EVALUATION OF DEVELOPMENT PLANS TOWARDS SUSTAINABLE URBAN TRANSPORTATION: A CASE STUDY OF PUNE METROPOLITAN REGION

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Evaluation of Development Plans towards Sustainable Urban Transportation: A case study of Pune Metropolitan Region

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Abstract

Pune, the second largest city of Maharashtra state, India has been experiencing continuous growth and change over the last decade. The total number of trips is drastically increasing due to rapid growth in population and employment. In the recent past, affordability and convenience have driven most of the working group of Pune towards two wheeler usage. The comfort and extra mileage provided by these vehicles had triggered a revolution in this area. But, if the situation is viewed from the transportation planning angle, it is not sustainable. The introduction of shared autos and the hike in public transport fares added further impetus to the unsustainable growth of private vehicles. The observed modal shares during the study indicate that the share of trips by public transport (bus) is only 13% whereas the share of private transport and intermediate public transport (IPT) respectively is 44.9% and 8.3% (Walk and Non-motorized transport – 33.8%). With increase in private vehicle ownership the situation is becoming worse and hence there is an urgent need to augment the current transportation system with modern high capacity transit systems like the Metro, BRTS/Light Rail systems with access being promoted by walk, bicycle, bus and Intermediate Public Transport (in that order). Considering the accelerated growth in population that has been observed in the recent past and the potential of future growth of Pune Metropolitan Region as evident from the population projections, implementation of land use and transport policies for moving towards a more sustainable modal share is of paramount importance. In this regard, Pune Municipal Corporation has proposed development plans for the implementation of high capacity transit systems in a phased manner with appropriate last mile connections (preferably with walk, bicycle, bus and IPT, in that order) and appropriate transit oriented development schemes considering the concept of sustainable urban transportation. The concept of mixed land use minimizing commuter trips in the large IT and ITES employment centers and other employment and growth centers which are being currently implemented and the ones planned in the future is considered in the present study. The study analyses the impacts of mixed land use and transit oriented development scenarios like increased FSI along the metro corridors for future years using the transportation planning model developed by IIT Bombay.

Keywords: sustainable urban transportation, high capacity mass transit systems, development plans, transit oriented development scenarios
1. Introduction

Transport in India is an important part of nation’s economy. Over the last decade, development of infrastructure within the country has progressed at a rapid pace with a variety of modes of transport by land, water and air. 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 and 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. Planning for sustainable urban development focuses on improvements in all of these characteristics of the functioning of cities.

2. Sustainable Planning and Transportation

As per the definition given by World Commission on Economic Development, sustainable development is defined as “development which meets present needs without compromising the ability of future generations to meet their own needs”. According to the literature (Camagni et al., 1998; Masser et al., 1992; Finco et al., 1999), there are five main factors that influence the development of transportation: Spatial and land use planning, government policy, economic forces, technology and social and behavioral trends. Each of these factors evolve over time, and affects both the others and the transportation system. Thus, these factors will determine whether the progress in transportation will be sustainable. Planning for a sustainable transportation system is a complicated task that involves a high degree of uncertainty due to several reasons: (a) the large number of alternative potential policy packages, (b) the way of implementation and (c) the travelers’ response to each of these policy packages. In addition, it depends upon how planners and policy makers define and interpret the concept of sustainable development. Transportation planning usually uses a cost-benefit approach or a multi-criteria analysis. In both cases, to evaluate the benefits and the cost of different scenarios, transportation planning usually applies statistical and behavioral models to analyze the performance of the transportation system under these scenarios. These tools, that have initially been developed to analyze the effects of new transportation infrastructure or public transport services, have been expanded to evaluate the environmental impact of transportation projects, as well as to analyze the sustainability of transportation alternatives. This approach, however, cannot be used as a systematic tool for developing a sustainable transportation system because of several reasons. First, it is not a planning tool; rather it is an evaluation tool, where the suggestion of alternatives is left to the planner. Second, with all the advances in this approach, it still lacks the capability to analyze the effects of many policies and is limited in the sustainable indicators it can predict (Shiftan et al., 2003). Third, this approach is based on extracting existing behavior and trends, making it difficult to account for significant changes in behavior, values or unexpected events.

Some authors have attempted to suggest approaches for sustainable development planning in the general (non-transportation) literature. However, even the most recent planning tools that make use of advanced methodologies and technologies fall short of developing an agreed strategy for sustainable transportation systems. Scenario planning focuses upon map representations developed through the employment of analytical ‘what-if’ functions and spatial modeling usually undertaken in a GIS. It is closely connected to the view that planning should offer inspired visions of the future, based upon likely or preferred scenarios which are either founded upon existing planning policy or used to formulate planning policy. As stated by Stillwell et al., (1999). According to Zegras et al., (2004) scenarios are not new to planning. Indeed, the use of the term scenario is quite common across a range of planning disciplines, from business-strategic planning to urban-transportation planning. For example, in travel-demand forecasting, it is common to develop scenarios of land uses that have a certain probability of developing in the future. Transportation projects can then be evaluated in the context of these different land-use scenarios. Similarly, different scenarios of economic growth, or fuel efficiency improvements, or price changes are often used to develop ranges of future possibilities i.e., the high-growth scenario and the low-efficiency scenario. In these cases, scenarios are simply alternative point estimates of potential futures. In scenario planning, however, the term scenario
adheres more closely to its literal definition of an imagined sequence of future events. Using what are sometimes called decision scenarios, scenario planning is a tool designed to help an organization judge how effective decisions made today will be in the uncertain future. Scenario planning is not a replacement for traditional planning techniques such as forecasting; instead it aims to help organizations better prepare for the unexpected. In short, scenario planning helps to make robust strategic choices. In this paper, the scenario approach was used as a framework for sustainable transportation planning.

3. Study Area

The study area is considered as Pune Metropolitan Region (PMR), with a population of 5.6 million (2011) and spread across an area of 444 km². The study area consists of Pune Municipal Corporation (PMC) area, Pimpri-Chinchwad Municipal Corporation (PCMC) area, Hinjewadi area, Pune and Khadki cantonments. The study area adopted in this study is similar to the one adopted during Pune Metro Project (2009). Figure 1 shows the study area marked in the Pune district map.

The zoning system considered for the Pune Metro Project (2009) comprises of only 91 internal zones and 13 external zones. In the present study, it is proposed to redefine these traffic analysis zones (TAZ) to the extent possible as per the administrative units like election wards. Accordingly, the zoning system comprises of 144 zones in the PMC area, 105 zones in the PCMC area and 16 zones in the Hinjewadi area. Pune and Khadki cantonments have been considered as two zones. In total, 267 internal zones and in addition 13 external zones to capture the external travel have been considered. Two screen lines, the first one along the Mula-Mutha river and the second along the existing railway line is adopted for the present study. Most of the past studies have adopted the same two standard screen lines and the boundary of the study area is considered as the outer cordon line. Figure 2 shows the zones, location of two screen lines and outer cordon traffic volume count stations.
4. Data Set

The data set available from the Pune Metro Project (2009) is made use of for the present study. The available data set comprises of:

- Home interview survey
- Traffic volume counts
- Occupancy counts
- O-D surveys
- Speed and delay survey
- Stated preference survey

Figure 2 Internal Zones, Screen Lines and Outer Cordon Stations in the Study Area

Home Interview Survey

Home interview survey was done during the Pune Metro Project (2009) and the same survey data has been used for the present study. This home interview survey was carried out in the year 2008. Home Interview Survey was conducted on a sample basis in 3000 households which included collection of information regarding the Household, Persons and Trips. From the HIS data it was observed that the share of Public Transit (bus) was as low as 13%. Figure 3 shows the obtained Modal Split from HIS data.
5. Plan Period and Planning Variables

For the present study, 2008 is taken as the base year since Pune Metro Study was carried out in this year. Two horizon years, 2021 and 2031 are considered for the present study. The planning variables considered are discussed in the following sections:

Population
The total population of study area in 2001 was 35.6 lakh (more than thrice the 1971 population of 10.7 lakh). The population growth in the study area from 1961 to 2001 is shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PMC</td>
<td>595762</td>
<td>856105</td>
<td>1203351</td>
<td>1566651</td>
<td>2328349</td>
</tr>
<tr>
<td>PCMC</td>
<td>46031</td>
<td>83542</td>
<td>220966</td>
<td>517083</td>
<td>1083967</td>
</tr>
<tr>
<td>Pune Cantonment</td>
<td>65838</td>
<td>69451</td>
<td>85986</td>
<td>82139</td>
<td>80191</td>
</tr>
<tr>
<td>Khadki Cantonment</td>
<td>58496</td>
<td>65497</td>
<td>80835</td>
<td>78323</td>
<td>77473</td>
</tr>
<tr>
<td>Total</td>
<td>766127</td>
<td>1074595</td>
<td>1591138</td>
<td>2244196</td>
<td>3569980</td>
</tr>
</tbody>
</table>

(Source: Census of India, 2001)

The projected population for the PMR is shown in Table 2. The population growth from 1961 to 2031(projected) is shown in Figure 4.

Table 2 Projected Population of Pune Metropolitan Region

<table>
<thead>
<tr>
<th>Region</th>
<th>2008</th>
<th>2021</th>
<th>2031</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMC</td>
<td>3394948</td>
<td>5239886</td>
<td>6197016</td>
</tr>
<tr>
<td>PCMC</td>
<td>1473210</td>
<td>2273805</td>
<td>2689144</td>
</tr>
<tr>
<td>Pune Cantonment</td>
<td>829888</td>
<td>128086</td>
<td>151483</td>
</tr>
<tr>
<td>Khadki Cantonment</td>
<td>80296</td>
<td>123931</td>
<td>146569</td>
</tr>
<tr>
<td>Hinjewadi</td>
<td>42810</td>
<td>66075</td>
<td>78144</td>
</tr>
<tr>
<td>Total</td>
<td>5074254</td>
<td>7831785</td>
<td>9232356</td>
</tr>
</tbody>
</table>
Employment
The projected employment for the PMR is shown in Table 3.

Table 3 Projected Employment for Pune Metropolitan Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Employment (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
</tr>
<tr>
<td>PMC</td>
<td>1.11</td>
</tr>
<tr>
<td>PCMC</td>
<td>0.54</td>
</tr>
<tr>
<td>Pune Cantonment</td>
<td>0.04</td>
</tr>
<tr>
<td>Khadki Cantonment</td>
<td>0.04</td>
</tr>
<tr>
<td>Hinjewadi</td>
<td>0.25</td>
</tr>
<tr>
<td>Total</td>
<td>1.98</td>
</tr>
</tbody>
</table>

Student Enrolment
The student enrolment in 1996 observed from census data is 6.62 lakhs. The base year aggregate student enrolment is obtained from HIS and it is forecasted to the future and the same has been divided into all the zones depending on the zonal proportions.

6. Travel Demand Modeling
To address equity issues population has been divided into the following 3 segments for the present study:
- Car owning Group (High Income Group-HIG)
- Two wheeler owning group (Middle Income Group-MIG)
- No vehicle group (Low Income Group-LIG)

Initially, the development process of transport network systems is discussed. Then, the four stages of the travel demand model consisting of trip generation, trip distribution, modal split and trip assignment are discussed in detail.

6.1 Transport Network Systems Development Process
Transport network developed comprises of two components:
- Highway Network for private vehicles
- Transit Network for public transport systems i.e. buses, rail and any new public transportation system.
**Highway Network**

Initially, the shape file (with only line features) for whole India was obtained from OpenStreetMap (a collaborative project to create a free editable map of the world by using GPS devices, aerial photographs, etc.) data server. The shape file contained almost the entire road network of all major cities in India. From this shape file, the study area (PMR) road network is separated out using ArcGIS software. Then, the network is converted to required .NET format using CUBE software.

The network built contained a very large number of links (about 31,000) and nodes (to retain the true shape) which makes the work of adding the road attributes/characteristics to all the links very cumbersome. The large number of links and nodes even adds to increasing the time required to run the travel demand model in an enormous way. Hence, the entire network was drawn manually connecting only the nodes at junctions and optimizing the number of nodes and links to the maximum possible extent.

After this exercise, attributes like number of lanes, divided/undivided, one way/two way, flyover, bridge are required to be added to define the link types. For doing this, the network in .NET format is converted into .KMZ format and is super imposed on Google Earth. Two monitors connected to a single CPU were used in which one monitor was used for Google Earth display and the other for adding the attributes (in CUBE) to make the process quicker and easier. The edited links were distinguished from unedited links by using a temporary attribute ‘Edited=0/1’ (0 for unedited and 1 for edited). The total length of network developed is 3596 km and consists of 20,594 links (excluding zone centroid connectors).

Once the links are added with all the necessary attributes, different link types are defined which in turn define the capacity (PCU/hr), free flow speed (km/hr), speed at capacity (km/hr). 13 different link types as per the Pune Metro Study and 9 new link types are adopted for the present study. Figure 5 shows the network with typical link attributes.

**Public Transit Network**

Once the highway network is developed, the public transport routes are coded on the network using PUBLIC TRANSPORT program in CUBE Voyager. The coded public transport routes consist of:

![Figure 5 Highway network with typical link attributes](image)
• PMPML (Pune Mahanagar Parivahan Mahamandal Limited) bus routes
• Intermediate Public Transport-IPT (Auto) routes
• Suburban rail routes
• BRTS (Bus Rapid Transit System) routes
• Shared liner routes (6 passenger autorickshaws)
• Out station bus routes
• Proposed metro routes
• Proposed mono rail routes

The PMPML bus routes were obtained from Pune Bus Guide data server. In total, 363 bus routes were coded along with their frequencies in 10AM to 11AM which is considered as the design hour (peak hour) for modeling. The horizon year (2021 & 2031) network with all proposed BRTS, metro and monorail routes is shown in Figure 6.

Figure 6 Horizon year (2021 & 2031) network with all proposed transit systems

The travel demand model development process is shown in Figure 7.
6.2 Establishing Base Year Travel Pattern

The base year travel pattern in PMR is obtained using the data from home interview survey, outer cordon OD survey, screen line traffic volume counts. The mode wise OD matrices obtained from these primary sources were then used for validation by assigning them on to the respective networks and comparing the observed and estimated flows from the model.

6.3 Trip Assignment

The trip assignment stage consists of two stages:

**Public Transport Assignment**

Peak hour public transport passenger matrix, which includes trips made by bus, Intermediate Public Transport (IPT), shared liners and train was assigned onto the public transport network. The public transport assignment is done based on generalized time. The components of generalized time are in-vehicle travel time (IVTT), waiting time (WT), transfer penalty, fare and discomfort in time units. Accordingly, the generalized time, GT is worked out as:

\[ GT = IVTT + WTFAC \times WT + TRFAC \times NTR + FARE / VOT + DF \]

Where,

- **GT** = Generalized time in minutes
- **IVTT** = In vehicle travel time
- **WTFAC** = Wait time factor
- **WT** = Waiting time
- **TRFAC** = Transfer penalty factor
- **NTR** = Number of transfers
- **VOT** = Value of travel time, in Rs per minute
FARE = Fare paid for journey between origin and destination in Rs.
DF = Discomfort Factor (worked out from SP Survey)

The values of the above parameters used in public transport assignment are worked out from the choice models developed using the Stated Preference and Revealed Preference (Home Interview Survey) data obtained from primary surveys.

There are two important steps in public transport assignment viz., path building and loading trips on to these paths. The purpose of path building is to identify all reasonable paths between zones and provide associated travel information in generalized time so that the proportion of trips using each path may be calculated at the loading stage. Between any pair of zones maximum number of trips are loaded on to the best path and other paths with longer generalized times will be loaded with fewer trips. The proportion of trips to be loaded is calculated on the basis of a logistic choice function based on generalized time.

The public transport (PT) 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 and revealed preference surveys. However, these values were slightly modified to get the assigned flows close to the observed ones. Several skim matrices for PT were obtained at the end of assignment which can be used for calibration of other demand models. The calibrated parameters of PT assignment Model are shown in Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Percent Standees</th>
<th>DF(Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTFAC</td>
<td>1.2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>TRFAC</td>
<td>3</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>VOT</td>
<td>Rs 0.53/ min</td>
<td>75</td>
<td>20</td>
</tr>
<tr>
<td>DF</td>
<td>As per Table 5</td>
<td>95</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

**Table 4 Calibrated parameters of Trip Assignment**

The public transport (PT) 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 and revealed preference surveys. However, these values were slightly modified to get the assigned flows close to the observed ones. Several skim matrices for PT were obtained at the end of assignment which can be used for calibration of other demand models. The calibrated parameters of PT assignment Model are shown in Table 4.

Highway Assignment

Highway assignment has been carried out for peak hour, preloading the highway network with peak hour public transport flows. The peak hour public transport passenger trips were converted into PCUs by using appropriate PCU-passenger ratios. These peak-hour public transport (bus and IPT) flows in terms of PCUs were preloaded on to the highway network before loading the two-wheeler and car O-D matrices. The passenger matrices of car and two-wheeler were converted into peak hour PCU units by using appropriate K factors (proportion of daily flow occurring during peak hour) and passenger-PCU conversion factors based on observed occupancies. An equilibrium procedure based on generalized cost was used in loading these car and two-wheeler matrices. The Commercial Vehicle (CV) trips were taken as preloads on highway network. The generalized cost, GC, used in highway assignment has the following form

\[
GC = VOT \times TT + TC
\]

Where,

\[
VOT = \text{Value of travel time} \quad TT = \text{Travel time} \quad TC = \text{Travel cost}
\]

Travel cost for car/two-wheeler is the perceived operating cost which was taken as the cost of fuel and oil. Two skims namely the highway time and highway travel cost were obtained from the loaded network. The parameters of generalized cost used in Highway assignment are given in Table 6.
Table 6 Parameters of Generalized cost used in Highway Assignment

<table>
<thead>
<tr>
<th>Mode</th>
<th>VOT (Rs/Hr)</th>
<th>TC (Rs/ Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Wheeler</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>Car</td>
<td>107</td>
<td>5</td>
</tr>
</tbody>
</table>

The assignment of PT and private vehicle trips were done iteratively till an overall equilibrium was reached between PT and highway networks.

6.4 Validation of Base Year Travel Pattern

The estimated private vehicle flows (in PCU) and public transport passenger trips in peak hour in peak direction are compared with the flows observed across the screen lines. The estimated traffic flow in terms of passenger car equivalencies across all screen lines was found to match very closely with the observed flows. In fact, the percent error between observed and estimated flows across the screen line was found to be within 5%. The percent error at individual screen line points, however, was found to be within 15% at most of the screen line points. As many of the adjacent links across the screen line provide alternate crossing paths, the above error at individual links is acceptable. The public transport passenger flows estimated by the model and those observed across screen lines also match within 5% indicating that the model is capable of capturing the observed distribution of public transport trips between bus and IPT modes. The comparison between observed and estimated trips across screen lines is shown Table 7. Therefore, the estimated travel pattern of the base year (2008) was found to be fairly accurate and the model performance was acceptable as established through these observations.

Table 7 Observed and Estimated Flows across Screen Lines

<table>
<thead>
<tr>
<th>Mode</th>
<th>Observed</th>
<th>Estimated</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vehicles (PCU)</td>
<td>72963</td>
<td>75352</td>
<td>+3.27</td>
</tr>
<tr>
<td>PT Trips (passengers)</td>
<td>124855</td>
<td>118674</td>
<td>-4.95</td>
</tr>
</tbody>
</table>

6.5 Trip Generation Models

The trip generation model estimates the number of trips produced and attracted to each of the traffic analysis zones (TAZ). The trips produced are estimated from the household socio-economic and trip making characteristics. The Productions (P) and Attractions (A) of internal passenger trips by all modes are calculated from the validated PA (Production Attraction) matrices. Trip generation models are developed using stepwise multiple linear regression technique. The calibrated trip end equations for different income groups are presented below in Table 8 & Table 9.

Table 8 Trip Production Models for different income groups

<table>
<thead>
<tr>
<th>Category</th>
<th>Model</th>
<th>$R^2$</th>
<th>$(t_{stat})_{POP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Owning Group</td>
<td>0.58 x POP_hig</td>
<td>0.957</td>
<td>2.51</td>
</tr>
<tr>
<td>Two Wheeler Owning Group</td>
<td>0.58 x POP_mig</td>
<td>0.88</td>
<td>6.18</td>
</tr>
<tr>
<td>No Vehicle Group</td>
<td>0.58 x POP_lig</td>
<td>0.949</td>
<td>9.85</td>
</tr>
</tbody>
</table>

Where,
POP_hig: population of high income group (car owning group)
POP_mig: population of medium income group (two wheeler owning group)
POP_lig: population of low income group (no vehicle group)
Table 9 Trip Attraction Models for different income groups

<table>
<thead>
<tr>
<th>Category</th>
<th>Model</th>
<th>$R^2$</th>
<th>($t_{stat}$)$_{EMP}$</th>
<th>($t_{stat}$)$_{STEN}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Owning Group</td>
<td>1.45 x EMP + 0.12 x STEN</td>
<td>0.695</td>
<td>19.28</td>
<td>2.72</td>
</tr>
<tr>
<td>Two Wheeler Owning Group</td>
<td>1.28 x EMP + 0.1 x STEN</td>
<td>0.80</td>
<td>18.69</td>
<td>1.87</td>
</tr>
<tr>
<td>No Vehicle Group</td>
<td>1.18 x EMP</td>
<td>0.639</td>
<td>8.58</td>
<td>-</td>
</tr>
</tbody>
</table>

Where,
EMP: Employment; STEN: student enrollment

6.6 Trip Distribution Models

A Gravity Trip Distribution model of the following form is calibrated for distributing the total internal passenger trips. The calibrated Gravity Model parameters are shown in Table 10.

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

Where,

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

$F_{ij} = $ the deterrence function

$$C_{ij} = \text{Highway travel time from i to j}$$
$$T_{ij} = \text{Number of trips between zones i and j.}$$
$$\alpha = \text{Calibration parameter – power function}$$
$$\beta = \text{Calibration parameter – exponential function}$$

Table 10 Gravity Model parameters for different income groups

<table>
<thead>
<tr>
<th>S.No</th>
<th>Class</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Car owning Group</td>
<td>-2.09557</td>
<td>-0.0001819</td>
</tr>
<tr>
<td>2</td>
<td>Two Wheeler Group</td>
<td>-1.07986</td>
<td>-0.0236587</td>
</tr>
<tr>
<td>3</td>
<td>No vehicle Group</td>
<td>-0.897392</td>
<td>-0.0255572</td>
</tr>
</tbody>
</table>

6.7 Modal Split Model

A multi-nomial logit model of mode choice for different income groups is developed for the entire study area of PMR which is as shown in Figure 8. The following multinomial mode choice model was calibrated for this purpose.

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

Where,

$P_j = \text{probability of choosing mode j, (Car, Two wheeler, PT)}$
$V_{ij} = \text{deterministic component of utility for mode j and}$
$j$ and $l$ are indices for modes

The utility functions of the following specifications are calibrated.

$$V_{car} = \alpha_{TTcar} + \beta_{TCcar} + \text{Const}_{car}$$
$$V_{2w} = \alpha_{TT2w} + \beta_{TC2w} + \text{Const}_{2w}$$
$$V_{pt} = \alpha_{TTpt} + \beta_{TCpt} + \gamma_{WTpt}$$

Where,
TT = Travel Time, TC = Travel Cost, WT = Waiting Time

**Figure 8 Multi-nomial logit model for different income groups**

The modal split equations calibrated are shown in Table 11.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Category</th>
<th>ρ square</th>
<th>Equation</th>
</tr>
</thead>
</table>
| 01    | Car Owning Group             | 0.1664   | a) $U_{car} = -0.0004147 \times TT - 0.001059 \times TC + 0.5425$  
       |                               |          | b) $U_{2w} = -0.0004147 \times TT - 0.001059 \times TC + 0.3125$  
       |                               |          | c) $U_{pt} = -0.0004147 \times TT - 0.001059 \times TC - 0.03141 \times WT$  |
| 02    | Two Wheeler Owning group     | 0.1732   | a) $U_{2w} = -0.003475 \times TT - 0.07817 \times TC + 1.312$  
       |                               |          | b) $U_{pt} = -0.003475 \times TT - 0.07817 \times TC - 0.00687 \times WT$  |

7. Development Scenarios

Various development scenarios can be evaluated taking into consideration the sustainability concept. Since for evaluation of any development scenario it is necessary to have a four stage travel demand model the same was developed as explained in the earlier sections. Using the travel demand model developed, the following two scenarios have been evaluated for the horizon years 2021 and 2031:

1) Usual Land Use Scenario (Scenario 1): With the prevailing land use pattern (base year is taken as 2008) traffic is forecasted for the horizon years 2021 and 2031 with different transportation network systems. The different transportation systems considered for the horizon years in both the scenario 1 and scenario 2 include metro, monorail and BRT corridors (Figure 11).

2) Increasing Floor Space Index (FSI) along Metro corridor (Scenario 2): Increasing the FSI to 4 along the Metro corridors (for 500m on both sides) for the years 2021 and 2031, the traffic is forecasted and compared with the usual land use scenario (Scenario 1).

The zonal map is superimposed on the road network for identifying the zones which fall under the influence of metro. ArcGIS software was used to calculate the metro influence area for 500m both sides along the metro corridors. Among FSI of 4, FSI 2 is provided for commercial activity (employment) and FSI 2 is provided for residential (population).

The basic assumption made to calculate the population along metro corridor is as follows:
- The size of each dwelling house is considered as 80 sq m.
- Household size is taken as 4.

The population under influence of metro corridor for each zone is found out as follows:
Population = (Area under influence of metro) * FSI * 4 / size of each dwelling house

The population of the zones under the influence of metro is calculated as above and the population of all other zones has been calculated as per the prevailing condition of land use pattern and also the total population is maintained as per the usual forecast.
The basic assumption made to calculate the employment along metro corridor is as follows:
- Employment is considered as 12 people per 1000 sq. m area.

The employment under influence of metro corridor for each zone is found out as follow:
Employment= (Area under influence of metro) * FSI * (employment/area)

= (Area under influence of metro) * 2*12 /1000

The employment of the zones under the influence of metro is calculated as above and the employment of all other zones has been calculated as per the prevailing condition of land use pattern and also the total employment is maintained as per the usual forecast.

8. Results and Discussion

Firstly, the increase in the public transport share (for the usual land use scenario i.e, for scenario 1) due to the augmentation of the present transportation system with high capacity mass transit systems like metro, BRT, monorail, etc., with appropriate last mile connections is discussed which is as shown in Table 12. The percentage share for the horizon years is calculated considering both the internal and external trips excluding the walk and bicycle trips (non-motorized trips).

| Table 12 Comparison of Percentage Share of Public and Private Transport |
|-----------------|-------|-------|-------|
|                 | 2008* | 2021  | 2031  |
| % PT Share      | 21.3% | 48.5% | 49.5% |
| % PV Share      | 44.9% | 51.5% | 50.5% |

* For the base year 2008, non-motorized transport share is 33.8%

It can be seen from the table that, the public transport share has increased to nearly 50% for the horizon years 2021 and 2031 with the proposed high capacity mass transit systems. However, the share is on a relative lower side due to the inherent deficiency of the Mode choice modal which was developed only on revealed preference data of the base situation. In reality the public transport might get a still higher percentage share for the horizon years resulting in increased passenger loads on metro.

Secondly, the peak hour passenger boardings and passenger distance for different public transport modes estimated from the model for two scenarios have been compared and is as shown in Table 13.

| Table 13 Comparison of Peak Hour Passenger Boardings and Passenger Distance for Scenario 1 and Scenario 2 |
|-------|-------|-------|-------|-------|-------|-------|
| Mode  | 2021  | 2031  | 2021  | 2031  | 2021  | 2031  |
|       | (Usual Land Use) | (Increasing FSI) | (Usual Land Use) | (Increasing FSI) | (Usual Land Use) | (Increasing FSI) |
|       | PB* (Km) | PD* (Km) | PB* (Km) | PD* (Km) | PB* (Km) | PD* (Km) |
| Bus   | 107899  | 422375  | 104818  | 374739  | 119804  | 456826  |
| IPT   | 30807   | 100084  | 19713   | 55340   | 36244   | 114333  |
| Train | 326     | 4945    | 8.8     | 125     | 372     | 5610    |
| BRTS  | 32234   | 93222   | 24465   | 62388   | 49098   | 140537  |
| Metro | 217654  | 1528152 | 222356  | 1370980 | 289960  | 2135564 |
| Mono  | 35160   | 157410  | 32759   | 119726  | 47050   | 214506  |
| PB* - Passenger Boardings | PD* - Passenger Distance (Km) |

For both the years 2021 and 2031, it can be seen from the table that there is a reduction in the passenger boardings of all modes except metro for scenario 2 compared with scenario 1 whereas for metro, there is a slight increase in the passenger boardings. It can also be observed from the table that the passenger distance travelled has been reduced for all modes for scenario 2 compared with scenario 1.
1. This is due to the fact that the increase in FSI along the metro corridors has reduced the average trip lengths and the same is discussed in the following sections.

Lastly, the average trip lengths for two scenarios have been compared as shown in Table 14.

<table>
<thead>
<tr>
<th></th>
<th>2021 (Usual Land Use)</th>
<th>2021 (Increasing FSI)</th>
<th>2031 (Usual Land Use)</th>
<th>2031 (Increasing FSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No vehicle group</td>
<td>33.8</td>
<td>25.7</td>
<td>34.6</td>
<td>26.6</td>
</tr>
<tr>
<td>TW owning group</td>
<td>35.7</td>
<td>26.5</td>
<td>36.5</td>
<td>27.3</td>
</tr>
<tr>
<td>Car owning group</td>
<td>34.4</td>
<td>25.5</td>
<td>35.2</td>
<td>25.7</td>
</tr>
</tbody>
</table>

It can be observed from the table that there is an overall 25% reduction of trip lengths for scenario 2 compared with scenario 1 for both the years 2021 and 2031. This is again due to the increase in FSI along the metro corridors and thereby reducing the average travel times.

The trip length frequency distribution graphs showing the reduction in the average trip lengths for different income groups for the horizon year 2021 are as shown in Figure 9. For the year 2031 also, similar behavior is observed.

Figure 9 Trip length frequency distribution graphs for different income groups (2021)
9. Summary and Conclusions

The observed modal shares in the base year (2008) indicate that the share of trips by public transport (bus) is only 13% and whereas the share of private transport and intermediate public transport respectively is 45% and 8.3%. Considering the accelerated growth in population that has been observed in the recent past and the potential of future growth of Pune Metropolitan Region as evident from the population projections, implementation of land use and transport policies for moving towards a more sustainable modal share is of paramount importance. Considering the concept of sustainable urban transportation, implementing high capacity transit systems in a phased manner with appropriate last mile connections (preferably with walk, bicycle, bus and IPT, in that order) and appropriate transit oriented development schemes becomes the need of the hour. The concept of mixed land use minimizing commuter trips should be adopted in the large IT and ITES employment centres and other employment and growth centres that are being currently implemented and the ones planned in the future. A scenario based approach was used to evaluate the development plans considered for the future years with the help a travel demand model.

The travel demand model was developed for PMR using the data available from the Pune Metro Study to test the land use and transport scenarios arrived at based on the above concepts.

In Scenario 1, the impact of the base land use scenario with the prevailing controls has been evaluated on the proposed transport system improvements. The share of public transport has increased to nearly 50% for the horizon years. This increase seems to be still on a lower side due to the inherent deficiency of the Mode choice modal which was developed only on revealed preference data of the base situation. In reality the public transport might get a still higher percentage share for the horizon years resulting in increased passenger loads on metro.

In Scenario 2, wherein densification has been done along the metro corridor, it has been observed that there is a reduction of 25% in the average trip length and also the boardings in the Metro has increased. It can be said that, increasing FSI along metro corridor will surely help rather than developing the city outwards. Therefore transit oriented development, i.e., densification along with new public transportation infrastructure like metro can lead to a sustainable development.

References


Pune Metro Project (2009), Detailed Project Report, Delhi Metro Rail Corporation, New Delhi.

