CHAPTER – 4

DEVELOPMENT OF OPERATIONAL TRAVEL DEMAND MODEL

4.1 INTRODUCTION

4.1.1 A Detailed operational model is required to enable estimation of future travel demand which will help in identifying transport requirements. A number of sub-models have to be developed as follows

- Trip end model
- Trip distribution model
- Modal split model
- Assignment model

4.1.2 India is one of the developing country having heterogeneous type of vehicles on road starting from slow moving vehicles such as cycles to medium speed auto rickshaws to fast moving two-wheelers, cars, buses, trucks etc. It is necessary to select appropriate travel demand software which can model multi modal transport system. Various soft-wares are available such as EMME2, SATURN, TRIPS/CUBE etc. An effort has been made in **Table 4.1** to compare these three popular soft-wares as mentioned above to select a best suited to Bangalore city.

Table 4.1 Comparative Capability Statement of three popular transportation planning software

S. No.	Particulars	EMME2	SATURN	TRIPS/CUBE
1	Network Scenario	Network consists of modes, nodes, links, turns and transit lines(up to 1,50,000 links, 60,000 nodes and 6000 zones) - up to 30 modes (such as car, truck, bus, train, walk etc.) - Possible to model the interaction between the modes. - A data bank can contain several scenarios - base year, alternatives to future years etc.	Network consist of modes, nodes, links, turns and transit lines (up to 2,00,000 links, 1,00,000 nodes and 8,250 zones) - Up to 32 modes - Possible to model the interaction between modes - Data bank contains all scenarios.	Network with links, nodes and transit links.
2	Matrices	Matrices contain results as well as in-put data - demand and travel time by O-D pair. - Zone grouping can be defined to allow the production of aggregate matrices.	Matrices contain results as well as in-put data - demand and travel time by O-D pair. - zone grouping can be defined to allow the production of aggregate matrices	Matrices contain input data - demand and travel time by O-D pair.
3	Functions	Functions are defined by the	Functions are defined by	Flexible command

		user.	the user.	language for implementing demand modals. - Advanced, built in functions for implementing standard modeling processes. - User interface in multiple languages
4	Matrix manipulation tools	Can be used to implement any travel demand forecasting model from the classical 4-step model to multi-modal assignment with direct demand functions as well as modes based on trip chains.	Provides facilities to build and modify trip matrices with options for factoring, combining, transposing, Furnessing, compressing / Disaggregating zones.	Matrix estimation functions for private and public transportation.
5	Assignment	Provides an equilibrium road assignment procedure.	Supports a wide range of assignment options, equilibrium, stochastic user equilibrium, All or nothing, stochastic, - Full demand responsive options available (elastic assignment)	Dynamic traffic assignment Multi-path public transit assignment
6	Transit assignment	Provides a multi-path transit assignment for modelling and analyzing.	Solution towards integrated transport - evaluate PT networks & service levels - examine routing options - determines route loading - skim public transport cost - Bus priority measure, LRT & guided bus system, park & ride and Traffic restraint.	Innovative multi-path and multimode approach for modeling public transit path building and assignment.
7	Graphic tools	All elements of the data bank may be displayed using various tools - interactive graphic editor, matrix histogram, shortest path builder, scenario comparison etc.	A vast range of display options - multiple network - analysis option - link and junction annotation - network comparison - turning movement annotation - GIS backgrounds - individual junction plot - lane allocations and speed - identification of problem junctions - journey time plots - bus route information	- Power of GIS -Capability to build, compare and spatially analyze transportation system.

8	Wide variety of application	Can be used to address wide variety of transportation planning problems from inter-urban highway studies to urban road, public transport and multi-modal studies.	Traffic congestion solution, revised traffic management arrangements by-pass or town center relief, development impact, local junction improvement, forecasting the impacts of traffic growth, assessing induced traffic, impact of capacity reduction economic or environmental assessment. From tolling to traffic management, from handful of junctions to full regional studies.	- Simulation of personal travel -Freight -Environmental impact
9	International user base	Supports international character sets, plot titles in several languages and representation of left-hand traffic.	Has over 300 users' world wide in 30 countries and also widely used for research projects. Has been used in Santiago, Cambridge, Kuwait, Dublin, Leeds, Chennai and Mumbai.	Used in many countries by various consultants.
10	Use in India	Information not available	Used in Chennai and Mumbai and the software is customized to Indian conditions	Information not available

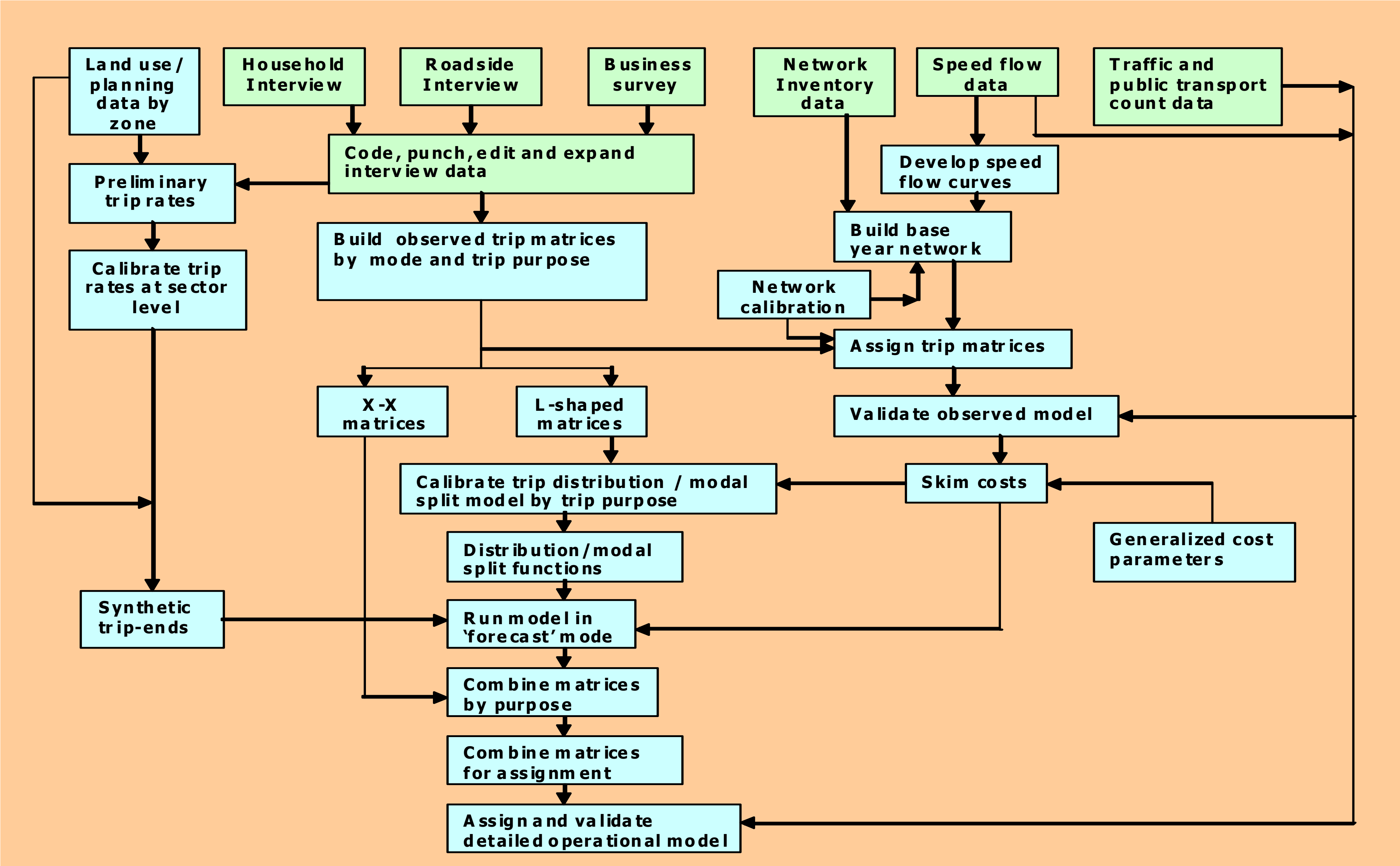
4.1.3 The comparison of the above three software infers that the software PT-SATURN developed by University of Leeds and M/s WSATKINS has been customized to Indian conditions while being used in Chennai and Mumbai. It will be prudent to mention here that the software at Chennai has been used by M/s RITES Ltd during the preparation of Comprehensive Traffic and Transportation Plan for Chennai Metropolitan Area in 1992-95. Hence SATURN was found the appropriate one to use for Bangalore.

4.2 METHODOLOGY FOR MODEL DEVELOPMENT

4.2.1 The steps involved in model development are indicated in **Figure 4.1**. Trip end models have been developed using multiple linear regression. SATURN /PT-SATURN packages have been used for the other three steps.

4.2.2 The model developed has been used for traffic forecasting for the horizon year at the strategic level including public transport corridor system. The extensive data base that was established as a result of the traffic surveys in 2006 provided the base for the model development, calibrated and validation.

Figure 4.1 Development of Detailed Operational Model



4.3 TRIP GENERATION

4.3.1 The first step is to derive the models for trip generation / production in different zones. The trip generation models can be obtained either by using Multiple Linear Regression (MLR) technique or simple linear regression techniques. The models are based on the premises that;

(i) a linear relationship exists between the trip generation and the other various independent variables which influence the trip production; and

(ii) The influence of each such independent variable on trip production is additive i.e. addition of each variable in the model contributes in a positive or negative way towards the value of dependent variable.

4.3.2 In case of MLR it takes the form

$$To = ao + a1\,x1 + a22x22 + \ldots\ldots\ldots. + an,\,xn$$

ao is a constant;
a1, a2, ……………. an are coefficients;
x1, x2, ……………. xn are influencing variables

which include one or more planning factors, socio-economic characteristics and trip characteristics. They should normally cover the factors like

(i) The land use pattern and development in study area
(ii) the user characteristics like household size, income, vehicle availability; and
(iii) the nature, extent and capacities of the transportation system

In case of simple linear regression equation the equation takes the form of:

$$Y = a + bX$$

Where, a is a constant, b is the coefficient and X is the independent variable.

4.3.3 Since number of households is highly correlated to either number of workers, number of students, or number of households as a variable would take a negative coefficient and it was not desirable to be included.

4.3.4 As the projection of vehicle ownership or number of vehicles in zone is difficult especially because of non availability of zone-wise economic data this variable has not been considered. But the variables which were decided to be included is as follows:-

For Work :'Zonal population'.
For Educ : 'Zonal population'.
For Other :'Zonal Population'.

The trip generation models developed for peak and off peak period for full BMA are given below:

WHOLE DAY MODELS

Work trips	=	**7092.014 + 0.230406 P**	**R2= 0.829**
Educ. trips	=	**3287.878 + 0.088129 P**	**R2= 0.759**
Other trips	=	**2734.769 + 0.108239 P**	**R2= 0.722**

Where
P = Population
R2 = Coefficient of Multiple Correlation

4.4 TRIP ATTRACTION

4.4.1 Trip attraction can be done only at zonal level. The trip attraction models are mostly derived using regression approach. The data availability at zonal levels, which could be forecasted were checked first. But the relevant data's like number of work places, student enrolment for future years and also land use in terms of commercial area for future years were not available neither in Master Plan prepared by BDA nor else where. In absence of such data effort was made to forecast work places and student enrollment based on information like population and future activity shifting as per the Master Plan. The equation for other trips were developed based on available data like area of commercial areas at planning district levels as data was not available at traffic zonal level. Based on the above the variables used were

Work Trips : Number of work places.
School Trips : Number of school enrolment
Other trips : Commercial area

WHOLE DAY MODELS

Work trips	=	**4904.793+0.68661*WP**	**R2= 0.768**
Educ. trips	=	**2469.983+0.415853*SE**	**R2= 0.700**
Other trips	=	**8989.15+ 401.10 * CA**	**R2= 0.7267**

Where
WP = Work places
SE = Students enrollment
CA = Commercial Area
R2 = Coefficient of Multiple Correlation

4.5 BASE YEAR NETWORK DEVELOPMENT

4.5.1 Introduction – SATURN / PT SATURN

Having identified the study area and traffic zones, the base road network (in SATURN) and public transport network (in PT-SAT) were defined.

4.5.2 SATURN (Simulation and Assignment of Traffic on Urban Road Networks)

4.5.2.1 SATURN is a suite of computer program which has four basic functions

- As a network database and analysis systems
- As a combined traffic and simulation and assignment model for the analysis of traffic management schemes over relatively localized networks
- As a conventional traffic assignment model for the analysis of larger network
- As a simulation model of individual junctions

4.5.2.2 The basic SATURN model has the following six components programs

- The Network build program
- Assignment program
- Simulation program
- Analysis program
- Network editing program
- Network plot program

4.5.2.3 **For the network build program SATNET, data required are the link data like** distance, free and capacity speed capacity, power of speed – flow curve, bans on links coordinates of nodes, public transport routes etc.

4.5.3 PT-SATCHMO (SATURN Travel Choice Model)

4.5.3.1 SATCHMO is a multi-modal transport package to complement SATURN and provide facilities to model the new measures and responses. The public transport programs are used to

- Build Network (SAT10)
- Build paths
- Skim trees
- Evaluate inter zonal costs
- Assign a trip matrix to network

4.5.3.2 To build network, link speed will be read from SATURN network factored for allowing slowing at stoppages. The bus route is also read from the SATURN private network.

4.5.4 Private Vehicle Network

4.5.4.1 The Bangalore Metropolitan Area is served by a network of roads and railways to facilitate travel within the area by both private and public transport. But the network within the area is not well defined on scientific basis and also it doe not have proper well defined hierarchy of roads. Depending on the characteristics of some of the roads it is possible to broadly divide them into 4 categories like

- Arterial roads
- Sub-Arterial roads
- Collector-distributors roads
- Local Streets

4.5.4.2 It was assumed that all trips generated within zone will emanate from zone centroid. In order to load the trips on to the network they are connected to the network with the help of zone centroid connector. The travel characteristics of a centroid connector will represent the zonal average of trips starting and ending at that zone. For any centroid there may be more than one centroid connector depending on the local conditions of a traffic zone, and network links in the zone. The base road network, centroid and centroid connectors are shown in **Figure 4.2** and **4.3**. Centroid connectors linking zones with nodes were assigned with speeds of 15 Kmph in the city, 20 Kmph in outer regions. Distance is measured from each loading point to the theoretical centre of gravity.

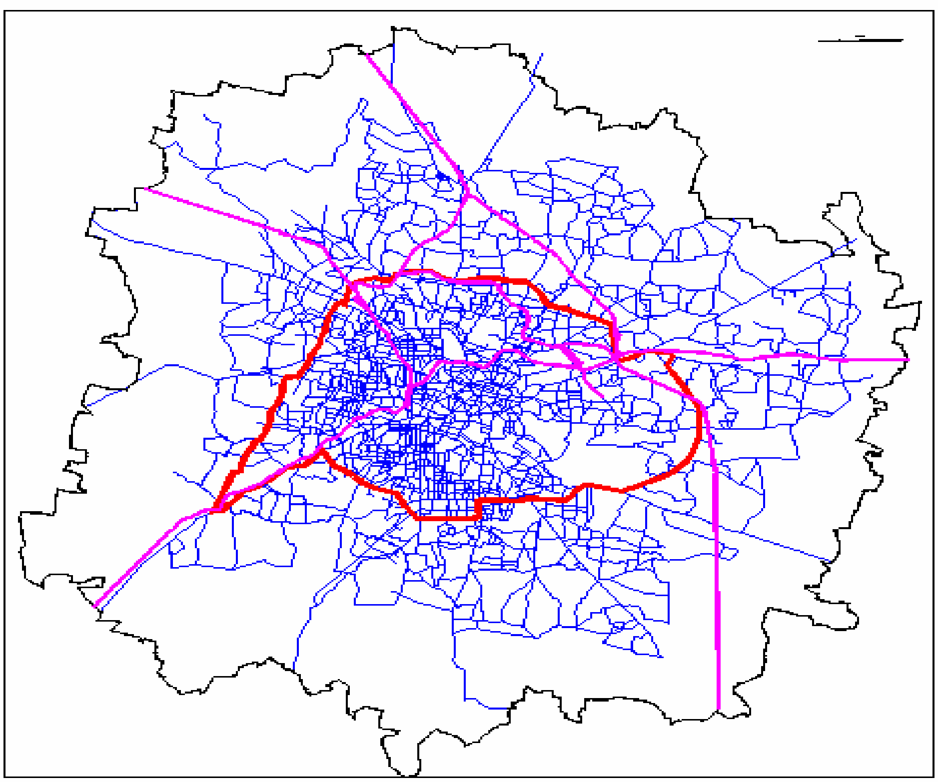


Figure 4.2: Base Road Network

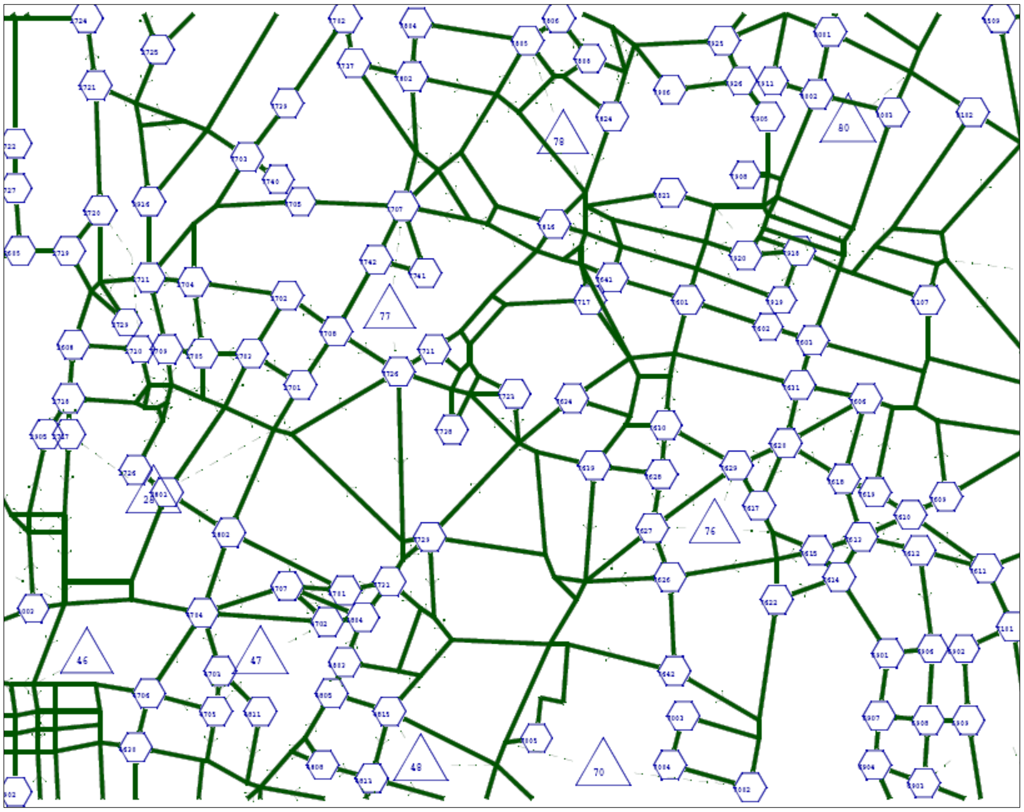


Figure 4.3: Road Node and Centroid and their Connectors

4.5.4.3 Link lengths were measured from the plans and checked at random by measuring at sites. Each link was also allocated a speed flow curve according to the speed flow study mentioned earlier and depending on category of the link in which it is falling.

4.5.4.4 Bus services of BMTC were coded with more details. The frequency of buses operating on each route was coded so as to preload the same to the private vehicle network. A bus PCU value of 3.0 was assumed.

4.5.5 Public Transport Network

4.5.5.1 The public transport network developed in PT-SAT is a composite network consisting of both bus and rail services. This helps in passenger interchange between the two. The composite network allows greater flexibility in route choice and helps in realistic assignment of trips from the combined public transport matrix.

4.5.5.2 PT SATURN extracts the bus routes and frequencies from SATURN network file. An extensive system of both bus and rail routes were modeled. This include all the intra city bus services run by BMTC and suburban rail service and exclude the intercity bus and rail services.

4.5.5.3 Bus speeds are read directly from SATURN network file which includes the effect of congestion due to private vehicles. A factor of 1.2 was used on these speeds to reflect time lost at bus stops.

4.5.5.4 Centroid connectors link centroids to the bus and rail network at major nodes and appropriate stations. The Centroid connectors represent overall walking time from Centroid to the public transport system. The mean walking speed was considered as 5 Kmph.

4.5.5.5 Transport links represent connections between bus to bus routes and railway stations. They are considered as walk links.

4.5.5.6 Important assumptions which were made whiling building public transport network are :

- Private Vehicle link times are factored by 1.2 to allow time lost at bus stops enroute
- Actual walk time is factored by 2.0 to represent perceived walk times.
- Waiting time is calculated as half the service head way. This is factored by 2.0 as for walking time.
- Bus transfers at a node accrue an additional 2 minute penalty.
- Bus fares calculated as Rs.1.00 as fixed fare, taking in to account the sale of monthly, weekly and daily passes, plus Rs.0.50 per Km. The fixed fare is charged every time a transfer is made.

4.5.6 Network Calibration

Both private and public transport networks were checked thoroughly and corrected wherever necessary in order to achieve reliability and accuracy. The rests included

- Private road network link lengths, bus and rail link lengths in PT network were checked.
- Test tree builds from selected zones to ensure logical routing pattern
- Modelled and observed journey time comparison
- Comparison of modeled and observed vehicles across screen lines in private network and passenger counts in public transport network.
- Assignment checks.

4.6 GENERALIZED COST

4.6.1 The generalized cost of travel is the sum total cost of a traveler's out of pocket expense and the perceived cost of his time of travel by the mode. Generalized cost may therefore differ not just by the mode of travel, but also according to the characteristics of the traveler and of the particular trip that he is making.

4.6.2 Value of Travel Time

4.6.2.1 In order to apply this approach to the valuation of travel time it is necessary to estimate average income and complete travel time cost. Based on the statistical data available the per capita income (per annum) has grown from Rs. 28305 during 1998-99 to Rs. 53625 by 2004-05 at constant prices. The average income per employed resident using a particular mode was extracted from 2% household data collected during HHI. The results are summarized in **Table 4.2**. Assuming full time employees work for 176 hours per month, the time cost was worked out per minute.

Table 4.2 Average per Capita Income per month of Persons Using Different Modes

Mode	Average individual income / month	Rs / hour
2-Wheeler	4469	25.39
Car	7388	41.98
IPT	3611	20.52
PT	2110	11.99

NOTE: 1. Extracted from household survey data.
2. Hourly incomes assume monthly working hours of 176.
3. Income is in Indian rupees

4.6.2.2 Business travel time is valued approximately at the person's wage rate, non-business travel or other trips like leisure, shopping, education etc., is valued at 25% of person's wage rate. In education and other leisure trips it is usually assumed as everyone in household behaves as if his/her income is equal to that of the head of the household, trip to or from work is valued as 50% of person's wage rate.

4.6.2.3 The value of time for peak and off-peak for different modes like car, two wheeler, IPT and public transport is shown in **Table 4.3**.

Table 4.3 Value of Time – Mode wise, Purpose wise and Period wise

Mode	AV Occu	Income/ Month (Rs)	Time Cost per minute	Value of Time / Minute		
				HBW	HBE/O	EB
2-Wheeler	1.53	4469	0.42 per person	0.21	0.11	0.42
			0.65 per mode	0.32	0.16	0.65
Car	2.59	7388	0.70 per person	0.35	0.18	0.70
			1.81 per mode	0.91	0.17	1.81
IPT	2.49	3611	0.34 per person	0.17	0.08	0.34
			0.85 per mode	0.43	0.21	0.85
PT		2110	0.20	0.10	0.05	0.20

NOTE: 1. Income of IPT user is weighted average of both auto rickshaw user and taxi user.
2. HBW cost = time cost per person * 0.5
HBO cost = time cost per person * 0.25
EB cost = time cost per person * 1.00
3. Income and time cost is in Indian rupees

4.6.3 Operational Cost

4.6.3.1 Car users:

This will include car operation in terms of fuel and oil. The break up of cars of various makes can be considered as Small cars 55%, big and SUV cars 30% and Rest: 15%. Accordingly the average operating costs will be worked out.

Also it is proposed to take in to account the type of fuel used by various cars and they are given in **Table 4.4**.

Table 4.4 Mileage by various Cars

CARS	Total	Km / Lt	Petrol	Diesel
Small Cars	55 %	16	35 %	20%
Big cars	30 %	10	20 %	10 %
Others	15 %	8	5 %	10 %

Average Vehicle Mileage – 13.35 Km/Lt
Cost of fuel – Rs. 50.40 for petrol and Rs. 35.26 for diesel as on 2006
Average Fuel cost per Km – Rs 3.31 per Vehicle.

4.6.3.2 **Two Wheelers**

Depending on the type & make of Two Wheelers available on road it is proposed adopt the breakup as given in **Table 4.5**.

Table 4.5 Mileage by Various Two wheelers

Mode	Total	Km/ Lt
Scooters	35%	35
Motor cycles	40%	50
Mopeds	35%	60

Average vehicle mileage – 48.5 Km/ Lt
Cost of petrol – Rs. 54.50 as on 2006
Average fuel cost per Km – Rs. 1.12

4.6.3.3 **Public Transport**

The out of pocket expense consists of fare paid by the passenger. The fare is minimum for the first few kilometers and increased on a per kilometer basis or depending on stages. For buses the average fare per km is Rs. 0.50 for ordinary bus with Rs. 3.00 as minimum and Rs.0.75 for pushpak buses with a minimum fare of Rs.4.00. The weighted average of minimum fare was worked out taking in to account the sale of daily passes, weekly passes and monthly passes and it is Rs.1.00

4.6.3.4 **IPT**

For Auto & Taxi the fare depends upon per km rate. At present min auto fare is Rs. 12.00 for 2.0 Kms & for Taxi it is Rs. 30.00 for 3 Kms. The weighted average fare for IPT per km works out to Rs. 7.50 / km and the same has been proposed to use in model.

4.6.3.5 **Commercial vehicles**

It is assumed that on an average the salary of driver and the helper works out to Rs.12000/- per month. It was also found that they work for about 20 days in a month and for a period of about 12 hrs in a day. Similarly on analysis of fuel consumption it was found that HTV give 3.84 km/ltr of diesel and LCV give 8.73 km/Lt. A combined weighted average for the commercial vehicles gives 5.13 km/Lt of diesel.

Time cost for Driver/helper – Rs.0.83/min
Expenditure on fuel – Rs.6.87/km (at 2005 price)

4.6.7 The determined time costs and operation costs goes as input in the assignment and distribution model to extract cost matrices for various modes and purpose.

4.7 CALIBRATION AND VALIDATION OF OBSERVED MODELS

4.7.1 There are two clear links between private vehicle and public transport assignments and the subsequent development of cost matrices – SATURN takes route and frequency data from the PT-SAT network takes link speed data from the SATURN assignment.

The private vehicle cost matrices were produced in three steps:

* Matrix development
* Network calibration/assignment validation
* Cost skims

4.7.2 Matrix Development

4.7.2.1 A total of 21 observed private vehicle trip matrices were produced as follows for the whole day.

* Light vehicles – 5 purposes (HBW, HBE, HBO, NHB, EB)
  3 modes (car, 2-wheeler, IPT)
* Commercial vehicles – (all employees business)
* Cycle – 5 purposes (HBW, HBE, HBO, NHB, EB)

4.7.2.2 Private vehicle passenger matrices and Public Transport passenger matrices both purpose wise and mode wise was built for distribution and modal split and the Private Vehicle (PV) matrices in terms of PCUs was built for assignment purposes. The heavy vehicles, private vehicles and cycle matrices were in PCUs and have been derived by converting person trips matrices from corresponding purpose wise occupancy figures and PCU values.

4.7.2.3 The private vehicle – car, IPT and two wheelers were combined for assignment to the private vehicle network (See **Table – 4.6**).

Table 4.6 Total number of Vehicles and trips Assigned

Vehicle type	Peak Period
Cycle	10233 PCU's
Commercial vehicles	10199 PCU's
Private modes – cars, 2-w and IPT	189569 PCU's
Public Transport	338195 person trips

Note: PCU values Car : 1.00, Cycle : 0.50, Truck : 3.00, 2-W: 0.75 and Auto : 1.20

4.7.3 Network Calibration / Assignment Validation

4.7.3.1 **Private Vehicles**

Approach to assignment in SATURN is to allow different vehicle types or road users to follow different routes through network up to 20 iterations for each ij pair. The basis for route choice was also varied and tested in each case in order to produce an assignment which best fitted observed behavior. BMTC scheduled bus routes were incorporated as fixed flows. Commercial vehicles and cycles were assigned to the network first as preloads. Here the trees were based on minimum distance paths for cycles and minimum cost paths using free-flow speeds for commercial vehicles.

4.7.3.2 The private vehicles – car, IPT and two-wheelers matrices were then assigned to minimize generalized costs.

4.7.3.3 An "Equilibrium" assignment technique was followed whereby traffic arranges itself across network in such a way that all routes used for any origin and destination movement have equal and minimum costs, while all unused routes have greater costs. The algorithm employed in SATASS uses an iterative sequence.

- The complete matrix are assigned to minimum cost trees to produce a set of link flows.
- A new set of link costs are calculated as a result of first assignment and used to define new minimum cost routes.
- The matrix is reassigned to produce a newest of link flows.
- An improved set of link flows are calculated from a combination of the first two, the proportion of each being calculated on the basis of the need to minimize overall costs on all links across the network.
- A new set of link costs are then calculated and so on.

4.7.3.4 This procedure provided for satisfactory convergence after 20 iterations, convergences was defined as a situation where sum of link costs across the network, is within 1% of the costs where all trips properly assigned to equal minimum cost routes. Thus in an un-convergent assignment, the above equilibrium condition is not satisfied because different routes carrying traffic between the same destination pairs are not all of equal cost.

4.7.3.5 **Calibration of Private Vehicle Network**

The resulting assignment flows and journey times were compared with the ground count (observed flows and observed journey times). These checks on validation led to a sequence of minor network corrections, followed by assignment and further validation checks. Particular attention was placed on.

- checks on link capacity throughout the network especially at level crossing, bridges across rivers, causeways, roads with encroachment etc. by comparing journey times with observed values.
- revision to some zone centroid connectors to load traffic on to the network at more appropriate locations.

Generalized cost and time only assignment were tested using the Wardrop equilibrium assignment in SATURN. The principle behind this technique is traffic arranges itself on congested network in such a way that the cost of travel on all routes used between each O-D pair is equal to the minimum cost of travel and all unused routes have equal or greater cost (i.e. same as above). The finally selected assignment methodology was all or nothing for cycles, stochastic user equilibrium (SUE) assignment for commercial vehicles. In SUE technique, the traffic arranges itself on congested network such that the routes chosen by individual drivers are those with the minimum perceived cost; routes with perceived costs in excess of the minimum are not used. The main difference is that SUE goes through a fixed number of all-or-nothing assignments randomizing costs (within a range) each time.

4.7.4 Public Transport Network

4.7.4.1 The public transport network develop in PT-SATURN consists of both bus and rail services, so that passenger may interchange between the two. Bus routes are read into PT SATURN directly from SATURN network file. Bus speeds are read directly from the SATURN loaded network file so that journey times by bus include the effect of highway congestion. Before it is being assigned with PT trips the network was thoroughly checked and amended where necessary.

- Numbers of assumptions were made while building PT network.
- Private vehicles link times are factored by 1.2 to allow stoppages of buses at bus stops.
- Actual walk times doubled to represent perceived walk time, a common assumption.
- Waiting time will be half the service headway.
- Bus transfer will mean additional 2 minutes penalty.
- Bus fares calculated on the basis of Rs.1.00 fixed fare and Rs.0.50 per km.
- Fixed fare is charged to Bus passengers every time a transfer is made.

4.7.4.2 PT-SAT assigns the public transport matrix of both bus and rail to single all or noting trees based on minimum cost. All passengers between any two zones are assumed to travel along the same route. Each route may contain various elements of travel including

- Walk to bus stop or Railway station
- Bus or Rail options for major travel
- Transfer between bus and train / bus & bus.
- Waiting time at bus stops & Railway stations.

4.7.5 Validation Statistics for Assignment of the Observed Matrices

Screen line Comparison

Validation was assessed on the basis of comparison of observed counts against corresponding model forecasts. Traffic counts were those carried out at each of the screen line survey sites.

Total modelled flows across screen line, are within 0.12% of counts for morning peak hour. Individual directional screen line totals are generally within 10%. **Table 4.7** shows comparison of observed and assigned flows across screen line.

Table 4.7 Comparison of Observed and Assigned flows

Direction	Assigned	Observed	Difference	% difference
UP	47972	43953	4019	9.15%
Down	35762	36153	-391	1.81%
TOTAL	83734	80106	7714	9.63%

4.7.6 Travel Cost Extraction

The trees output by the final assignment from the SATURN for whole day were extracted to provide cost matrices for all modes and purposes, the bus passenger costs were obtained from extraction of the PT-SATURN assignments. Since a converged assignment by definition may contain a number of different but equal cost routes between pair of zones, it was necessary only to skim the final set of trees. The total cost for each zone pair was incorporated in a set of cost matrices.

4.7.7 Calibration and Validation of Gravity and Modal Split Model

4.7.7.1 The purpose of trip distribution modeling is to find equations that reproduce intra-zonal patterns of surveyed traffic. It should function to fill any unobserved cells of a partially observed trip matrix or to forecast the effects of changes in the transport system on the choice of trip destination used to predict changes in patterns of movement resulting from new infrastructure, changed land-use etc.

4.7.7.2 Modal split or modal choice modeling attempts to estimate the total amount of patronage on the different transport modes. Trip distribution indicates the spatial pattern of this demand. Modal split is the allocation of the total surveyed traffic to separate modes as normally used in the bi-partition of traffic in to private and public mode. For this study we have adopted joint distribution / modal split model based on gravity modeling as this option is available in SATURN / PT-SAT suite.

4.7.7.3 **The process of trip distribution and modal split is shown in Figure 4.4**

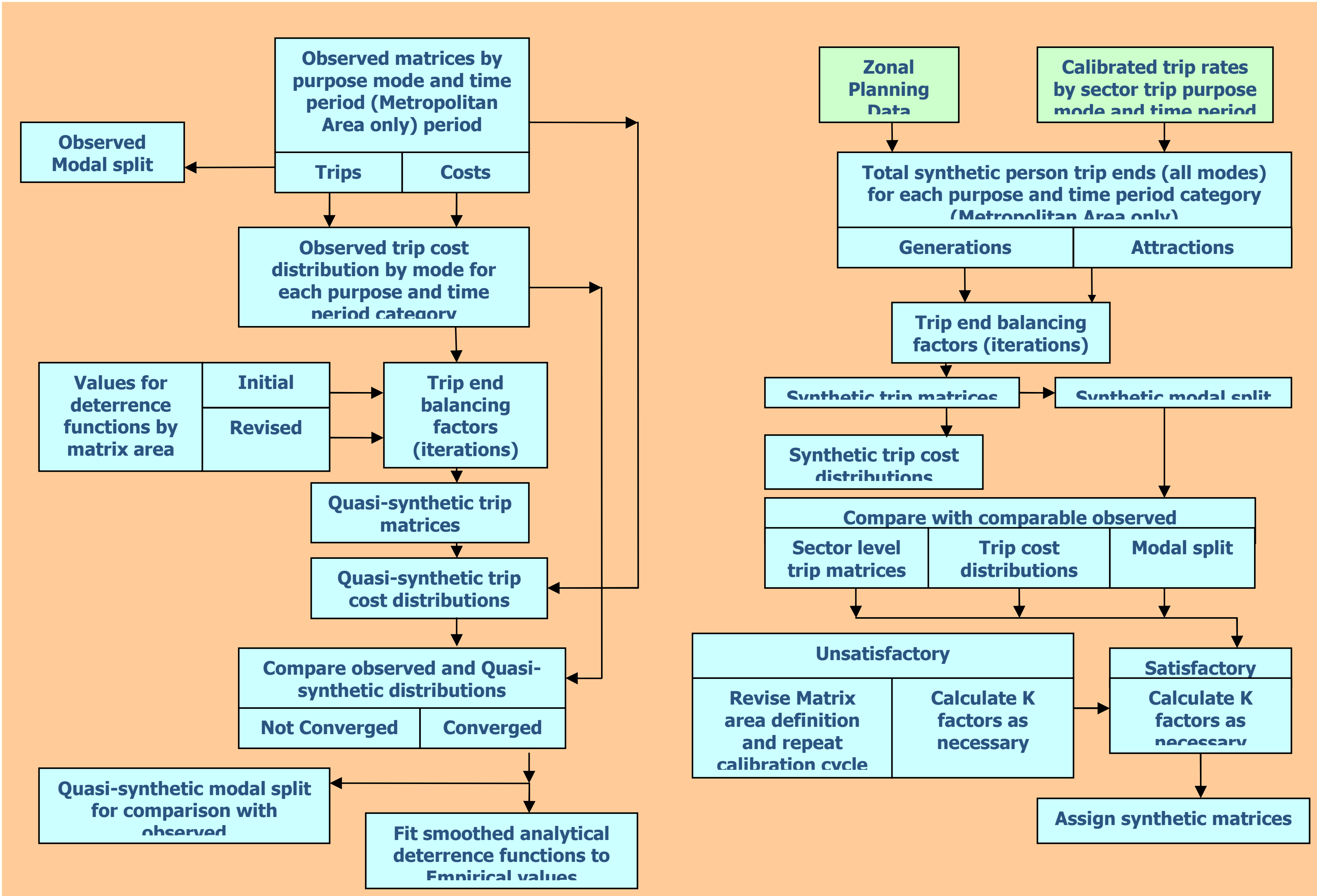


Figure 4.4 PROCESS OF TRIP DISTRIBUTION AND MODAL SPLIT

4.7.8 Approach

4.7.8.1 After successful completion of calibration and validation of observed models, the trip distribution and modal split phase were carried out jointly using a conventional doubly constrained gravity model of the form.

T_{ijm} = $r_i\, G_i\, S_j\, A_j\, F_{ijm}$

Where = T = number of interzonal trips by mode m

G = Total generation trip ends by zone

A = Total attraction trip ends by zone

i = Generation zone

j = attraction zone

r, s = balancing factors (constant)

F_{ij} = deterrence function for mode m

= $K_m\, e{-}Bc_{ijm}\, C_{Jim}$

Where K = constant factor

C = generalized cost of travel

= Calibration constant – exponential function

= Calibration constant – power function

Double constraints are imposed by ensuring that

$\Sigma\, T_{im} = Gi$ $\Sigma\, T_{im} = A_j$

Jm im

The form of the model in such that exponential (α = o) or power (β= o) functions may be used for the deterrence function. The inclusion of both α and β represents a gamma function, sometimes called a Tanner function.

4.7.8.2 Given a matrix of intra-zonal costs and a set of generation and attraction trip ends, a gravity distribution model estimates the factor r and s automatically, leaving the calculation of the deterrence function as the main feature of the models calibration. The cost of travel between zones is associated with a deterrence function whereby the higher the intra-zonal cost, the greater the deterrence to trip making, and therefore the lower the number of trips between zones. This is the principle of the gravity distribution model.

4.7.8.3 Trip distribution models are generally run subsequently for a number of different trip purposes time periods or modes. A joint distribution and modal split model carries out this same process but for a number of different modes simultaneously. Calibration of a joint model is achieved by calculating deterrence functions for each mode as for a normal distribution model, but weighting these functions in accordance with observed modal split. The proportion of trips made by each mode is a function of the cost of travel on that mode compared with the costs by all other modes. It is these weights which represent the different characteristics of each mode, the effects of which are not adequately determined by generalized cost variables.

4.7.8.4 Calibration constants defined by mode for each purpose and time period category are used to forecast the distribution and modal split of trip ends in conditions of changing inter-zonal costs.

4.7.8.5 This is conventional, calibrating the model on the basis of observed trip and cost matrices, and building synthetic matrices by applying the calibrated constants in forecast mode.

4.7.8.6 **Model inputs**

Trip matrices

The following observed trip matrices were input to the distribution/modal split model calibration:

- HBW, HBE & HBO trip purposes
- Whole day
- Car, two wheeler, IPT and PT passenger modes

This provides a total of 14 matrices.

Employers business and Non home based trips were not distributed, as these trips will make calibration of deterrence functions unreliable. Since small number of trips relationship between trip ends and planning data are difficult to establish. Cycles, Commercial vehicles were also excluded form distribution / modal split as these will be assigned as observed.

4.7.8.7 **Software**

The computer programme which is part of SATURN / PT-SAT is for distribution & modal split, and it includes four programs.

D1 – builds observed trip cost distribution
- Calculates trip end balancing factors
- Calculates empirical deterrence functions
- Builds quasi – synthetic trip cost distribution

DFIT – Fits smoothed analytical deterrence functions to empirical functions

M5 – Compares matrices form zone to sector level

M2 – Compares observed and synthesized matrices at the sector Level.

Calibration Statistics

Area definition

The deterrence function includes a factor K which allows different functions to be calculated, even with the same calibration constant, for different areas of the matrix that is different local areas within the study area. Here the model used a single area definition that is Bangalore Metropolitan Area, because results of a single area definition were adequate. This simplifies the forecasting procedure and makes the model more robust. The external trip ends were not distributed. This 'L' shaped portion of matrix consisting of external trips was input directly into the final synthetic matrix in different mode / purpose matrices.

Generation / Attraction

The distribution of trip ends is based on generation and attraction, rather than origins and destinations.

4.7.8.8 **Input Values**

Initial input values for α & β were provided as 0.07 and 0.001. This provided a starting point for distributing observed trip ends which led to convergence after 18 – 19 iterations. Within these, the cycle of calculating balancing factors generally involved between 2 – 6 iterations. An initial value of 1.0 was input for the K factors.

4.7.8.9 **Intra-zonal costs**

In order to ensure that complete trip cost distributions are used in the estimation of deterrence functions, intra zonal costs are required by the distribution model. These do not appear in the cost skim matrices since intra zonal trips are not assigned to the model networks. Private vehicle costs were estimated using the generalized costs, average intra zonal speeds of 15 kph for the zones in the BMA and average intra zonal trip length based on the area of the each zone.

Average intra-zonal trip length = SQRT (7 / 22) * zone area

* Zone areas were calculated as part of the dis-aggregation of planning data to CTTS zonal level.

The intra zonal costs for cars, 2W, IPT and public transport for whole day were.

Cars: Travel time * Time cost
2-W: Travel time * Time cost

IPT: (Distance * Time cost) + Min. fare
PT: Less than 2 km –
(fixed fare / km) + (Waiting time + travel time) * Time cost

More than 2 km –
(Distance * fare / km) + Fixed fare + (Waiting + travel time) * time cost.

4.7.9 Calibration Statistics

The single set of calibration constants were used for distributions over the complete matrix for mode / purpose categories.

4.7.9.1 Deterrence Functions

Deterrence functions (power functions, exponential function and constant) values were identified for different purpose, mode and period. The final analytical function outputs are given in **Table 4.8**.

Table 4.8 Calibrated Deterrence Functions for both Peak and Off Peak Periods

Purpose	Mode	Whole Day		
		Power Function	Exponential Function	Constant
Work	Car	-0.55279	-0.02618	0.79802E-01
	2-Wheeler	-1.02436	-0.02280-	0.74206E+00
	IPT	-1.08434	-0.05119	0.54307E+00
	PT	-1.72920	-0.02498	0.34888E+01
Education	Car	-1.48284	-0.03640	0.12916E+00
	2-Wheeler	-1.60020	-0.01896	0.12781E+00
	IPT	-1.27244	-0.07009	0.29600E+00
	PT	-2.05416	-0.02477	0.42883E+00
Others	Car	-0.93514	-0.02995	0.64678E-02
	2-Wheeler	-1.16506	-0.04154	0.67888E-01
	IPT	-0.51559	-0.09502	0.43992E+00
	PT	-1.79569	-0.04521	0.38062E+01

Note: 1. Observed = Observed matrices
2. Synthetic = Synthetic matrices from gravity model

4.7.10 Comparison of Total Trips

4.7.10.1 **Table 4.9** shows corresponding comparison of total trips in each purpose and mode for both observed and synthetic trips. **Figure 4.5(a) to 4.5(c)** shows the comparison of trip cost distribution for different purposes for peak period. This guarantees the close fit shown in distribution model both in total number of observed and synthesized trips and also trip cost distribution.

Table – 4.9 Comparison of Total trips by Purpose, Mode and Time Period

Purpose	Mode	Peak Period		
		Observed	**Synthesised**	**Difference**
Work	Car	303274	303865	-591
	2-wheeler	1367549	1369695	-2146
	IPT	170541	171599	-1058
	PT	840104	836409	3695
	TOTAL	2681468	2681468	0
Education	Car	76784	76991	-207
	2-wheeler	159171	157869	1302
	IPT	77663	77620	43
	PT	784871	786058	-1187
	TOTAL	1098490	1098490	0
Others	Car	9812	10196	-384
	2-wheeler	112840	112469	371
	IPT	358600	359553	-953
	PT	659697	658755	942
	TOTAL	1140949	1140949	0

Note: 1. Observed = Observed matrices
2. Synthetic = Synthetic matrices from gravity model

4.7.10.2 **Table 4.10** also shows the comparison of observed modal split with synthesized modal split. It depicts that both the values are within 5% for each purpose and mode. Synthesized average trip costs were also close to observed values.

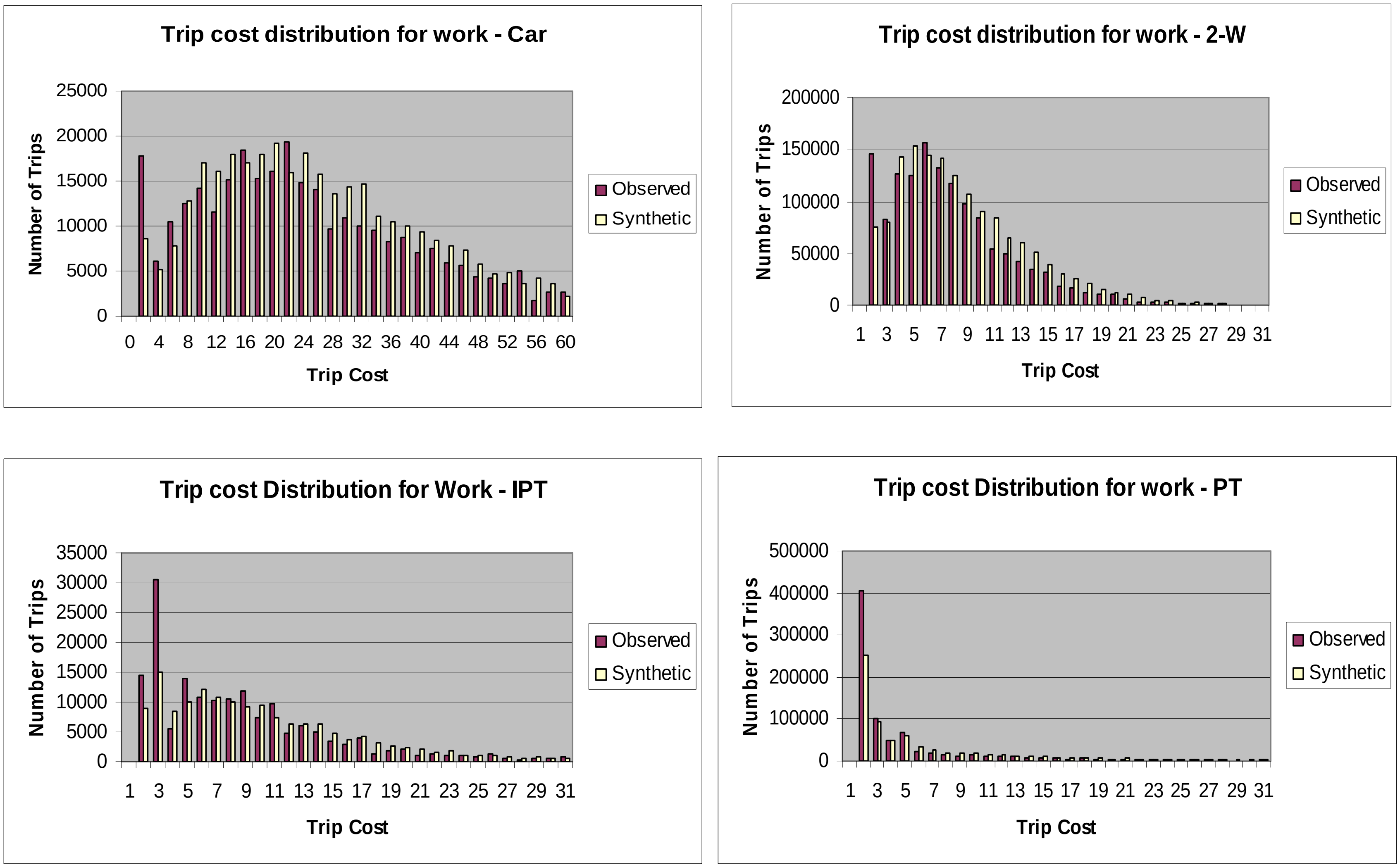

Trip cost distribution for work - Car
Number of Trips
Trip Cost
Observed
Synthetic
Trip cost distribution for work - 2-W
Number of Trips
Trip Cost
Observed
Synthetic
Trip cost Distribution for Work - IPT
Number of Trips
Trip Cost
Observed
Synthetic
Trip cost Distribution for work - PT
Number of Trips
Trip Cost
Observed
Synthetic

FIGURE 4.5 (a)

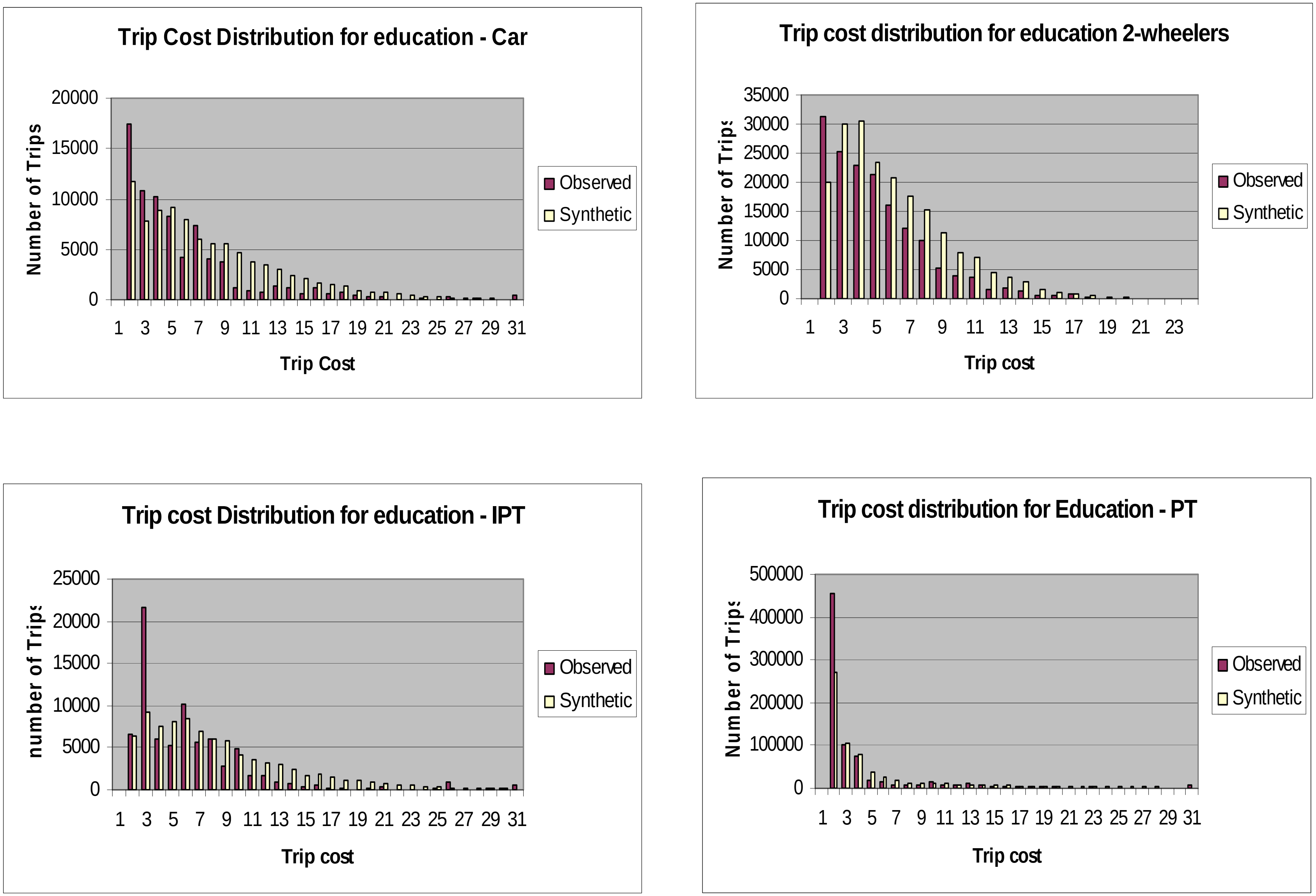

Trip Cost Distribution for education - Car
Number of Trips
Trip Cost
Observed
Synthetic
Trip cost distribution for education 2-wheelers
Number of Trips
Trip cost
Observed
Synthetic
Trip cost Distribution for education - IPT
number of Trips
Trip cost
Observed
Synthetic
Trip cost distribution for Education - PT
Number of Trips
Trip cost
Observed
Synthetic

FIGURE 4.5 (b)

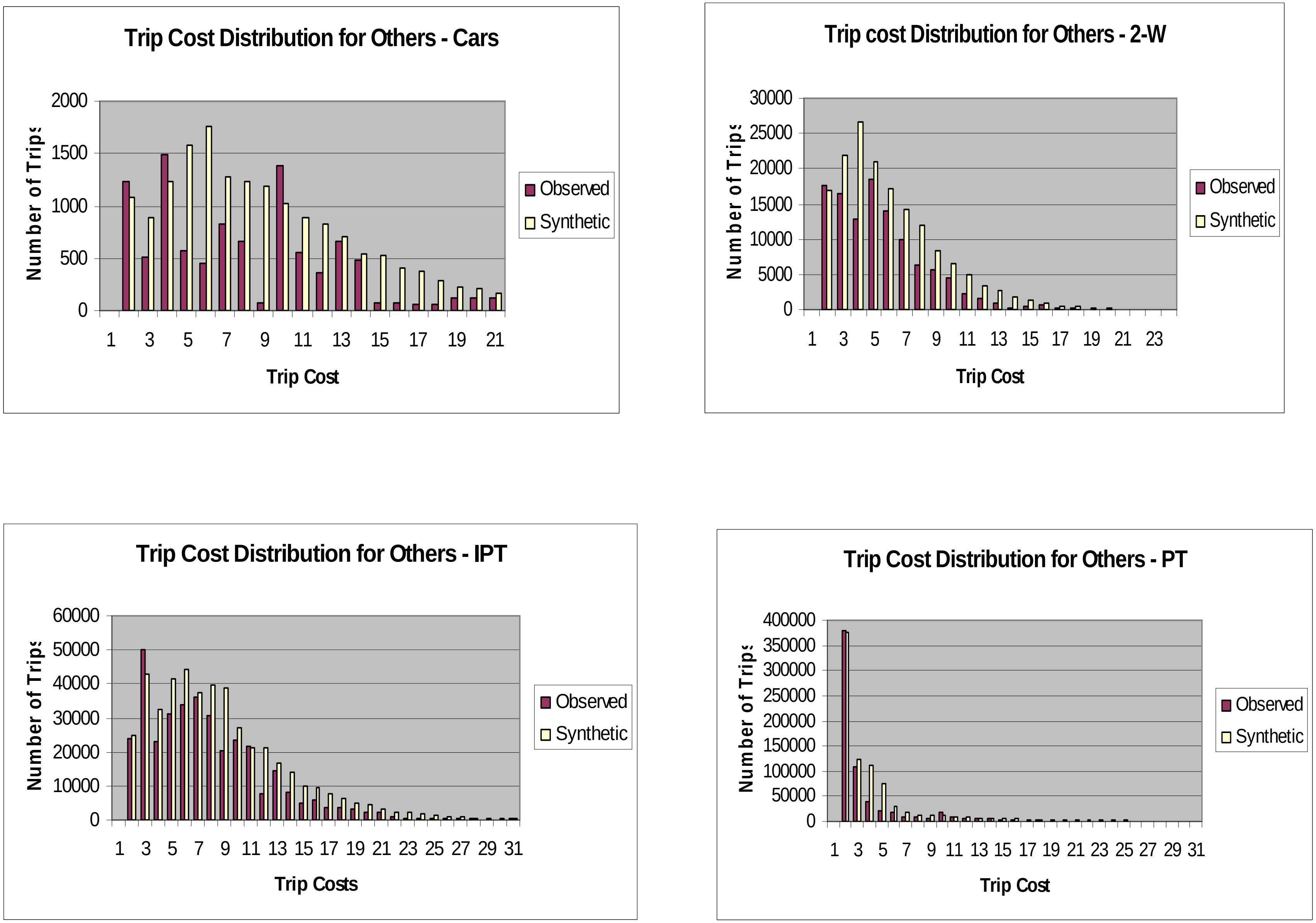

Trip Cost Distribution for Others - Cars
Number of Trips
Trip Cost
Observed
Synthetic
Trip cost Distribution for Others - 2-W
Number of Trips
Trip Cost
Observed
Synthetic
Trip Cost Distribution for Others - IPT
Number of Trips
Trip Costs
Observed
Synthetic
Trip Cost Distribution for Others - PT
Number of Trips
Trip Cost
Observed
Synthetic

FIGURE 4.5(C)

Table 4.10 Comparison of Modal Split by Purpose and Time Period

Purpose	Mode	Peak Period	
		Observed	Synthesized
Work	Car	11.31	11.33
	2-wheeler	51.00	51.08
	IPT	6.36	6.40
	PT	31.33	31.19
Education	Car	6.99	7.01
	2-wheeler	14.49	14.37
	IPT	7.07	7.07
	PT	71.45	71.56
Others	Car	0.86	0.89
	2-wheeler	9.89	9.86
	IPT	31.43	31.51
	PT	57.82	57.74

Note: 1. Observed = Observed matrices
2. Synthetic = Synthetic matrices from gravity model

4.7.10.3 These test results led to the following observations

i) The detailed operational model is able to synthesize trip movements during peak and off peak period on the basis of travel costs. The travel costs are based on both value of time and out of pocket expenses. The model considers 4 different modes (cars, 2-wheelers, IPT, and public transport)

ii) The model has been calibrated from the existing data and validated at various stages by comparing modeled and counts of traffic and passengers using public transport across screen lines. Journey times both modeled and observed are compared very well.

iii) The model is sufficiently robust at strategic level to use for forecasting. The model has performed well at screen line levels and speeds.

4.8 CONCLUSIONS

4.8.1 Operational transport of CTTS as developed using SATURN and PT-SATURN is able to synthesize patterns of trip movement during the whole day on the basis of travel costs. The model includes 4 modes (cars, two wheelers, IPT and public transport) and travel cost is based on value travel time and out of pocket expenses.

4.8.2 Patterns of movements and choice of mode are determined by a joint trip distribution / modal split model of gravity type. All other things being equal, the number of trips between any two zones will decrease as the cost of travel increases, and the number of people selecting a particular mode will decrease as its cost relative to other modes increases.

4.8.3 The model has been calibrated and validated from existing data by comparing modeled and counted flows of traffic and public transport passengers across screen lines.

4.8.4 Now the Model can be used for forecast with confidence.