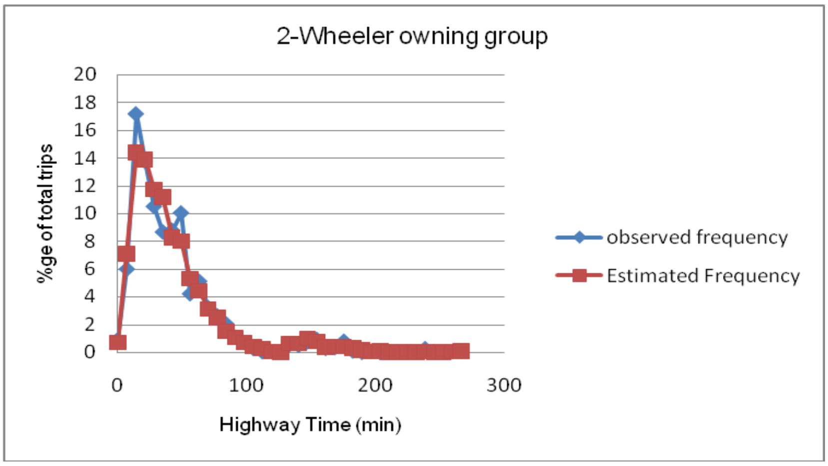


Figure 4.1 (b): Trip Length Frequency Distributions corresponding to 2-wheeler owning group

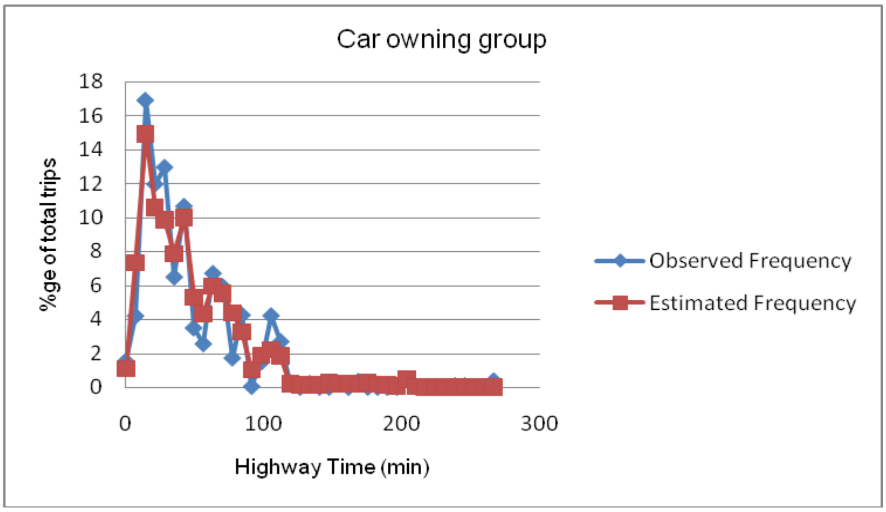


Figure 4.1 (c): Trip Length Frequency Distributions corresponding to car owning group

4.3 Modal Split Model

A multi-nomial logit model of mode choice for different income groups is developed which is shown below for high-income group category. The following multinomial mode choice model was calibrated for this purpose.

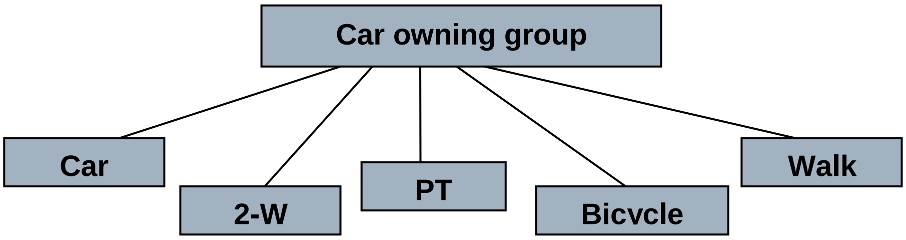


Figure 4.2: Multi-nomial logit model for High Income group category

$$P_j = \frac{e^{V_j}}{\sum_l e^{V_l}}$$

Where,
P_j = probability of choosing mode *j*, (Car, Two wheeler, PT, bicycle, walk)
V_j = deterministic component of utility for mode *j* and
j and *l* are indices for modes

The utility functions of the following specifications are calibrated.

V*car* = α *TTcar* + β *TCcar* + *Constcar*

V*2w* = α *TT2w* + β *TC2w* + *Const2w*

V*pt* = α *TTpt* + β *TCpt* + γ *WTPt* + *Constpt*

V*cycle* = δ *TDcycle* + *Constcycle*

$V walk = \delta\, TDwalk$

The **modal split** parameters for PT and private vehicle split are estimated using the skims obtained from PT and Highway assignments.

S No	Category	ρ square	Equation
01	Car Owning Group	0.1664	a) U_{car} =-.4147E-03*TT-.1059E-02*TC-0.1425 $const_{CAR}$ b) U_{2W} =-.4147E-03*TT-.1059E-02*TC +0.6125 $const_{2w}$ c) U_{PT} =-.4147E-03*TT-.1059E-02*TC-.3141E-01*WT +0.6395 $const_{PT}$ d) U_{CYCLE} = -.9277E-01*TD-0.5878 $const_{CYCLE}$ e) U_{WALK} = -.9277E-01*TD
02	Two Wheeler Owning group	0.1732	a) U_{2w} =-.6061E-02*TT-.1086E-02*TC +1.114 $const_{2w}$ b) U_{PT} =-.6061E-02*TT-.1086E-02*TC+0.2528 $const_{PT}$ c) U_{CYCLE} = -.5634E-01*TD-0.4055 $const_{CYCLE}$ d) U_{WALK} = -.5634E-01*TD
03	No vehicle group	0. 2639	a) U_{PT} =-.1194E-01*TT -.9738E-02*TC-.2331E-02*WT b) U_{CYCLE} = -.7404E-01*TD-1.201 $const_{CYCLE}$ c) U_{WALK} = -.7404E-01*TD -.9331 $const_{WALK}$

4.4 Forecasting of External Trips and Commercial Vehicle Trips

All the external passenger trips are forecasted using growth factor method. These growth factors are arrived at based on the growth of external traffic observed at the cordon. The commercial vehicle matrix is forecast using growth factor method. The growth factors are obtained by observing the growth rates of employment.

4.5 Details of Forecasts

The calibrated travel demand models have been incorporated in CUBE software. For each forecasting year the model is run in an iterative manner with complete feedback structure amongst the sub models. The overall travel estimated by the model in the above manner for the forecast years 2011, 2021, 2031 is given in Table 4.3 The model also gives the demand by individual modes for various network scenarios.

Table 4.3 Estimated Travel for Base year and Forecast Years

Mode	**2008**	**2011**	**2021**	**2031**
PT	286343	330916	452002	578809
PV	65456	79681	113633	138115
CV (PCU)	15855	16051	17895	18356

5 Testing of Scenarios

5.1 Scenario 1:

If PT is improved, how much percentage of people are shifting from Car Owning category, two wheeler owning category and no vehicle category

Table 5.1 Change in Proportion of passenger trips with and without metro

	2011		2021		2031	
	Without Metro	With Metro	Without Metro	With Metro	Without Metro	With Metro
High Income Group	0.14	0.13	0.16	0.12	0.17	0.13
Middle Income Group	0.41	0.41	0.41	0.41	0.41	0.41
Low Income Group	0.46	0.46	0.43	0.47	0.42	0.46

From the results as shown in table 5.1, it can be inferred that:

- The proportionate shift in no vehicle owning group is reducing because of high percentage of shift from car owning group. This can be attributed to their captive nature who have only Public Transport
- There is no shift in 2-Wheeler owning class

5.2 Scenario 2:

Comparison of pollution load due to personalized vehicles with and without metro
(Pollution norms adopted are shown in Table 5.2)

Table 5.2 Emission norms for each vehicle type
(Central Pollution Control Board, India)

mode	CO(gm/km)	HC+Nox(gm/km)
2w	4.5	3.6
car	8.68	4
BUS	11.2	14.4
IPT	7.5	4

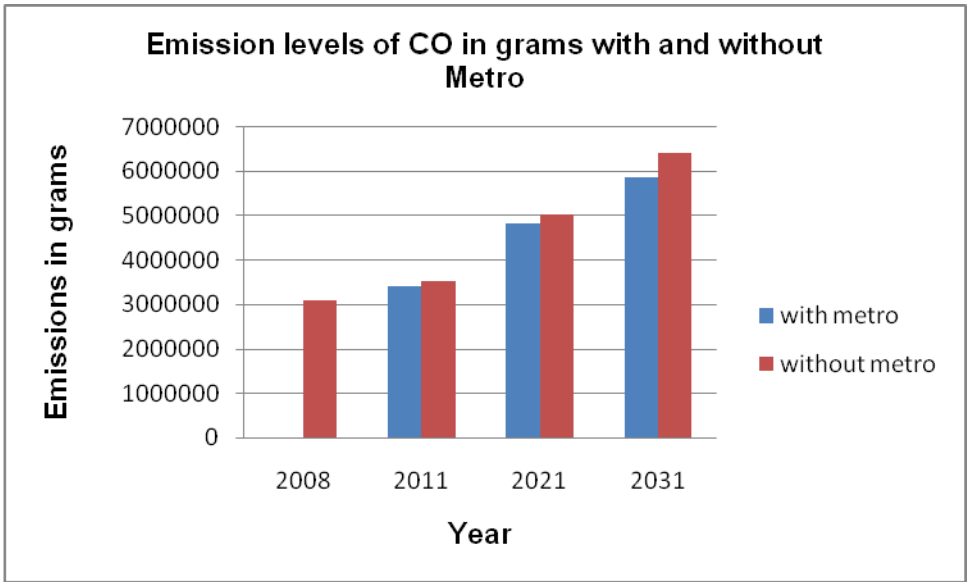


Figure 5.1: Emission levels of CO with and without metro

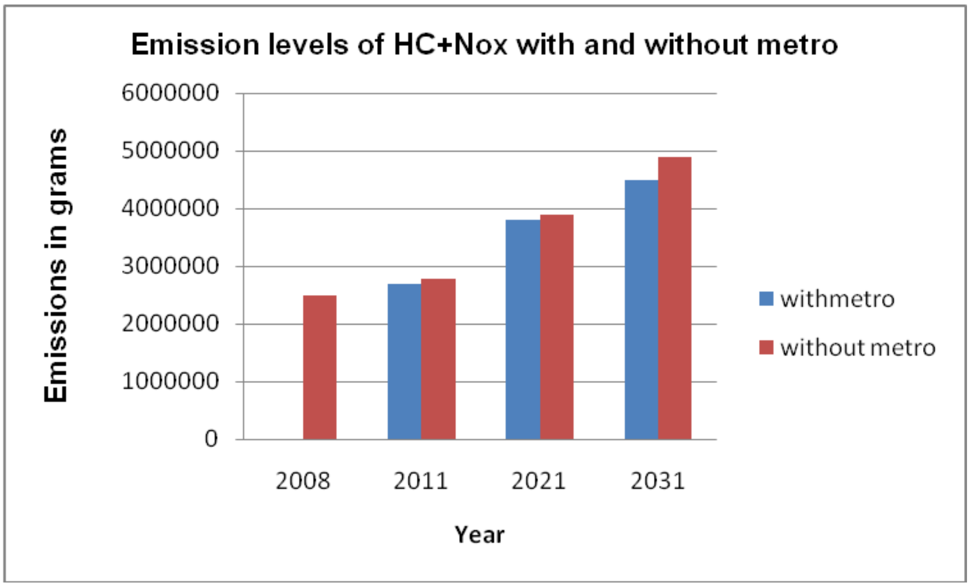


Figure 5.2: Emission levels of HC+Nox with and without metro

From the fig 5.1 and 5.2 it can be observed that for a horizon year, with metro there is a significant decrease in vehicle-kms by bus and IPT modes and hence a significant reduction in levels of CO and HC+Nox emissions.

Hence the major shift to metro from Bus and IPT modes results in the reduction of emission levels to a great extent.

5.3 Scenario 3:

Ridership estimation on metro corridors.

In order to know the priority of the metro lines, 2 lines are coded in the network for 2011 and the remaining 4 for 2021 and 2031. The forecast of ridership on all these lines for each of the forecast year has been presented below:

Forecast for Year 2011

The estimated peak hour loading for year 2011 is displayed in Table 5.3 and the flow diagram for the same is displayed in Fig 5.1. The salient features of loading in the year 2011 are as follows:

• In terms of peak hour passenger boarding Line 2 running from *Kothrud To ramwadi* carries the maximum number of passengers i.e. around 59455

• However, with respect to the index of Passenger kilometers per kilometer, Line 1 gets the first priority followed by Line 2.

• The Peak hour peak direction passenger flow (PHPD) is maximum on Line 2 at 10425.

Table 5.3 Peak Hour Metro Loading for the Year 2011

Line Alignment	*Length (km)*	*Passenger Boardings*	*Passenger Kms*	*Lead (km)*	*Passenger-km/km*	*Combined Max Link Load*	*Loading (PHPD)*
Pimpri Station to Swargate	*16.58*	46934	351171	*7.48*	*21180*	*27415*	*15638*
Kothrud To ramwadi	*13.27*	59455	246655	*4.14*	*18587*	*32821*	*20242*

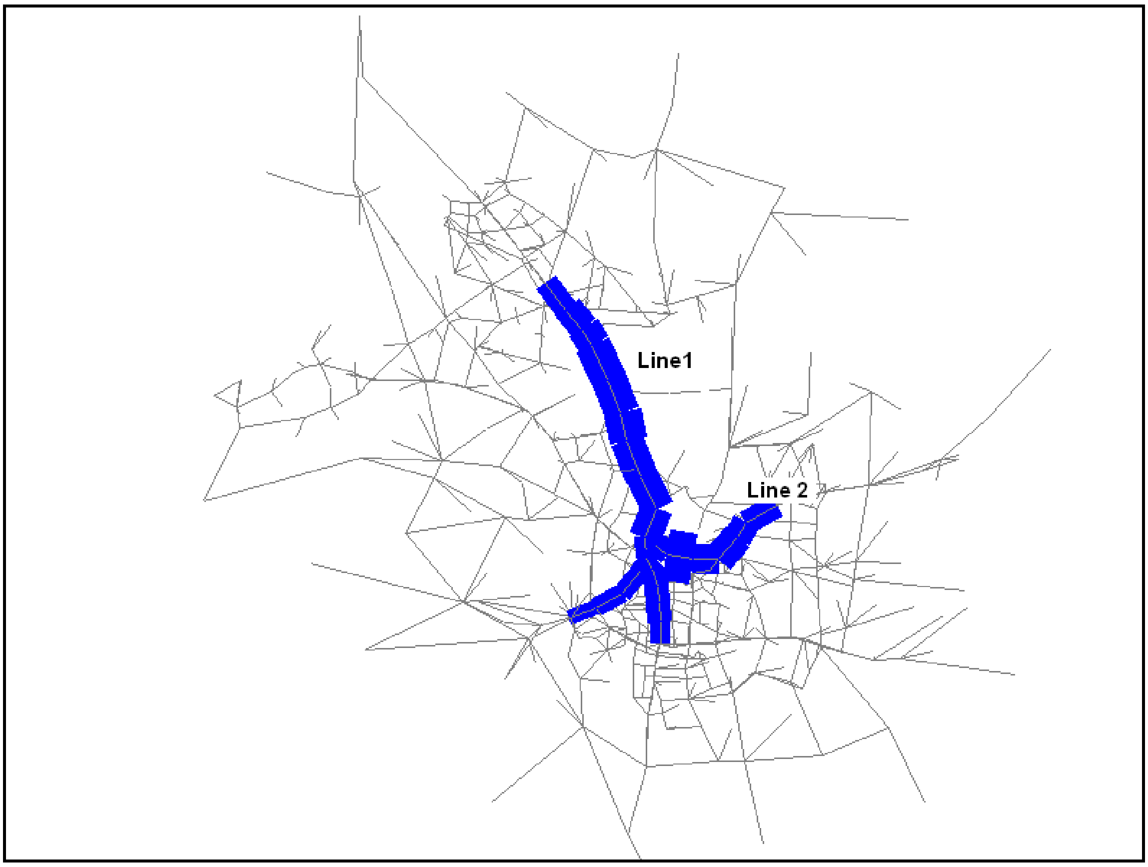


Figure 5.1 Flow Diagram for Horizon year 2011

Forecast for Year 2021

The estimated loading for horizon year 2021 is displayed in Table 5.4 and the flow diagram for the same is displayed in Fig 5.2.The salient features of loading in the year 2021 are as follows:

• In terms of peak hour passenger boarding Line 6 ruining form Agricultural college to Hinjewadi carries the maximum number of passengers.

The passenger demand on this line is as per the observed employment potential at Hinjewadi in the year 2021.

• Line 5 running from Agricultural College to Wagholi follows the suit with peak hour passenger boarding of around 72355.

• However, with respect to the index of Passenger kilometers per kilometer, Line 5 gets the first priority closely followed by Line 1 and Line 4.

Table 5.4 Peak Hour Metro Loading for the Year 2021

Line Alignment	*Length*	*Passenger Boardings*	*Passenger Kms*	*Lead (km)*	*Passenger-km/km*	*Combined Max Link Load*	*Loading (PHPD)*
Agricultural College to Nigdi	16	69086	474894	6.87	29680	47170	24316
Agricultural College to Warje	8.7	16513	74555	4.52	8570	14224	7906
Agricultural College to Swargate and Katraj	16	51876	315850	6.09	19740	43973	23849
Agricultural College to Vagholi	16	72355	337382	4.66	21086	47051	28296
Agricultural College to Hinjewadi	17.5	92592	853077	9.21	48745	62403	32271
Agricultural College to Hadapsar	12	46801	239233	5.12	19936	25157	12884

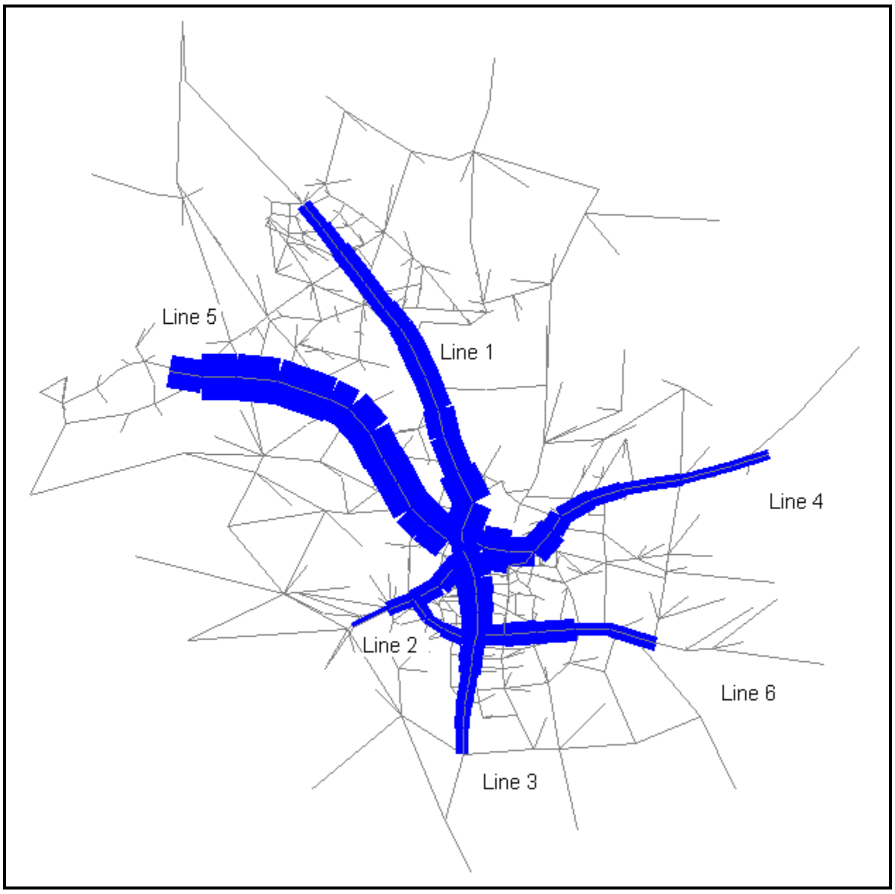


Figure 5.2 Flow Diagram for Horizon year 2021

Forecast for Year 2031

The estimated loadings for horizon year 2031 are shown in Table 5.5 and the flow diagram for the same is displayed in Fig 5.3. The salient features of loading in the year 2031 are as follows:

- In terms of peak hour passenger boarding Line 5 ruining form Agricultural college to Hinjewadi carries the maximum number of passengers
- The passenger demand on Line 5 is as per the observed employment potential at Hinjewadi in the year 2031. Line 1 is also found to be very closely competing in terms of passenger boardings.
- With respect to the index of Passenger kilometers per kilometer, Line 5 gets the first priority again as in 2021.
- The Peak hour peak direction passenger flow (PHPD) is maximum on Line 5 at 34704.
- It is observed that Line5 and Line4 running from Agricultural college to Hinjewadi and Wagoli respectively had a PHPD of 34704 and 30851 indicating the need for a High capacity Mass Transit System.

Table 5.5 Peak Hour Metro Loading for the Year 2031

Line Alignment	*Length (km)*	*Passenger Boardings*	*Passenger Kms*	*Lead (km)*	*Passenger-km/km*	*Combined Max Link Load*	*Loading (PHPD)*
Agricultural College to Nigdi	16	86032	625174	7.22	39073	52390	28505
Agricultural College to Warje	8.7	23418	108678	4.64	12491	16505	11846
Agricultural College to Swargate and Katraj	16	58974	395781	6.71	24736	47534	25078
Agricultural College to Vagholi	16	81012	375718	4.64	23482	48921	30851
Agricultural College to Hinjewadi	17.5	98404	915682	9.30	52324	63971	34704
Agricultural College to Hadapsar	12	62023	339940	5.48	28328	29220	16978

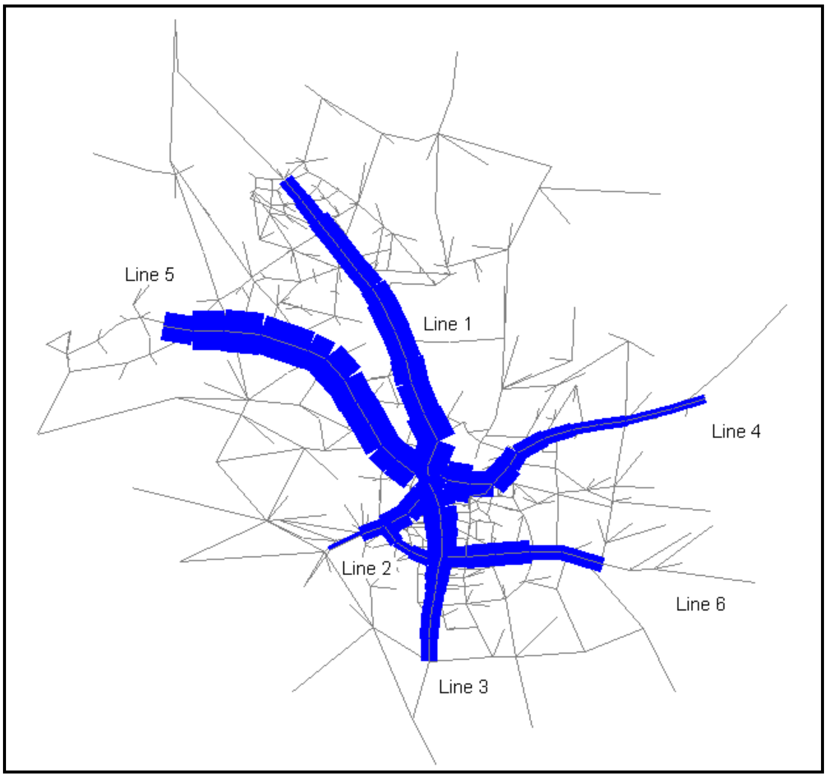


Figure 5.3 Flow Diagram for Horizon year 2031

6 Conclusions

Sustainable development focuses on intergeneration from an integral viewpoint and is dynamic in its character. The analysis in this paper has shown that sustainable transportation development should be regarded as a process of harmonizing sustainability and development requirements for transportation, which include infrastructure improvements. Four Stage travel demand modeling has been adopted in CUBE platform. Based on the estimated ridership for different forecast years the study area requires a Metro system as on today. As the existing modal share of motorized modes is highly skewed towards Private vehicles (i.e. 67% of Private vehicles Vs 33% of Public Transit and IPT), there is a huge potential for achieving a shift towards public transport by introducing efficient systems like Metro. The inherent drawbacks of Choice Model can be subsequently captured to redesign the urban transportation systems.

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