# DEVELOPMENT OF LAND USE TRANSPORT MODEL (A CASE STUDY)

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abstract: Lowry type land use transport model has been developed for Madras Metropolitan Area, India during World Bank aided project on the Comprehensive Traffic and Transportation Study in order to test alternative development strategies together with transport implications for the horizon year 2011. The study area was divided into sixty-five zones with compatible transport network. The model was calibrated to the base year and was based on the travel time between zones. The model has been developed for two categories of service employment viz., educational and all other. Several future alternatives were formulated and tested for different employment locations, population distributions and networks. Comparisons were made for all the alternatives with respect to population allocations and trip lengths and the best was selected.

## 1. INTRODUCTION

Urban Planning in Indian cities has gained importance and is being following the pattern of activities adopted in the western countries. Master Plans prepared are useful in directing the growth and redevelopment of urban areas in a preferred direction. The most important problem in Indian cities is the lack of efficient transport infrastructure and this has further aggravated by the increasing demands in intra city travel due to rapid growth both in population and employment.

Till recently, most of the traffic and transportation studies conducts in India have used the traditional four step travel demand modelling and the demand forecast has lead to the recommendations of high capacity facilities requiring large capital expenditure. This has lead to a study of Land use Transport Planning which attempts to minimise travel demand through manipulation of land use.

This paper describes a land use transport model which was developed for Madras Metropolitan Area to guide the Madras Metropolitan Development Authority (MMDA) the implications of transport networks and travel costs for land users and the future direction of urban growth. The model was built, calibrated to the base year and was tested for different future alternatives.

There is a tremendous range in the characteristics of the socio-economic groups who live in Indian cities. The spatial distribution of employment and housing opportunities, as well as the transport services that are compatible with each of the socio-economic groups vary widely.

## 2. THE LAND USE – TRANSPORT MODEL

The Lowry model, originally presented in 1961, has generated more interest from planners. This model requires less land use information to be specified exogeneously and allow land use allocations in terms of zonewise population and service employment in total minus the given basic employment. This land use model has been widely used on account of its simple structure, flexibility and adaptability to a variety of practical problems. There are two major functions of the Lowry model.

> Firstly, it relates three elements of the urban/regional system i.e., population, employment and transport and describes their interactions.
>
> Secondly, it incorporates within its structure both allocations and forecasting procedures.

These models are based on the premise that, govern the basic employment locations, it is possible to predict population and service employment. These services inturn generate more population and more service employment opportunities and the cycle continues till its balance.

The Land Use Transport Model developed comprise the following sub system:

(i) Economic base mechanism

(ii) Allocation base mechanism

(iii) Transport sub system

The Lowry model assumes an economic base mechanism where employment is divided into basic and non—basic (service) sectors. The basic premise is that the number of people employed in basic and service industries measures the economic activity of an urban area. The basic employment is related to the people working in such industries whose locations is not dependent on the people of that area and is export oriented. Hence, this employment is an exogenous variable decided by the policy made. The service employment relates to those workers in service industries whose locations are depended on the population. Hence it is obtained based on the total population distribution endogenously. The economic base mechanism is show in the Figure-1.

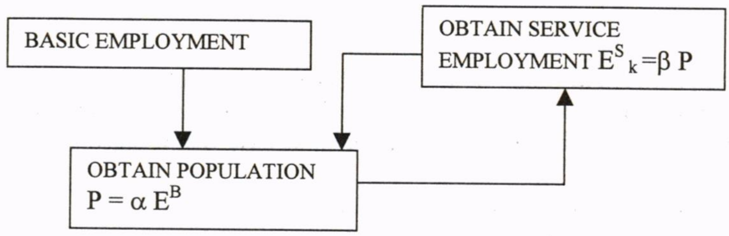


**FIGURE – 1 : ECONOMIC BASE MECHANISM**

Where

$\alpha$ = Population multiplier (inverse of participation ratio)
$\beta$ = Service employment ratio by type $E^S{}_k/P$
$E^B$ = Basic employment
$E^S{}_k$ = Service employment by type k
P = Population

Since the total employment is

$$E = E^B + \Sigma E^S{}_k \tag{1}$$

The loop of generating service and population will produce the total employment and population as follows

$$E = E^B (1- \alpha \Sigma_1{}^k \beta^k)^{-1} \tag{2}$$

$$P = \alpha E^B (1- \alpha \Sigma_1{}^k \beta^k)^{-1} \tag{3}$$

In allocation mechanism, residential location is a function of employment location and the trip making behaviour of the population. The basic employment is allocated to residential zones for housing using singly constrained gravity model.

$$T_{ij} = A_i \; E_i \; H_j \; \exp(-\lambda C_{ij}) \tag{4}$$

$$A_i = [\, H_j \; \exp(-\lambda C_{ij})]^{-1} \tag{5}$$

Where

$E_i$ = the employment in zone I (initially it is basic employment)
$T_{ij}$ = the number of people working in zone i and located in zone j for housing
$H_j$ = the attraction variable, zonal population in the base year is taken as the attraction variable
$C_{ij}$ = the travel cost/time between zone i and j
$\lambda$ = the deterrence parameter of the allocation function to be calibrated with respect to base year basic trip
$A_i$ = Balancing factor

This allocation will be subjected to external constraints such that the population in a zone does not exceed the holding capacity of the zone in terms of total population or density.

The population supported by the workers located in zones by the allocation mechanism of equation (4) and (5) will demand services and this level of demand will be obtained using observed service employment ratios. The model the uses the second allocation mechanism to locate the services as a function of the location of population and travel time.

$$S_{ij} = B_j \; P_j \; F_i \; \exp(-\mu^k C_{ij}) \qquad (6)$$

$$B_j = [\, F_i \; \exp(-\mu^k C_{ij})]^{-1} \qquad (7)$$

Where

$S_{ij}$ = the flow of people from residential zone j to service in zone i
$P_j$ = the population distributed to zone j by the residential allocation mechanism
$F_I$ = the attraction variable of service centre to zone i. The number of service employee or service employment will be the attraction variable (Some researchers use floor space, rental area of different categories, sales turnover etc, as a alternative variant). Since obtaining such disaggregated zonewsie data is difficult, the number of service employment positions has been used as variable.
$C_{ij}$ = the travel cost/time between zone i and j
$\mu^k$ = this is a deterrence parameter of the allocation function to be calibrated with respect to the base year service trip.
$B_j$ = Balancing factor

The total number of people demanding services in zone i ($S_i$) is therefore

$$S_{ii} = \Sigma_j \; Sij \qquad (8)$$

These allocations will form a loop mechanism and which continue until the increments of population and service employment become insignificant. Figure – 2 describe the function structure of the model showing the loop mechanism. The complete details of all the components of the Land Use Transport (LUT) Model is shown in Figure – 3.

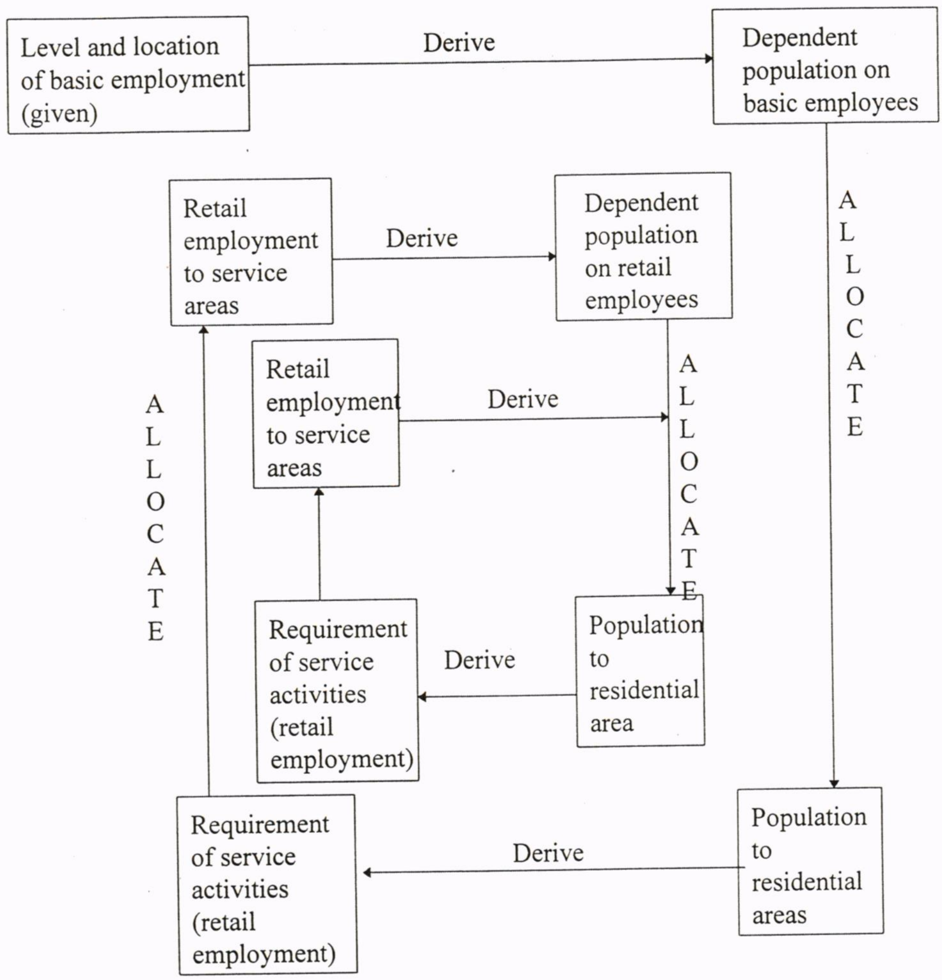


**FIGURE - 2 : FUNCTIONAL STRUCTURE OF LOWRY MODEL**

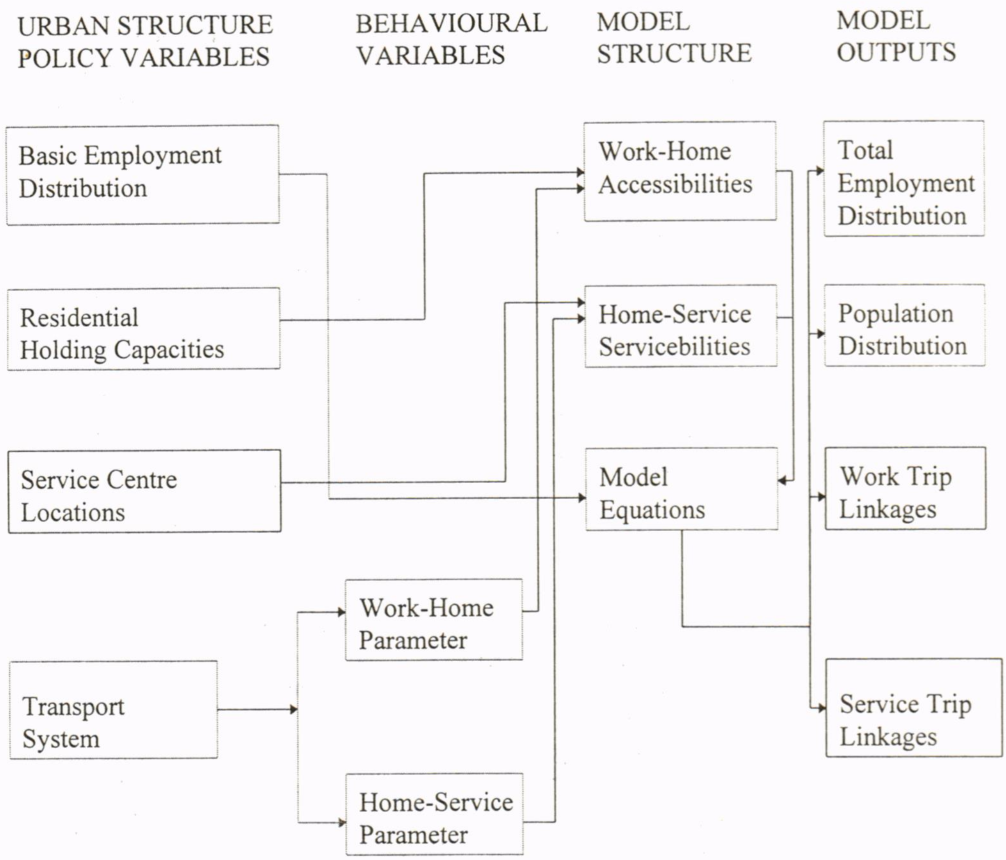


**FIGURE - 3 : LAND USE TRANSPORT (LUT) MODEL**

## 3. MODEL CALIBRATION AND BASE YEAR APPLICATIONS

The model was developed to calibrate on the basis of the given land use and transport data. Its aim being to simulate the distributed population and employment in the study area/region and along with this, the model will simulate travel behaviour in terms of home base work and service trips (educational and other). Thus, three parameters $\lambda$, $\mu^1$ and $\mu^2$ will be estimated to satisfy the observed land use distribution and travel matrices. Figure – 4 shows the mechanism for LUT model calibration. It is seen from the figure that the allocation is checked for population holding capacity, service employment and for minimum trip length (MLT) criteria.

The model calibrated is Lowry type land use model with transport linkages derived from the population and service allocations. The original model is an aggregated model and in the present study, the model has been disaggregated for two services such as education and ali other (shopping, recreation and other) because of the availability of the required data.

### 3.1 Study Area and Data Collection

Madras is the fourth largest city in India. It is a coastal city with Bay of Bengal along the eastern side. Madras Metropolitan Area (MMA) has a total area of 1172 Sq. km out of which 172 Sq. km forms the city. The city has developed along the north – south and west direction. The study area is divided into 65 zones with 37 zones within the city and the rest in the metropolitan area. The base year land use data in terms of zonal population and employment (basic, educational and other employment) were collected to be used for calibration. Figure – 5 shows all the 65 zones in the study area and Figure – 6 shows the population and total employment for all these zones. Total areas in different types of land uses in MMA are:

| | | |
|---|---|---|
| Residential use | : | 290.5613 Sq. km |
| Basic Employment Locations | : | 107.9731 Sq. km |
| Educational Employment | : | 22.5333 Sq. km |
| Other employment | : | 35.6246 Sq. km |
| Area unable for development | : | 599.0547 Sq. km |
| Vacant Land | : | 116.2533 Sq. km |
| Total area under use | : | 456.6924 Sq. km |
| Total Area of MMA | : | 1172.0000 Sq. km |

The transport network considered for the model has been the composite network of road and rail facilities available at present (base year) in MMA. As mode choice implications are not relevant at the strategic level analysis and as Lowry model normally does not account for modes, the composite network with appropriate characteristics of links was considered. The coded base year network had 926 one way links.

The observed trip matrices of work, education and others were derived from the household survey interview for the MMA in 1992 and the trip summary is as follows:

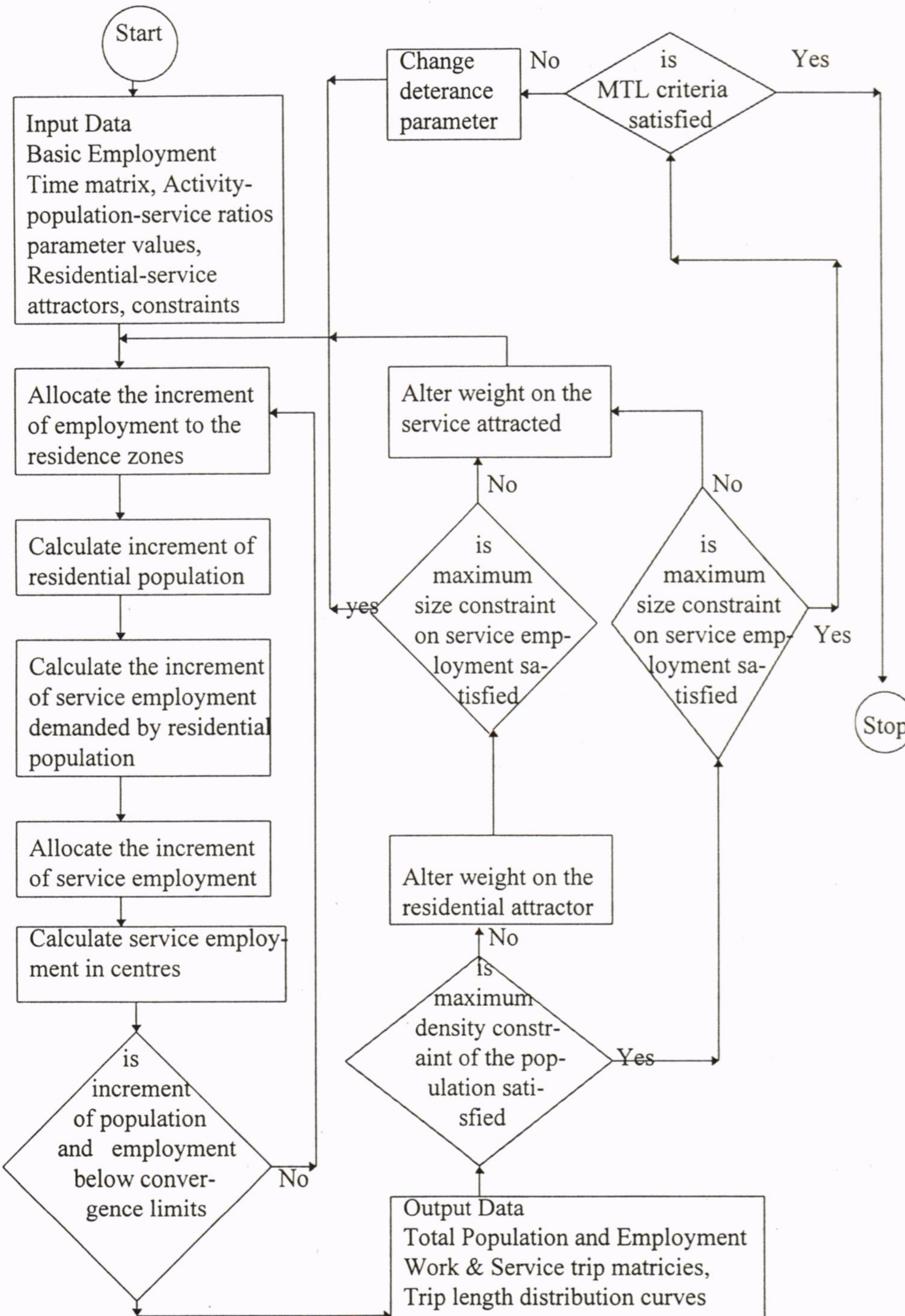


**FIGURE - 4 : MECHANISM OF LUT MODEL CALIBRATION**

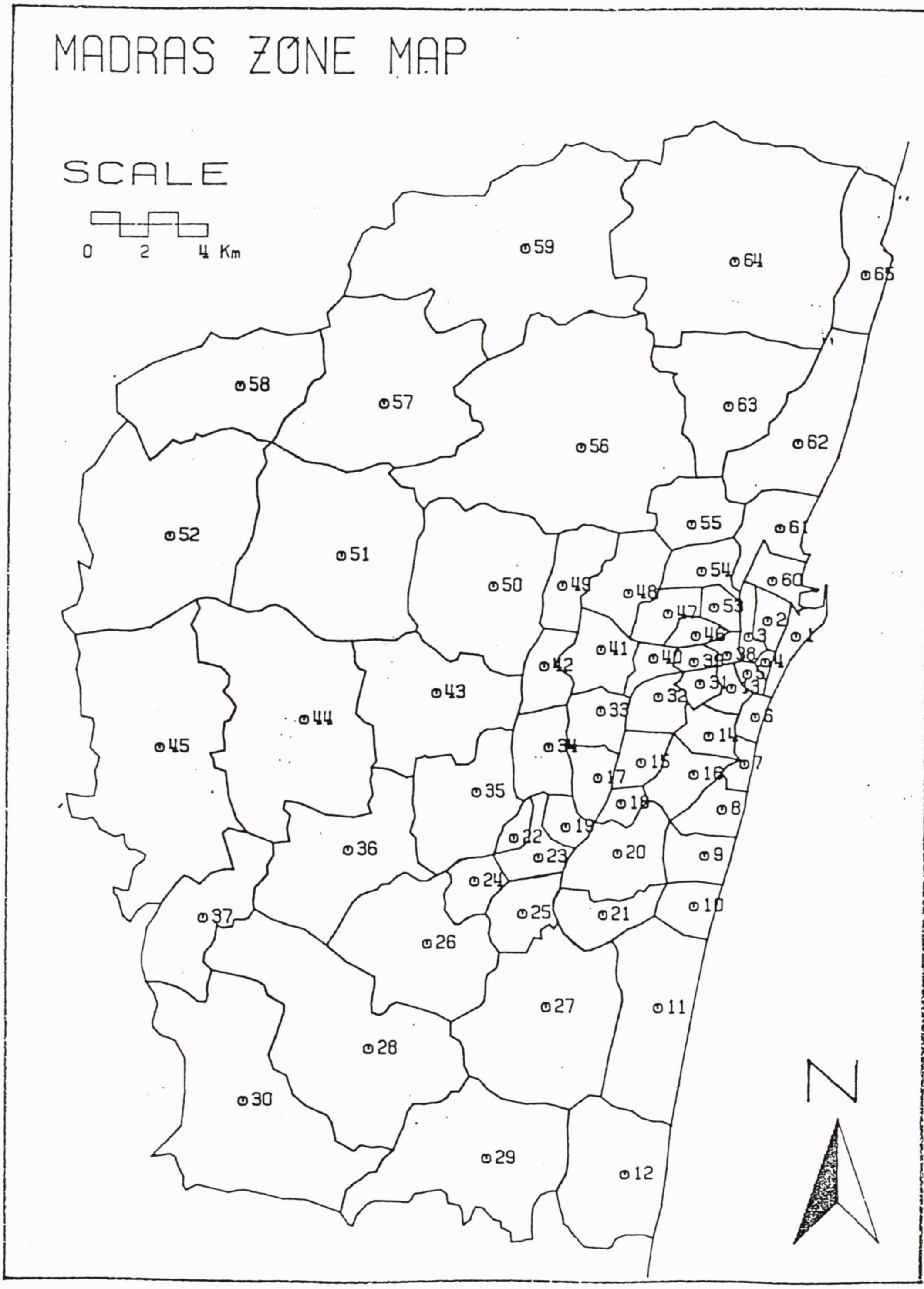


FIGURE - 5: STUDY AREA

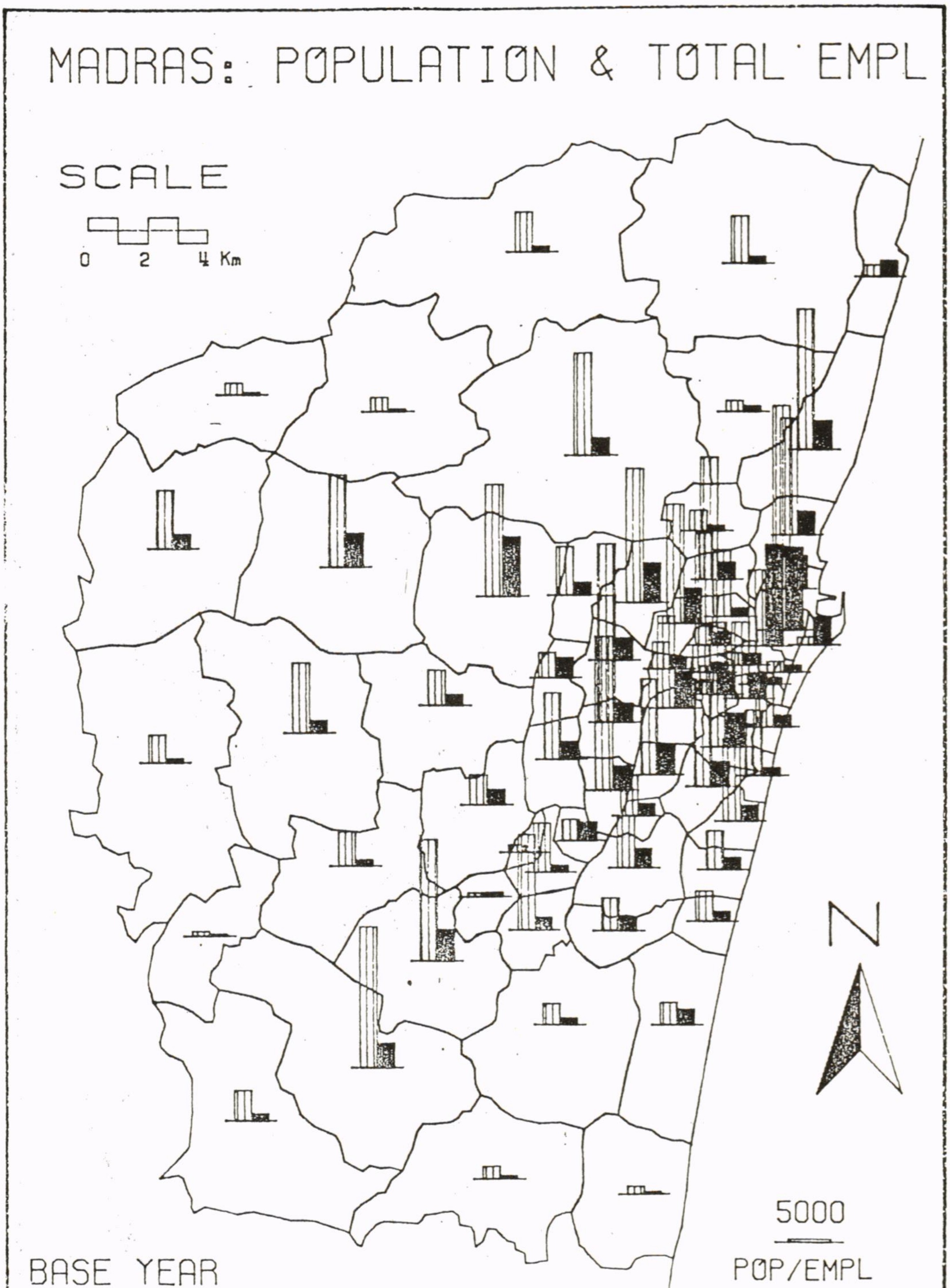


FIGURE -6 : POPULATION AND TOTAL EMPLOYMENT

| | | |
|---|---|---|
| Works Trips | : | 2,470,431 (62.728%) |
| Education Trips | : | 828,143 (21.028%) |
| All Other Trips | : | 639,700 (16.244%) |
| Total Trips | : | 3,938,274 (100%) |
| Mean Work Trip Length | : | 32.48 minutes |
| Mean Education Trip Length | : | 31.57 minutes |
| Mean Other Trip Length | : | 33.36 minutes |

### 3.2 Model Calibration

The calibration aims at matching the observed distribution of population and employment in the study area. Further, the transport loop of the model works for simulating the trip length frequencies and the mean trip lengths.

The following controls were used while calibrating the LUT model:

(i) The population and service employment increments were terminated when they reached a value within less than 1 percent of respective observed (base year) value of the zone

(ii) The minimum threshold values of educational and other employment were set at 25 and 100 respectively

(iii) The land use allocation iterations were allowed to continue for satisfaction of the constraints till the allocation within the allowed limits (1 percent of observed values)

(iv) In case of not meeting the constraint marginally ever after large number of iterations, the check was made for change in allocations from one to next iterations. If this change is very negligible for all zones, then also the loop for meeting constraints in the allocation mechanism is terminated. However, the constraints will be met by all means even with modification of deterrence parameters. The criteria of change in allocations from iteration to iteration for stopping constraints checking are taken as within 1 percent.

(v) The corrective iteration for calibrating deterrence parameters were allowed to continue till the degree of match between the observed and estimated mean trip lengths for work, education and other trips were found within 0.01 percent.

The calibration results in terms of population and service employment allocated to zones were obtained during this process, attraction weights have been evolved for the base year variables which will be used for the forecast year. The calibration results showing the quality of the model in terms of correlation and the calibration results are given in Table –1 and Table – 2 respectively.

**Table – 1 : Quality of Model Calibrated (Correlation Statistic)**

| Variable | Correlation |
|---|---|
| Population | 0.9999993 |
| Total Employment | 0.9999940 |
| | |
| Work Trips | 0.5607075 |
| Education Trip | 0.5397002 |
| Other Trips | 0.5138008 |

**Table – 2 : Calibration Results from Model**

| Calibration Variable | Magnitude |
|---|---|
| **Deterrence Parameters** | |
| Work Trips | 0.05139 |
| Education Trips | 0.05788 |
| Other Trips | 0.04779 |
| **Mean Trip length (Minutes)** | |
| Work Trips | 32.4593 |
| Education Trips | 31.5072 |
| Other Trips | 33.3326 |
| **Estimated Trips** | |
| Work Trips | 2,458,237 |
| Education Trips | 824,023 |
| Other Trips | 636,547 |

Although the model has simulated the gross behaviour very well as indicated by the correlation of population and employment distribution, the individual cell of the trip matrices has been relatively less accurate. This relates to unaccounted location behaviour.

## 4. MODEL FORECAST FOR HORIZON YEAR

Land use transport model described in the earlier sections produces consistent and compatible land use transport demand outputs for the type of information normally available in urban and regional planning studies. Policy intervention variable required for input to the model could be established quickly and easily be planners and decision-makers. Alternative sets of policy variables along with the required information on the model parameters may be used by the model to produce allocations of population and employment by zone along with the associated travel demand.

In this section, the land use transport model is run for the horizon year (2011) and the objective of the application is to demonstrate the usefulness of the model as a tool to assist planning department to select the most suitable development plan from a range of alternatives.

On the basis of Master Plan, Structure Plan and subsequent broad policies of Madras Metropolitan Development Authority, different alternative plans were developed and tested for their spatial distributions of population holding capacities and employment. These alternatives are analysed with respect to different transport networks for the horizon years.

### 4.1 Basic Employment Strategy

Three strategies of basic employment variation were evolved for running the model. It was assumed that there will be an increase of five lakhs (0.5 million) basic employment in the horizon year.

In the first strategy, the major basic employment will be concentrated in and around CBD (Central Business District) as it has been developed traditionally. There will be four other separate corridors type developments of basic employment, all of which is located outside the city (in metropolitan area). This strategy was aimed at intensively utilising the existing high capacity radial transport corridor of MMA.

In the second strategy, four nodal areas of employment one in core, north, west and south were considered. This was aimed at minimising the transport demand by balanced grwoth of population and employment activities while utilising the radial corridors.

In the third strategy, it envisages the continued location of basic employment in the CBD, and its fringes and along the wide belt just outside the city limits. In addition to this there will be continued development of basic sector along the existing transport corridor. This strategy was aimed at optimally using the proposed high capacity corridor along the edge of the city limits and in addition to the utilisation of the existing corridors.

### 4.2 Population Holding Capacity Strategy

Looking to the developable land area available in the individual zones and considering the environmental situation of residential densities, the population holding capacities of the zones were determined. The total population for the entire MMA area for the year 2011 has been estimated as 9.5 million out of which the city can hold 6 million. Five different scenarios were considered varying the population densities in different zones depending upon the basic industry location and along the future road/rail network.

### 4.3 Transport Network Strategy

Madras has three prominent radial rail and road corridors with a loop formation of rail facility in the CBD. It has three other road corridors fully developed. The previous comprehensive study in 1974 had recommended strengthening of existing rail corridors and provision of two rail facilities I) the North-South MRTS along the coast and ii) in continuation of MRTS, a ring rail corridor just on the periphery of the city known as Inner Circular Corridor Rail. In addition, the study has proposed an Inner Ring Road (IRR). A dedicated busway was considered on one of the busiest road corridor of 12 km length.

Taking all these proposals and studying the future developments, three network scenarios were considered for running the model forecast along with the do- nothing condition.

### 4.4 Assumptions in Forecast

The following assumptions have been made in the forecast

(i) The structural parameters like population multipliers and the service ratios as computed form the base year data are assumed to remain valid in the horizon year. However, the change in the per capita trip rate over time has been accounted as per the projections made.

(ii) The deterrence parameters calibrated for work, education and other trips were used for forecasts.

(iii) The attraction weights designed in the calibration were used for the forecast.

(iv) The population and employment (particularly the service sector) are likely to show a shift in location in a period of 10 to 20 years as has been observed in other major cities. For better accessibility, housing, education or job related advantages, population has been found to move within an urban area. Keeping this in view, in case of forecast, it is more appropriate to reallocate the total population and employment generated by the overall distribution of basic sector in the study area. However, alternatively the model has capability to allocate the incremental population and employment when run in forecast mode. In this study, the different alternatives for the future have been tested by reallocating the total population and employment. (Before accepting this, a set of test runs was made by the allocation techniques and their difference was found to be not much significant.

(v) The model can be run by two different ways.

   (a) Constrained mode where there is constraint in holding capacity of the zone i.e., the maximum allocated population of a zone is the holding capacity of that zone

   (b) Unconstrained mode where there is no constraint in holding capacity i.e., there is no limit for the allocation of population to a zone.

Twenty-one alternatives of different combinations of employment, population and network scenarios in constrained and unconstrained mode were tested and results were analyses. The main criteria are that the population with the city must be limited to 6 million. Trip lengths were compared for all the alternatives.

## 5. DISCUSSIONS

In all these alternatives, the model was allowed to freely allocate the population. This allocated population was checked with the holding capacities. In most of the cases the variation was very high and these alternatives were rejected even though the mean trip length was low. In case of constrained run, if the allocation was more than the holding capacity the model has to allocate to the next nearest zone thereby increasing the trip length. So the alternatives having higher mean trip lengths was rejected. The alternatives when run under unconstrained mode which did not allocate more than its holding capacity and when run under constrained which had less trip length were compared for the final selection.

First, the model was tested for twenty alternatives and it was found that the network construction and employment distribution as considered would result in a total population of about 9 million against 9.5 million projected in year 2011. This was discussed with the planners and was decided to raise the employment level to attract an aggregate population of 9.5 million by raising the participation ratio to 30%.

The first basic employment strategy discussed in section 4.1 was modified and with the road network consisting of the existing road network, the inner and outer ring road, the MRTS, inner circular rail and the dedicated busway was taken as the twenty first alternative and the model was run.

With these alternatives, the preferred alternative was selected based on the minimum travel time, minimum investments for change in land use and network form the existing situation. The preferred alternative will be the combination of best employment, population and network development and the twenty-first alternative was selected.

In this alternative, the population allocation was within the zonal holding capacity in most of the zones. Later it was discussed that for the few zones where the allocation was more than the holding capacity, corrective measures in terms of employment, better accessibility or some restriction on the development would be taken.

## 6. UTILITY OF MODEL

Using this model, it is possible to illustrate how alternative urban development programmes by different ministries or concerned organisation may be converted into input variables that are acceptable to the model. Figure – 7 shows the role of model in development policy testing. Alternative set of policy variables along with the required information on the model parameters may be used by the model to produce allocations of population and employment by zone along with the associated travel demands.

The process shown in the figure may be used to identify the public development policy set which is most likely to yield a preferred structure plan. In addition due to any change in uncertainties associated with the future model parameters magnitudes, the process may be used to test the sensitivity of the structure plan.

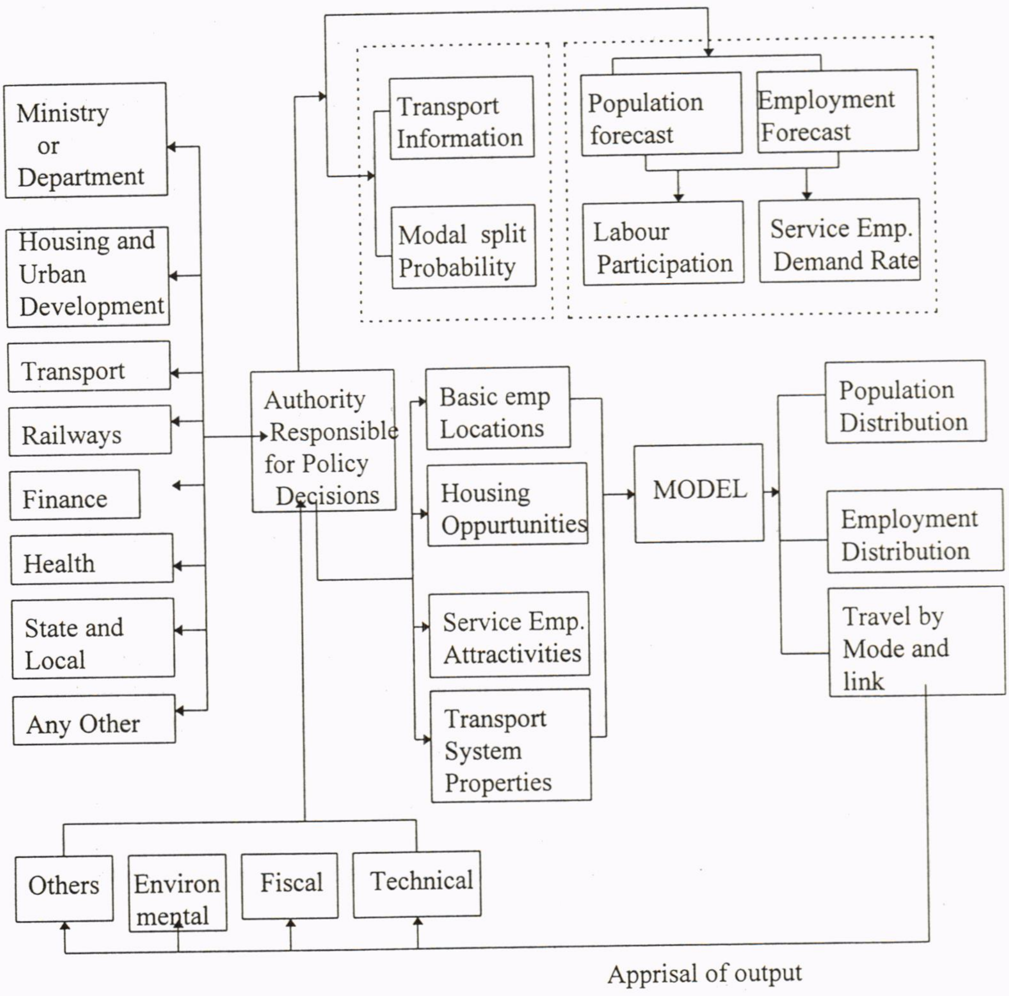


**FIGURE - 7 : ROLE OF MODEL IN DEVELOPMENTAL POLICY TESTING**

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