CHAPTER-III

REGIONAL TRANSPORT PLANNING MODELS
3.1.0 Introduction

In Chapter-I (sections 1.1.0 and 1.1.1) the background of this research is explained, while Chapter-II (sections 2.2.0, 2.3.0) elaborates various concepts of region and identifies the role of transport planning in regional development.

But no matter which concept of regional transport planning and development is considered for discussion in general, one has to understand transportation models in each case. However, in the chapter-I section (1.1.0) it was observed as a paradox that the models used for planning of transport facilities and thereby stimulating economic growth in developing countries are largely derived from the existing methods devised for urban transport planning in developed countries. In fact, there was no tested alternative in existence for developing countries to use. In other words, the principles of urban transport planning can be adopted to regional transport planning as well with due modifications.

In actual practice, the whole problem of planning transport in a regional framework gives way to the determination of appropriate models which will provide best transportation solutions in regional efficiency and development programmes. This task of determination of appropriate models in a given region contribute to what is called regional transport planning models.

Empirical tests with regional transportation variables would get more and more complicated as a region under consideration involve more and more number of factors in context to which concept of regional transport modelling, planning and development is to be finalized.

However, in this chapter we attempt to discuss the analytical models which would be used in regional transport planning analysis and development. These models are discussed in the context to empirical problems considered in this study. The models will also be adopted wherever feasible for actual regional transport planning analysis of the study region. Different models in actual practice may or may not yield the same results. Therefore, the final selection of the models to be used will largely depend upon its data availability and compatibility to the situations as it prevails in empirical sense in this research.
In the earlier discussion in chapter-II (sections 2.2.0, 2.3.0), the problem of planning regional transportation facilities and development was defined as a determination of models in the study region so as to provide transportation efficiency and also work out a transport network in a manner such that caters the total regional traffic demand generated at minimum cost to the society as a whole. At the same time it aims to meet socio-economic objectives and interdependence with the study region and areas around it at maximum benefits.

This problem has been attempted in the recent past by various researchers in regional science, transportation science and transportation research journals with varying degree of success.

These models are described in the forthcoming sections of this chapter.

**3.2.0 Transport Generation Model**

This model has its origin in the works of urban transport planners, Martin 1961 [65], Lamb 1970 [61], Hutchinson 1973 [46], Stopher 1975 [99], Hutchinson 1974 [47], Douglas 1970 [26]. In their conventional research, they observed that the total urban traffic generated or attracted zonewise has a function on land-use development patterns, socio-economic characteristics of population and capability of transportation system in the study area. Herewith, they established a mathematical relationship between these variables for the purpose of urban planning policies and management. One of the mathematical techniques used in this case is regression analysis which is also known as General Linear Regression Model (GLRM).

The above model can be used in regional transport planning and development straight away. The data (variables) considered for the same are, total regional passenger or freight transport generated or attracted zonewise, zonal number of population, zonal number of transport modes, zonal employment and other activities over space in the study region.

In this context, let us consider the case of two regional variables $Y_i$ and $X_i$. Suppose that $Y_i$ represents total number of passenger or freight transport generated zone-wise, and $X_i$ represents zonal employment of $i^{th}$ regional zone unit. Specifically, we will assume that
Y is given by a general linear model with the measure of accessibility to \( X \) as an independent variable. The simplest form of the relation between two variable \( Y_i \) and \( X \) given below is called a linear regression model:

\[
(3.2.1) \quad Y_i = a + bx_i + u_i
\]

where \( "Y_i" \) is dependent variable, \( "a" \) is an intercept, \( "b" \) the linear coefficient, \( "X_i" \) independent variable and \( "u" \) is error term. The subscript \( i \) refers to the \( i^{th} \) observation. The error term \( u_i \) implies that for every \( i^{th} \) regional transport unit value of \( "X_i" \) zonewise there is a whole probability distribution of values of \( "Y_i" \) which is either passenger or freight traffic generated or attracted in the \( i^{th} \) observation. In regional transportation analysis the researchers have used a variety of ways the information generated by the linear regression model as shown in the above relation 3.2.1. And the statistical theory of regression in this analysis is based on the following assumption:-

(i) the variance of \( Y \) values about the regression line must be the same for all magnitudes of the independent variables.

(ii) the deviations of \( Y \) values about the regression line must be independent of each other and normally distributed.

(iii) the \( X \) values are measured without error.

(iv) the regression of the dependent variable on the independent variables is linear.

(v) influence of independent variables is additive, that is the inclusion of each variable in the equation contributes a distinct portion of the regional traffic numbers.

(vi) the endogenous and exogenous parameters exist.

For the estimation and inference problem of these Models (3.2.1, 3.2.2) can be referred to Koutsoyiannis 1977 [59].

In actual practice, if one faces a situation involving several regional transportation variables.
For instance, let us consider the case of more than one regional transport unit independent variables. Suppose "X_2" represents zonal land-use development patterns, and "X_3" represents population of i^{th} regional zone units. Assuming that "Y" remaining the same as earlier relation (3.1.1), then regional traffic generation can be expressed in a multiple regression equation as [47] [68]:

\[ Y_i = a + b_1 x_{1i} + b_2 x_{2i} + b_3 x_{3i} + b_4 x_{4i} + \ldots + b_n x_{ni} + u_i \]

Where there are \( x_{1i}, x_{2i}, x_{3i}, \ldots, x_{ni} \) independent variables in relation of \( i^{th} \) regional transport zonal unit of employment, mode of transport, landuse, population, socio-economic activity characteristics over space and so on. Where also the regression coefficients \( b_1, b_2, b_3, b_4, \ldots, b_n \) are usually referred to as partial regression coefficients of the respective independent variables in the \( i^{th} \) regional zone units, which has been obtained from zonal linear regression equation model (3.2.1).

Empirically, the above models (3.2.1) and (3.1.2) have their own merits. The estimated equations of these relations in each \( i^{th} \) regional zone is efficient for zonal transport generated by various types of landuse and activities over space. In other words, these models can take more variables which may be easily computed and developed by using stepwise regression analysis computer programme.

However, these models are much limited to regional transport generated from various types of landuse in each \( i^{th} \) zonal units. Therefore, the use of regression equations based on zonally aggregated measures of the \( i^{th} \) zonal characteristics tend to submerge important characteristics of demand in the study region. If the aggregation of data used in zonal-regression equation is to be effective, one has to have much homogeneity within the units of aggregation as possible. In actual practice it would be recalled that the purpose of a regression is to explain the traffic generated between any two zones in terms of a number of independent variables (landuse, population and so on).
From the above context, past researchers in their analysis of regional transport variance demonstrates that the greatest amount of variation in transport generation is found within the various areal units rather than between zonal units. To resolve this difficulty a number of transport planners proposed the use of households rather than traffic zones, as the basic unit of traffic generation zonewise. One of the technique which is based on the household and its characteristics is known as category on cross-classification analysis. This technique will be discussed in the subsequent section.

In regional transport planning we have, therefore, delineated Bharuch region into eleven (11) zones. Each zone is represented with 10 independent variables as sample size corresponding to each variable zonewise. In this case, for estimating a cross-sectional analysis between zonal transport generated (passenger or freight) and category activities over space. One will adopt relation 3.2.1 and 3.1.2 as expressed earlier in this chapter. In regional transport planning, therefore, one may obtain different traffic generation equation with varying characteristics. Hence, a planner will select best zonal regression equations to resolve the problem at hand in terms of transportation and development policy of the study region.

3.3.0 Category Analysis Method

This method is one of the ways through which regional traffic production or generation characteristics of households within areal zone units are estimated. Here a number of separate categories are sorted out according to a set of properties which characterize the zonal household. Zonal traffic attraction may also be estimated using the same method, Martin 1961 [65], Douglas 1971 [26], Hutchinson 1974 [47] and Kadiyali 1991 [54].

This method found its origin in the works of Woolten and Pick 1967 [108]. In actual practice the method assumes that when regional traffic production is considered at household level, zonal traffic rates will remain constant in the future, and that each i^th zonal traffic rate can be established for each household categorized by only three factors: (i) mode of transport ownership; (ii) household structure and (iii) household income. However, in the recent past
category analysis programmes have been expanded to incorporate more categories by adopting a wider range of household income groups.

As explained earlier the zonal regression equations estimate variation in traffic attraction between \( i^{th} \) regional zones units but not within areal zones. In various researchers it is observed that greatest amount of regional transport variation in traffic generation is found within the various zonal areal units rather than between zones units. In this context, zonal linear regression model has failed to estimate variation of traffic generated within \( i^{th} \) regional zones units. Therefore, this difficulty will be resolved in the present study by adopting the above category analysis method.

In the present study, suppose that there are different characteristic of household size with varying categories spread over \( i^{th} \) regional zone unit, then one is interested to arrange these categories zonewise in terms of decreasing order of their mode of transport accessibility, household structure and household income. Therefore, the zonal household will be classified in terms of the above three mentioned variables. Then regional traffic production matrix will be prepared by sorting all household interviewed in the transport survey into each of \( i^{th} \) regional zone sample cells. The magnitude number of traffic produced by all zonal households in each cell matrix will then be summed over \( i^{th} \) regional zone units. Hence, traffic rate for each \( i^{th} \) zonal cell will be established by dividing the number of traffic by the number of households zone-wise. In this context, we may easily translate zonal traffic-production estimates. Thus, the number of households within each traffic-analysis zone that are expected to fall within each cell of the matrix are estimated and multiplied by the appropriate traffic rate and then these products are summed up in the form of:

\[
(3.2.1) \quad P_{i q} = \Sigma h_i (c) \cdot tp (c)
\]

Where \( P_{i q} \) represents the number of zonal traffic produced by zone \( i \) by type \( q \) people, \( h_i (c) \); the number of households in zone \( i \) in category \( c \); \( tp (c) \); the zonal traffic-production rate of household category \( c \) (the summation in over all categories of type \( q \) people).
Alternatively, each \( i \)-th regional zone traffic attractions would also be estimated in a similar manner by the following expression:

\[
(3.2.2) \quad a_j = \sum b_j(c)ta(c)
\]

Where, \( b_j(c) \) represents the magnitude of regional work-traffic attracted by zone \( j \); \( b_j(c) \), the number of employment opportunities in category \( c \); \( ta(c) \), the magnitude of traffic attraction rate of employment category \( c \); and the summation is over all employment types if work-traffic attractions are being estimated.

The above relations (3.2.1) and (3.2.2) will be estimated on the basis of the following assumptions:

(i) the zonal household is the fundamental unit in the regional traffic generation process, and most traffic begin or end in response to the requirements of household zonewise.

(ii) the regional traffic generated by the household depend upon the characteristics of that household and its location relative to its required facilities such as market centres, production centres, employment centres, educational institutions and mode of transport and availability of the whole transport system.

(iii) zonal households with one set of characteristics generate different rates of traffic from households with other set of characteristics zonewise.

(iv) only three factors are of prime importance in affecting the amount of regional transport that a household produces; mode of transport ownership, income and household structure.

(v) within each of the above three factors, a limited number of ranges can be established so as to describe the regional traffic-generating capacity of a household by a limited number of categories.

(vi) regional traffic generation rates are stable over time so long as factors external to the household are the same as when the traffic were first measured.
Based on the above assumptions, one is, therefore, interested to determine average response or average value in each $i^{th}$ regional transport zone, the dependent variable for certain defined zonal categories of the independent variables. The earlier $i^{th}$ regional zone matrix defines the categories and each dimension in the matrix represents one independent variable which themselves are classified into a definite number of discrete class interval in regional transport planning analysis.

However, the above model has claimed various advantages in regional transport planning analysis. These advantages are as what follows: First, the whole concept of household traffic generating is simplified in this model. The method categories in household according to certain socio-economic characteristics appears rational over regional transport planning. Second, unlike, the earlier relations 3.2.1 and 3.2.2 zonal regression analysis technique, no mathematical relationship is derived between zonal traffic-generating and household. This takes away many of the statistical drawbacks of the regression analysis over the study region. Third, the computations are relatively simpler, this method does not require computer programs. Fourth, the zonal data can be used directly to the above method, therefore, it saves considerable efforts, time and money spent on zonal household research. Fifth, since disaggregated data are used, the above model, therefore, simulates human behaviour more realistics than the zonal aggregation process normally employed in regression analysis over the study region.

In this context, calculation of regional traffic generation by household zonewise observed in each $i^{th}$ regional zone unit is likely to be more accurate than that of traffic attractions. In actual practice, it is usual that for all zonal traffic attractions to be scaled up by a common factor to equate to the total generations of each $i^{th}$ regional zone units. To resolve this difficulty a number of transport planners, Wells 1975 [106], Martin 1961 [65] and Hutchinson 1974 [97] have proposed simulation models which will be discussed in the subsequent sections.

In a regional transport planning analysis the above method has its own drawbacks. First, it does not incorporate other important variables to test statistical significance of the various
explanatory zonal variables over the study region. Owing the above drawback, statistical
tests in this method normally accompany zonal regression analysis to allow the planner to
comment on the reliability of each \( i \)-th regional transport partial-regression coefficients. As
explained in the earlier relation (3.2.2) section 3.2.0 of this chapter that the t-test may be
used to test whether the magnitudes of the zonal partial-regression coefficients are statistically
significant. In this context, transport planners will also be interested in the reliability of
the traffic rates in each \( i \)-th regional transport zones within each cell of category analysis
matrix.

This has been seen in various transport planning studies [47] that a sample of zonal “n”
households out of total “n” households within each study area zone unit is selected. Then,
a transport planner is interested in estimating a mean traffic rate within some band of confidence
all over \( i \)-th regional zone. In this case, suppose for large sample \( n > 30 \), then the confidence
interval of the true mean is given by:

\[
(3.3.3) \quad \bar{x} \neq z \sigma \bar{x}
\]

Where subscript \( \bar{x} \), represents, the mean zonal traffic rate; \( \sigma \bar{x} \), the standard error of
sample means, or the standard error of the estimate; and \( z \), coefficients which varies with
the particular level of confidence desired over the study region.

In this case, the standard error of zonal sample means is given by:-

\[
(3.3.4) \quad \sigma \bar{x} = \frac{\sigma}{\sqrt{n}}
\]

Where \( \sigma \) represents standard deviation of the zonal population traffic rate for households
equation (3.3.4) implies population in each \( i \)-th regional zone unit of infinite size which
will be corrected in the following way for populations of finite size \( n \).
From estimation (3.3.5) the margin of error is given by:

\[(3.3.6) \quad d = Z \sigma \sqrt{\frac{N-n}{n}} = Z \sigma \frac{1}{\sqrt{n}} \frac{1}{N}\]

Various researchers have examined these zonal margins of error associated with each zone unit traffic-generating category analysis of transport data for regional transport planning.

Second drawback, is that, this method normally makes use of past studies made elsewhere and update them broadly for the same. This is impossible in case of the present research.

Third drawback, the analysis of this method assumes that zonal household income and mode of transport accessibility increase in the future planning period. In actual practice, the categories of high household income and mode of transport accessibility are, the ones least represented in the base year. Moreover, they are the ones most likely to be used for future estimates of each \(i^{th}\) regional zone traffic-generation.

Fourth drawback is that, new variables will not be introduced at future date of this method. Last drawback, large samples are needed to assign zonal traffic rates to any one category.

In Bharuch region this method would be adopted in 11 (eleven) sample zones already delineated for regional transport planning analysis. In each of the \(i^{th}\) zone household size will be categorized for 6 variables in terms of their economic status (income) in relation to regional transport system performance and accessibility to various zonal employment modes within the study region. In each category household traffic research is conducted and then estimated for regional traffic production. The regional transport variable will, therefore, be summed up to \(11 \times 6 = 66\) parameters.

Owing to the earlier limitations, category method may not be suitable or workable in the present study. In this case, earlier zonal regression analysis (3.2.1) is most likely appropriate
for Bharuch regional transport planning analysis. The main difficulty facing these models (3.2.0) and (3.3.0) already discussed above is how to equate regional traffic attracted to that one of total generated zonewise in the study region. This problem may be resolved in the context of the subsequent section.

### 3.4.1 Approach to regional O-D transport matrix

The origin-destination (O-D) transport matrix was first attempted in the works of urban transport planners, Williamson 1981 [109], Malachy 1981 [69], Bell 1983 [9], Fisk 1983 [30], Ennio 1984 [28], Suemcneil 1985 [104] and Williamson 1980 [110] as a fundamental input for problems regarding planning and management of transportation systems. These researchers, used O-D matrix approach to determine and estimate totals of regional traffic generation or attraction ends in the study areas. In regional transport planning, therefore, each entry of such matrix represents the zonal traffic volume of transport pattern originating at a particular "zone" using a certain transport network links and destined for some other particular zones in the study region.

It is observed that entries in these matrices have been commonly estimated by surveying individual traffic generators or attractors from all zones in the study area. But, however, such surveys have no doubt been both time consuming and expensive. To overcome this constraint, therefore, various researchers in the recent past, proposed that, first one may update the existing matrices if any to current values to reflect changes overtime. Secondly, incomplete data from a narrow application in a study area can be expanded to form matrix entry estimates. Finally, zonal transport volume forecasts can be obtained in each transportation network link by sequential application models which will be discussed in the preceding sections of this chapter.

However, in actual practice (O-D) matrix is seldom, if ever available then various models as mentioned above can be utilized mathematically for its estimation. This models, therefore, estimates the total regional number of traffic generated by or attracted to a i<sup>th</sup> zones (i.e.
“traffic generation”) and then distributes the expected traffic among potential destination zones (i.e. “traffic distribution”). Thus, each of these estimates procedures relies upon some current information such as zonal row and column totals or attributes within a distribution function.

In regional transport planning, therefore, the above mentioned (O-D) matrix can be undertaken straight away. Suppose one is interested in finding O-D matrix of the area within and around the study region that generates or attracts traffic for daily transportation system. Then, the regional data required consist of zonal passenger and freight traffic, mode frequency in terms of buses and trucks zonewise within the existing road transport network over the study area and surrounding regions. In this case one can use a bigger map of the study region and then form O-D matrix zonewise.

Table 3.4.1.1 REGIONAL O-D MATRIX TABLE

<table>
<thead>
<tr>
<th>Origin Regional Zones</th>
<th>Destination Regional Zones</th>
<th>Total base year traffic originated</th>
<th>Total year traffic originated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 -- -- n</td>
<td></td>
<td>P₁(b)</td>
<td>P₁(h)’</td>
</tr>
<tr>
<td>1 *₁₁ *₁₂ *₁₃</td>
<td></td>
<td>P₁</td>
<td>P₁’</td>
</tr>
<tr>
<td>2 *₂₁ *₂₂ *₂₃</td>
<td></td>
<td>P₂</td>
<td>P₂’</td>
</tr>
<tr>
<td>3 *₃₁ *₃₂ *₃₃</td>
<td></td>
<td>P₃</td>
<td>P₃’</td>
</tr>
<tr>
<td>..</td>
<td></td>
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<td>..</td>
</tr>
<tr>
<td>..</td>
<td></td>
<td>..</td>
<td>..</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>Pₘ</td>
<td>Pₘ’</td>
</tr>
</tbody>
</table>

Total traffic Attraction ends Base Year a₁(b) a₂ a₃ -- -- aₙ

Total traffic Attraction ends Base Year A₁(h)’ A₂’ A₃’ -- -- Aₙ’
In the present case, one will consider a regional economy with a transportation network configuration, which is characterized by a finite number of links shipping a certain transport units as represented in the table matrix above. In this table matrix, it is observed that there are \( m \) \( i^{th} \) regional originating zones which is assumed that at each regional origin there are \( P_i(b) \) transport units during the observed base year \( b \), where \( i = 1, 2, 3, ..., m \). On the other hand, there are also \( n_j^{th} \) regional destinations, where each destination requires a shipment of \( A_j(b) \) unit of transportation, hence \( j = 1, 2, 3, ... n \). In the regional table matrix above \( P_i(b) \) and \( P_j(h) \) represents regional transport row requirements, also \( A_j(b) \) and \( A_i(h) \) column requirements which are both in base \( b \) and future planning years \( h \) respectively. Each cell values in the regional rows and columns requirements are assumed positive, in which zero or negatives have no physical meaning for this research.

In this matrix, it is assumed that the total sum of \( i^{th} \) regional row requirement must equal the total sum of \( j^{th} \) column requirement zonewise in terms of traffic generation or attraction ends in the form of:

\[
\sum_{i=1}^{m} P_i(b) = \sum_{j=1}^{n} A_j(b)
\]

Where the cost of shipping a unit of transport product from origin \( i \) to destination \( j \) is given by \( C_{ij} \). In this case the negative shipping costs may not appear to be realistic. In other words, \( C_{ij} \) will represent regional transport cost coefficients zonewise in this study.

In regional transport planning, such entry matrix are specified as rows and column requirements. Consequently, the above regional row totals \( P_i(b) = (P_1(b), P_2(b), P_3(b), ..., P_m(b)) \) indicates the total traffic originating zonewise, alternatively, regional column totals \( A_j(b) = (a_1(b), a_2(b), a_3(b), ..., a_n(b)) \) represents the total traffic attracted at each \( j^{th} \) zones in the study region. Conversely, \( P_i(h) = (P_1(h), P_2(h), P_3(h), ..., P_m(h)) \) and \( A_j(h) = A_1(h), A_2(h), A_3(h), ..., A_n(h) \) represent total traffic originating \( i \) and attractions ends at each \( j^{th} \) zonewise during the future planning year \( h \) of the study region.
From this context, past experiences and transportation studies shows that this O-D matrix with only row and columns totals is the most fundamental specification of a regional transport demand in a spatial geographic terms. In this case, it is observed that the degree of Spatial separation of the origins and destinations can be recorded in a separate matrix of distances. These two matrices together will specify the basic demand for transportation in the study region.

In actual practice, if one inserts cell values in the matrix above will be equivalent to specifying the flow volumes between each regional location zones and this makes it possible to determine the output demanded from regional transport network system of the study region. Therefore, the multiplication of the corresponding zonal cells in the above traffic matrix and the distance matrix yields an output matrix solutions in which regional transport units are of output to the existing road transport network system of the study area. (Work done equals distance matrix x traffic matrix, for example ton-miles or passenger-kilometers).

In the earlier researchers, treated the above regional O-D matrix table as transportation problem in which they resulted to a solution matrix as table 3.4.1.3.

**Table 3.4.1.3 : Solution Matrix Table**

\[
\begin{bmatrix}
  t_{11} & t_{12} & t_{13} & \cdots & t_{1n} \\
  t_{21} & t_{22} & t_{23} & \cdots & t_{2n} \\
  \vdots & \vdots & \vdots & \ddots & \vdots \\
  t_{m1} & t_{m2} & t_{m3} & \cdots & t_{mn}
\end{bmatrix}
\]

Similarly this solution matrix will be reached at in regional transport planning to obtain future transport demand requirements for the present research. Where each \( T_{ij} \) represents future regional transportation volumes between \( i^{th} \) origin and \( j^{th} \) destination zones from the study region.

This relation (3.4.1.3) is constrained to be non-negative by:
In the above discussion, we observed that there are \( P_i(b) \) regional transport units which must be shipped from each origin, at the same time each regional transportation solution matrix must also satisfy:

\[
(3.4.1.5) \quad \sum_{j=1}^{n} t_{ij} = P_i(b) \quad \text{for } i = 1,2,3, \ldots, m
\]

Alternatively,

\[
(3.4.1.6) \quad \sum_{j=1}^{n} t_{ij} = a_j(b) \quad \text{for } j = 1,2,3, \ldots, n
\]

\[
(3.4.1.7) \quad \sum_{j=1}^{m} \sum_{i=1}^{n} t_{ij} = \sum_{i=1}^{m} P_i = \sum_{j=1}^{n} A_j = T
\]

The above relation 3.4.1.6 shows that \( A_j \) regional transport units must also be shipped in the regional transport network system of the study area. Where relation 3.4.1.5 represents total number of regional transport units produced at zone \( i \); relation 3.4.1.6 indicates the total number of \( j^{th} \) traffic attracted zonewise; and relation 3.4.1.7 represents the regional total number of traffic generated and attracted zonewise in the entire regional transport network during the study period \( b \) considered. Therefore, in actual practice this relations will result to many regional transportation solution demand matrices that satisfy relation 3.4.1.5, 3.4.1.6 and 3.4.1.7 respectively. In this case, the regional cost of transporting each zonal relation is given by:-

\[
(3.4.1.8) \quad Z = T_{11} C_{11} + T_{12} C_{12} + T_{13} C_{13} + \ldots + T_{mn} C_{mn}
\]

which can be written more compactly as:

\[
(3.4.1.9) \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} T_{ij} C_{ij}
\]
Therefore, the main objective of the above problem is to find out future regional transportation solution demand matrix that satisfies relation 3.4.1.5, 3.4.1.6, 3.4.1.7 and minimizes relation 3.4.1.8 so as to maximize regional transportation efficiency for the study region.

Empirically, in regional transport planning, the above relations 3.4.1.5, 3.4.1.6, 3.4.1.7 and 3.4.1.8 can be used for the study region straight away after obtaining O-D matrix as discussed earlier in section (3.3.1) of this chapter. It was observed that Bharuch region has been delineated into eleven (11) internal zones and six (6) external zones which totals to seventeen (17) zones together connected with 32 road transport network linkages. This could imply a regional data matrix size of $17 \times 17 = 289$ cells samples corresponding to each transportation unit variables. This type of formulation could enable regional traffic modelling for the study region according to alternative distribution models which will be discussed in the subsequent sections below. Finally, by estimating the above 289 regional cell values one may obtain different feasible regional transportation solution matrices in Bharuch region which could imply optimum output demand requirements from the existing road transport networks system for years to come.

Hence, in Bharuch region given 17 x 17 data matrix, the problem is then how to determine relation 3.4.1.5, 3.4.1.6, 3.4.1.7 and 3.4.1.8. To overcome this problem, recent past transport planners have proposed various distribution models.

3.5.1 Transport Distribution Models

These models were first attempted in the works of transport planners, Hutchinson 1974 [44], Martin 1961 [65], Christian 1979 [17] and Bruton 1988 [7]. They considered that the total number of regional traffic generation estimated in every zone of the area under study has to be apportioned to various zones to which these traffic are attracted. The main objective of these models is to forecast the regional traffic flows expected at the end period of the planning year considered, given the O-D matrix of zonal traffic inter-changes for the based year as discussed in the earlier section 3.5.1 of this chapter and the zonal transport-distance
matrix describing decay in transportation pattern with increased travel costs. Thus, if $P_{i,j}(t)$ is the number of regional traffic ends generated in zone $i$ and $a_{j,i}(t)$ is the number of traffic ends attracted to zone $j$, transport distribution model stage, therefore, determines the number of regional traffic $t_{i,j}$ which would originate from zone $i$ and terminate in zone $j$ during the period $t$. In this context, regional future zonal traffic-volume production and attractions are assumed to be known or easily established.

As discussed in the earlier sections 3.2.0, 3.3.0 and 3.4.0 the main task of regional transport planning is based on how all $i^{th}$ zonal traffic generation could be scaled up by a common factor into equilibrium with each $j^{th}$ zonal attraction ends. In doing so, one may be interested to adopt various regional transport-distribution models based on certain assumptions to resolve the above mentioned task in the study region. This section, therefore, deals with distribution models as what follows:

### 3.5.2.0 Growth Factor Models

These models have already been developed and used to synthesize planning (horizon) year traffic distribution matrices in various study areas. In this case, four different growth factor models has been discussed and incorporated in this research each of these models are based on the assumption that present regional transport pattern can be projected into future study period can be projected into future study period using expected differential zonal rates of growth. In actual practice, these group of models could be represented in a general term by the formula in relation to:

$$T_{i,j} = t_{i,j} E$$

Where subscripts $T_{i,j}$ represents future regional number of traffic from $i$ to zone $j$; $t_{i,j}$ present number of traffic from zone $i$ to zone $j$; $E$ is a growth factor.

Thus, depending on the model used the regional transport growth factor ($E$) can be a single factor or a combination of several factors derived from landuse data and regional traffic
generation or attracted projections already discussed in the earlier section 3.2.0 of this chapter. Therefore, this can be calculated for the whole study region or for any number of spatial zones within it and is then adopted to complete O-D matrix as discussed in the earlier section 3.4.0 for the study region.

These models will be discussed in a chronological order of their development as follows:

3.5.2.1 Uniform Factor Model

This model is the oldest and simplest used for projecting future transport distributions. In this case, a single growth factor is calculated for the entire area under study and then used to multiply all regional inter-zonal traffic volumes so that to produce estimates of future inter-zonal traffic volumes matrix.

Mathematically this can be expressed as:

\[(3.5.2.1.1) \quad T_{ij} = t_{ij} E\]

Where subscript E is equal to \( T/t \); \( T_{ij} \) represents future number of traffic from zone i to zone j; \( t_{ij} \) is present number of traffic from zone i to zone j; where \( T \) represents total future number of traffic zone-wise and \( t \) is also present number of traffic in the area under study.

In this case, the basic assumption behind this model is that the expected growth in the study region as a whole will exert the same influence on the growth of transport movement pattern between any pair of zones located within its area respectively. However, this assumption is not strictly correct because for differential rates of regional development inevitably result in different rates of growth in transportation movement pattern zone-wise.

Conversely, the study region with those zones where present day development is limited, the potential changes in the pattern, density and type of landuse pattern will be such that the application of the above mentioned model to the existing volume of transportation movement pattern would lead to an underestimation of future transport movements. Similarly, another
drawback is that the model could also lead to an over-estimation of the same in those regional areas which are already intensively developed.

Because of the above mentioned limitations, this model is nowadays used only to update the results of recent O-D surveys in study areas where the pattern and intensity of landuses are relatively stable.

In regional transport planning this can be adopted with certain limitations. But owing to the above limitations, the model may not be appropriate for Bharuch region because it is of recent dynamic transformation and unbalanced development.

3.5.1.2 Average Growth Factor Model

In this model, a growth factor for each zone is calculated based on the average of the growth factors calculated for both ends of regional traffic generated and attracted zonewise. The factor thus represents the regional average growth associated both with the origin and the destination zones of the study area. The following mathematical relationship represents the principle employed:

\[
(3.5.2.2.1) \quad T_{i \rightarrow j} = t_{i \rightarrow j} \left[ \frac{E_j + E_i}{2} \right]
\]

where,

- \( T_{i \rightarrow j} \) = future number of regional traffic from zone i to zone j.
- \( t_{i \rightarrow j} \) = Present traffic from zone i to zone j.
- \( E_i \) = \( \frac{P_i(G)}{P_i} \) = Generated traffic growth for zone i.
- \( E_j \) = \( \frac{A_j}{a_j} \) = attracted traffic growth factor for zone j.
- \( P_i(G) \) = future generated traffic for zone i.
\[ P_i = \text{Present generated traffic for zone } i. \]
\[ A_j = \text{future attracted traffic for zone } j. \]
\[ a_j = \text{Present attracted traffic for zone } j. \]

It is observed that \( P_i(G) \), \( P_j(G) \) are future regional traffic generated originating in zone \( i \) destined for zone \( j \).

In general, after the distribution matrix has been completed on the above basis, then the regional calculated values of the transportation data matrix will be found that the row requirement sums of the traffic from zone \( P_i \) will probably not agree with the projected regional traffic ends in zone \( P_i(G) \) and also regional column requirement sums of traffic to zone \( a_j \) will not agree with the future traffic ends in zone \( A_j \) projected estimates derived from the regional transport generation analysis as discussed in the earlier section 3.2.0 and section 3.4.0 relation (3.4.1.2), (3.4.1.4), (3.4.1.5) and (3.4.1.6). That is:

\[(3.5.2.2.2) \quad P_i \neq P_i(G)\]
\[(3.5.2.2.3) \quad a_j \neq A_j\]

Where subscript \( P_i \) equals to \( \sum_{j=1}^{n} P_{i,j} \) which is also represented to total present calculated traffic originating in zone \( i \) of the study region and \( P_i(G) \) represents future regional transport generation estimates for total traffic originating in zone \( i \). And subscript \( a_j \) is total present calculated traffic attracted to zone \( j \) and \( A_j \) represents total future regional traffic attracted in zone \( j \).

The above discrepancies can be overcome by an iterative process using new regional values for \( E_i \) and \( E_j \) calculated from:
where \( P_i \) and \( a_j \) are the total generations and attractions of zones \( i \) and \( j \) respectively obtained from the first stage of distribution. Therefore, the first iteration will be in the following form:

\[
(3.5.2.2.5) \quad T_{i-j} = t_{i,j} \left[ \frac{E_i' + E_j'}{2} \right]
\]

The iteration process is continued until the new growth factor approaches unity and the regional traffic values balance within, say, plus or minus 1% in the study region's O-D matrix. Finally \( P_i \) will converge to \( P_i(G) \). In actual practice, such convergence could imply optimum output demand requirement from the existing road transport network system of the study region. In this case, this model has solved the earlier problem in sections (3.3.0) and (3.4.0) respectively in this study.

However, this model is levelled at same drawbacks as those ones discussed in the earlier section (3.5.2.0). In addition, it is observed that, the residual discrepancies mentioned earlier in the iteration process between forecasted and computed zonal traffic generation or attraction patterns are not randomly distributed, but are inversely related to the growth factors. Thus for the study regional zones with lower than average factors, the computed zonal traffic ends are greater than those originally predicted from the generation stage, while the reverse applies for those zones with higher than average growth factors.

In the study region the above bias (3.5.2.2.2) and (3.5.2.2.3) declines with each succeeding iteration process: but if a large number of iterations is required to minimize this bias, then the accuracy of the results may be seriously affected.

Also the regional multiplying factor has no real significance and is only a convenient tool to balance the regional transportation movement zonewise. Otherwise there is no explanation
of the transport movement between zones and factors causing the movement. As in the case of the earlier uniform model (3.5.2.1), if \( t_{ij} \) is zero, \( T_{ij} \) also becomes zero. Because of these drawbacks the model discussed above in this section is rarely used today, except for updating existing stable data for quick results.

Empirically, in regional transport planning, Bharuch region has a data matrix size of 17 x 17 = 289 zonal cells corresponding to each transportation unit variable. Thereof, the above model can be used to obtain feasible solution matrices requirement for the future planning year in the study region, despite of its drawbacks.

3.5.2.3 Fratar Growth Factor Model

This model was first introduced by Fratar [31] and is based on predicting future interzonal transportation by successive approximations which overcomes the drawbacks associated with the earlier discussed models (3.5.2.1) and (3.5.2.2).

According to this model, the total regional traffic for each zone are distributed to the interzonal transportation, as a first approximation, according to relative attractiveness of each transportation. Thus, the future traffic estimated for any zone would be distributed to the transportation involving that zone and in proportion to the expected growth of each other zone.

In practice, the researchers considered iteration process to develop the earlier models 3.5.2.1 and 3.5.2.2 based on the following assumptions: (i) the distribution of regional future traffic from each study zone of origin is proportional to the present traffic distribution from those zones and (ii) the distribution of these future traffic is modified by the growth factor of the study regional zones to which these traffic are attracted.

Given a study region, such modification takes into account the effect of the location of each \( i^{th} \) zone with respect to all other zones and this is expressed as the reciprocal of the regional average attracting "pull" of all these zones.

Broadly, the formulation of this model involves the following premises:
(i) The regional estimation of total number of traffic expected to originate and terminate in each traffic zone at the date for which transport distribution is required.

(ii) Distribution of future regional traffic ends from each zone to all other zones in the study region are in proportion to the present distribution of traffic, modified by the growth factor of the zones to which the traffics are attracted. Thus, this yields two values for each regional interzonal transportation movement (i-j), (j-i) and an average of these values is taken as the first approximation of the interzonal traffic volumes.

(iii) For each regional zone the sum of the first approximation volumes is divided into the regional total traffic volume desired for the zone, as estimated from the earlier transport generation stage to derive the new growth factor to be used in computing the second approximation.

(iv) The estimated regional interzonal traffic volumes for each zone in the first approximation are again distributed, in proportion to the present interzonal volumes and the new growth factor obtained in the first approximation. The pairs of values derived are again averaged and the process is repeated until the conformity between calculated and "desired" transportation is achieved.

Mathematically, the above (i) to (iv) formulation can be expressed to synthesize horizon-year-traffic interchange magnitudes of the study region as discussed in the earlier data matrix table 3.4.1.

\[ T^h_{i-j} = t^b_{i-j} E_i E_j \left( \frac{L_i + L_j}{2} \right) \]

Where subscript \( T^h_{i-j} \) represents regional predicted number of traffic (i-j) between zone i and j in the horizon year of the study region; \( t^b_{i-j} \) represents present number of traffic between zone i and j observed in the base year of the study region; \( E_i E_j \) are the regional growth factors for individual zones i and j which reflect the growth in regional traffic productions and traffic attractions expected between the base and horizon year of the study region, where \( E_i \) equals to \( P_i h/P_i b \) and \( E_j \) equals to \( a^b_j/a^h_j : L_i, L_j \) represents the locational factors where L,
equals to \( P^b_i / \sum_{j=1}^{n} t^b_{i-j} E_i \) (also \( L_j \) will be derived from a similar expression).

In the study region, relation 3.5.2.3.1 could imply a basic premise that distribution matrix of horizon year zonewise is proportional to the base-year matrix modified by the growth factors of the zones under consideration. Hence the regional locational factors defined above 3.5.2.3.1 are reciprocals of the zonal average attracting forces of all the surrounding zones of the study area.

Therefore, if constraint equation 3.4.1.6 explained in the earlier section 3.4.1 of this chapter is violated, then the procedure must be reiterated using the following expressions:

\[
(3.5.2.3.2) \quad T^h_{i-j} = t^h_{i-j} E^*_i E^*_j \left( \frac{L^*_i + L^*_j}{2} \right)
\]

where,

\[
E^*_i = \frac{P^b_i}{\sum_j t^b_{i-j} E^*_i} \quad \text{and} \quad E^*_j = \frac{a^b_j}{\sum_i T^b_{i-j}}
\]

and

\[
L^*_j = \sum_{i=1}^{n} \frac{t^b_{i-j}}{\sum_j \sum_{i=1}^{n} (t^b_{i-j} E^*_i) E^*_j}
\]

\[
L^*_i = \sum_{j=1}^{n} \frac{t^b_{i-j}}{\sum_i \sum_{j=1}^{n} (t^b_{i-j} E^*_i) E^*_j}
\]

Subscript * identifies the new regional transport zonal matrix parameters to be used in successive iterations of the of regional distribution matrix equations until \( E^*_i \) and \( E^*_j \) approach unity one or in other words the earlier relation constraint 3.4.1.4; 3.4.1.5 and 3.4.1.6 are satisfied when \( E^*_i \) and \( E^*_j \) are both equal to unity one.
In regional transport planning, this could imply a regional transportation balance between predicted traffic number \(T_{i,j}^h \) and the expected traffic number \(t_{i,j}^h \) zonewise required for transport facility provision in the study region. However, the procedure is observed as laborious except for simple problems, but can be conveniently tackled by a computer. This model has the same drawbacks as earlier growth factor models 3.5.2.1, 3.5.2.2 and is unable to forecast regional transportation units for those areas which were predominantly underdeveloped during the base year. It does not also take into account the effects of regional changes in accessibility for various portions of the study area.

3.5.2.4 Detroit Model

This model was first evolved by Detroit Area transportation study, in an attempt to overcome the shortcomings of the earlier models 3.5.2.1, 3.5.2.2 and 3.5.2.3 discussed in this chapter section 3.5.1, while at the same time reducing the computer operations necessary to bring these models to a satisfactory balance. It is similar in approach to the average factor and fratar models, but introduces the assumption that although the regional number of traffic generated in zone \(i \) will increase as projected by the appropriate growth factor \(E_i \), which will be distributed to zone \(j \) in proportion to the appropriate growth factor \(E_j \) divided by the growth factor for the area under study as a whole. This will be expressed mathematically as:

\[
(3.5.2.4.1) \quad T_{i,j}^h = t_{i,j}^h \frac{E_i x E_j}{E}
\]

Where subscript \(T_{i,j}^h \), \(t_{i,j}^h \) and \(E_i \), \(E_j \) are as discussed earlier in sections 3.5.1, 3.5.2.1, 3.5.2.2, and 3.5.2.3, \(E \) represents growth factor for the area under study as a whole.

As in the earlier models (3.5.2.1, 3.5.2.2, 3.5.2.3) it is observed that the computed regional traffic generated or attracted ends \((T_{i,j}, t_{i,j})\) for any zone will generally not equal the \(i^{th}\) regional future traffic ends; for that zone\( T_{i,j}^h \). In this case, iteration is therefore necessary to bring the result into balance and the new regional growth factor \(E_i' \) and \(E_j' \) are computed for future regional traffic ends. Thus this can be expressed as:

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Where subscript $T_{i}^{h}$ represents regional future traffic ends originated in zone $i$ from transport traffic generation stage. $t_{i}^{h}$ also represents present computed traffic ends in zone $i$. The same applies to $T_{j}^{h}$ and $t_{j}^{h}$. Therefore it is observed that the regional growth factor used in this model is much simple to calculate than complicated factors used in the earlier discussed models 3.5.2.2, and 3.5.2.3.

### 3.5.2.5 Furness Model

This model was first devised by K. P. Furness [32] which is also an iterative in nature. For this, the regional estimates of future traffic originating and terminating at each zone are required, thus yielding origin growth factors and destination growth factors for each zone. The present regional traffic movements are made to agree alternatively with the future traffic originating in each zone and the estimated future terminating in each zone, until both these conditions are roughly satisfied.

In the regional O-D matrix table discussed earlier section 3.4.1 of this chapter gives the base-year distribution $P_{i-j}^{h}$. From the regional values of the predicted future origin and destinations $P_{i-j}^{h}$ the origin and destination growth factors are calculated for each zone. Each column of the matrix is then scaled by the appropriate destination growth factor, such that the present column totals become equal to the predicted column totals zonewise. A new set of origin growth factors is computed for each zone by dividing the predicted trip total by the total obtained for the row by the column scaling as mentioned earlier.

In the next step, each regional row is scaled by the new growth factor giving correct row totals. This, however, disturbs the column totals. As before, new destination growth factors are computed for each zone by dividing the predicted traffic totals by the total obtained by the row scaling.
The regional columns are now scaled again using the new destination growth factors and this iterative procedure is repeated until all growth factors are unity or sufficient near to unity for the user to feel satisfied and confident that he has obtained the degree of accuracy he needs. This model gives results similar to fratar model already discussed in section 3.5.1.3, but requires less computations.

In actual practice Bharuch region has a data matrix size of 17 x 17 = 289 cells. Then the problem in front of a planner is to search for future transport demand solution matrices by using any of the above models 3.5.2.1 to 3.5.2.5 so as to satisfy earlier relation 3.4.1.5 to 3.4.1.8 respectively in the present research.

However, the above discussed models section 3.5.2.1 to 3.5.2.5 has the following limitations:–

(i) Present regional trip distribution matrix has to be obtained first, for which large scale O-D studies with high sampling sizes are needed so as to estimate the smaller zone-to-zone movements accurately.

(ii) The error in original data collected on specific zone-to-zone movement gets magnified.

(iii) None of these models provide a measure of resistance to travel all imply that resistance to travel will remain constant in the area under study. They neglect the effect of changes in travel pattern by the construction of new facilities and new network.

(iv) They assume that regional transport network of future period will provide the same level of services as at present.

(v) They are incentive to changes in growth of regional areas.

Despite the above limitations, the growth factor models are relatively simpler to use and understand. They can be used for studies of smaller areas and for updating stable and uniform data. However, the above fundamental limitations associated with the use of growth factor models in regional transport planning has been identified and gives way to development of alternative method as well as improvement of the same. The most widely used alternative
to resolve this problem is generally referred to as the synthetic models based on the following assumptions that (i) before future regional transport patterns can be predicted, the underlying causes of transportation must first be understood, (b) the causal relationships are established between regional traffic and measures of attraction, generation and travel resistance. Synthetic models have an important advantage that they can be used in area under study not only to predict future regional traffic distribution but also to synthesize the base-year transportation flows. The necessity of having to survey every individual cell in the regional traffic matrix is thus obviated and the cost of data collection is reduced. One such synthetic method is gravity model discussed in the preceding section of this chapter.

3.6.1 Gravity Model

This model is the most widely used synthetic method for transportation distribution of the area under study, Hansen 1962 [41], Hutchinson 1974 [44], Anthony 1962 [2] and Kadiyali 1991 [54]. The model adopts the concept of gravity as advanced by Newton in 1686 and given the earlier regional O-D matrix table (Tij) section 3.4.1, this model will assume that the regional traffic produced or attracted interchange between zones i and j in a study area is dependent upon the relative attraction $A_j$ between zones i and j and the spatial separation between them as measured by a distance function $d_{ij}$. This function of regional spatial separation $d_{ij}$ adjusts the relative attraction $A_j$ of each zone for the ability of the transport maker to overcome the spatial separation $d_{ij}$. Whereas the regional traffic interchange $P_i$ is directly proportional to the relative attraction $A_j$ of each zone and inversely proportional to the measure of spatial separation $d_{ij}$ between zones.

The above relationship can be expressed mathematically in the following form:

$$T_{ij} = \frac{KPA_j}{d_{ij}^\alpha} \tag{3.6.1.1}$$

Where $T_{ij}$ represent total regional traffic generated or attracted between zone i and j, $P_i$ is the regional traffic produced is zone i, $A_j$ is also regional traffic attracted to zone j, $d_{ij}$
represents distance between zone i and j or the time or cost of travelling between zone i and j, K equals to a constant usually independent of i and a is an exponential constant whose value is usually found to lie between 1 and 3. K also represents total number of zones.

The above simple relation 3.6.1.1 was a major breakthrough in the field of transport distribution. This model (3.6.1.1) stressed the importance of specific values of zonal traffic attraction, resistance, and recognized the influence of trip purpose on travel pattern. It could be used with an advantage over the growth factor methods already discussed earlier in section 3.5.1: in that changes in the future land-use pattern could now be accounted for, and that improvements to existing transportation facilities could be taken into consideration in the regional travel resistance factor.

Despite these advantages, the above simple gravity model 3.6.1.1 is faced with two major shortcomings; (i) the inverse power of distance was an unsatisfactory resistance function because it could not cover the range of zonal trip possibilities and failed to give valid estimates when the distance factor was very small or very large; (ii) the comprehensive regional iteration process required to calibrate the model, allied to the zonal number of traffic (T_i) purposes used as input and the regional variations in travel pattern with zonal location that had to be accounted for, gave rise to serious computational problems.

However, in an attempt to overcome these difficulties considerable research has been undertaken in North America and Great Britain, primarily aimed at developing a measure of the effect of spatial separation on zonal trip interchange which more accurately reflects the complex nature of this relationship than the single exponent of either distance or time (3.6.1.1). In North America this work has led to the development of gravity model formulation which incorporates empirically derived travel time factors to express the effect of regional spatial separation on zonal traffic interchanges. In Great Britain also a generalized measure of the regional “cost” of various aspects of trip making such as cost, time, has been developed to represent regional travel impedance. In this context, to overcome the above shortcomings
of simple gravity model 3.6.1.1 which considers only the distance as regional spatial separation
factor, in above discussion another gravity model formulation had been developed incorporating
the empirically travel time factors today in the following form [50]:

\[ (3.6.1.2) \quad T_{i-j} = \frac{P_i A_j F_{i-j} K_{i-j}}{\sum_{j=1}^{n} A_j F_{i-j} K_{i-j}} \]

Where,

- \( T_{i-j} \) = Number of regional trips from zone i and zone j.
- \( P_i \) = Total number of regional trips produced in zone i.
- \( A_j \) = Total number of regional trips attracted to zone j.
- \( F_{i-j} \) = Empirically derived travel-time factor expressing the average regional
  area-wide effect of spatial separation.
- \( K_{i-j} \) = Specific regional zone to zone adjustment factor to account for other
  social and economic factors influencing travel pattern but not accounted
  for in the model.

In actual practice, the above mentioned regional travel time factors are a measure of the
probability trip making at each chosen increment of time. They are empirically derived
through a "trial and error" process and the usual procedure is to starts with the adoption
of a set of regional travel time factors already calculated for the study region (an alternative
is to assume that regional travel time has no effect on regional traffic distribution and adopt
1 as the first travel-time factor). The next step involves the calculation of zonal interchanges
using the gravity mode \( T_{i-j} \) discussed above, which are then compared with the regional
present traffic zonal interchanges derived from the O-D matrix \( t_{i-j} \). An iterative process
is adopted until there is close agreement between the two sets of regional interchanges.
Generally it is accepted in the model that satisfactory agreement is reached when the difference
between average regional trip lengths is ±3 per cent, and trip length frequency curves are "close" when compared visually.

Mathematically, this iteration is achieved by [50]:

\[(3.6.1.3) \quad P_{i-j} = F_i-j \times \frac{t_{i-j}}{T_{i-j}}\]

Where,

- \(F_{i-j}\) = regional travel factor to be used in the next step of the procedure.
- \(F_{i, j}\) = regional travel factor adopted from the similar study region (or assumed 1).
- \(T_{i,j}\) = regional trips between zone i and zone j as a percentage of total zonal trips calculated from gravity model.
- \(t_{i,j}\) = regional trips between zone i and zone j as a percentage of total zonal present trips generated or attracted derived from the study region.

In addition to the above described regional travel-time factors incorporated in the gravity model (3.6.1.1 and 3.6.1.3) used today, provision is also made for the inclusion of zone to zone socio-economic adjustment factors \((K_{i,j})\), should they prove necessary for the successful calibration of the model.

The procedure adopted to calculate the regional socio-economic adjustment factor is to compare the estimated regional trips interchanges between large generators of regional transportation using the gravity model \((T_{i,j})\) with the regional observed present traffic interchanges \((t_{i,j})\). Both these set of regional transport movements are manually assigned to a existing transport network, to reveal any systematic discrepancies. Mathematically the adjustment factor \((K_{i,j})\) is derived from

\[(3.6.1.4) \quad K_{i-j} = R_{i-j} \frac{I-X_i}{I-X_i R_{i-j}}\]
Where,

\[ R_{r_{i,j}} = \text{regional ratio of O-D trips interchanges (t_{i,j}), to gravity model trip interchanges} \]

\[ T_{r_{i,j}} \]

\[ X_{i} = \text{regional ratio of O-D trips between zone i to zone j to total O-D trips leaving zone i.} \]

The above discussed gravity models relation (3.6.1.1), (3.6.1.2), (3.6.1.3) and (3.6.1.4) can also be classified into the following four types based on the conditions which they satisfy in the study area: (i) unconstrained gravity model (ii) production constrained gravity model (iii) attraction constrained gravity model (iv) fully constrained gravity model [50]. We discuss these models as what follows:-

(i) Unconstrained gravity model

The formulation of this model is

\[ T_{i-j} = K P_{i-j} F(t_{i,j}) \]

Where \( T_{i-j} \) is the regional number of trips estimated from the model between zone i and j, \( P_{i-j} \) represents the total regional number of trips produced in zone i and attracted to zone j, \( F \) equals to empirically derived travel time factor zonewise multiplied by \( t_{i,j} \) O-D present trips observed in the study region. \( K \) also represents constant of proportionality which ensures that total regional number trips estimated from the model equals the total regional number of trips observed from the study area.[50]

(ii) Production Constrained Gravity Model

This model is of the form that:

\[ T_{i-j} = \frac{P_{i} F(t_{i-j}) \sum_{j} A_{i,j} F(t_{i,j})}{\sum_{j} A_{i,j} F(t_{i,j})} \]
Where the regional constant of proportionality $\sum_j A_jF(t_{i,j})$ ensures that the row totals of
the model estimated matrix $(T_{i,j})$ equal to the row totals of the observed O-D matrix $(t_{i,j})$
(such that regional production constraint is satisfied).

(iii) Attraction Constrained Gravity Model:

The mathematical form of the model is

$$T_{i,j} = \frac{P_iA_jF(t_{i,j})}{\sum_i P_iF(t_{i,j})}$$

(3.6.1.7)

Here the regional constant of proportionality guarantee that when summed down the columns
of the model $T_{i,j}$ matrix the zonal trip destinations are in balance with observed trip destinations $t_{i,j}$.

(iv) Fully Constrained Gravity Model:

This model is represented by

$$T_{i,j} = R_iC_jP_iA_jF(t_{i,j})$$

(3.6.1.8)

Where $T_{i,j}$ is estimated regional number of trips matrix between zone $i$ and $j$, the value of
$R_i$ is the regional production balancing factors for each zone $i$ which is estimated using the
following equation:

$$R_i = \frac{1}{\sum_j C_jA_jF(t_{i,j})}$$

$c_j$ is also regional attraction balancing factor for each zone $j$ which is estimated using the
following equation:

$$C_j = \frac{1}{\sum_i R_iP_iF(t_{i,j})}$$
The above $R_i$ and $c_j$ are regional balancing parameters which ensure that column totals and row totals of modelled O-D matrix $T_{ij}$ equal to the same as observed O-D $t_{ij}$ matrix such that satisfy the two conditions.

In regional transport planning and development, fully constrained gravity model is considered to give better results in regional future transport requirements than the other three types. However, all these models are expected to satisfy the earlier relation 3.4.1.2, 3.4.1.5.

Thus, in Bharuch region we already considered a data matrix size of $17 \times 17 = 289$ cells samples corresponding to each zonal passenger and freight transport unit variable for the base-year 1991 connected with 26 road transport linkages. Now our problem is to forecast this data matrix $17 \times 17$ ($t_{ij}$) to the planning year 2041 matrix ($T_{ij}$) and match the same respectively. In this case, gravity model relation 3.6.1.1 to 3.6.1.8 could be adopted with an help of computer programs such that to obtain future transport solution matrices ($T_{ij}$) that satisfy earlier relation 3.4.1.1 to 3.4.1.7 in Bharuch region. The empirical tests of the same has been discussed in the subsequent chapter VI.

### 3.7.1 Lowry-Garin Model

In the earlier sections (3.2.0, 3.3.0, 3.4.1, 3.5.1 and 3.6.1.0) of this chapter we have theoretically discussed generation and distribution models in terms of their viability to regional planning and development.

In Hutchinson [45] and Kadiyali [57], it was observed that the basic requirement of these models (generation and distribution) is land-use development patterns for the year being studied in a given region. Thus, the major weakness of this models is that they require a completely specified regional land-use allocation both at the production and attraction end of trips. Another limitation is that the estimation of transport demand of the earlier models already discussed in sections (3.5.1.0 and 3.6.1.0) tend to be high in the principal highway corridors, which results to costly surveys of rapid transit systems of the study region.
In this context, an attempt to overcome this deficiencies in the earlier models have given way to an entirely different regional transport planning model, whereby land-use allocation and transport demands has come into being in the contents of “Lowry-Garin solution matrix”. The appeal of this model is that regional land-use is not exogenously specified but is on the contrary determined by the model itself, along with transport demand respectively in the study region.

In other words, Lowry-Garin solution matrix is called land-use transport model. This model is observed as sensitive to major development policy variables and thus give a scope for manipulation in a variety of ways so as to select the best alternative plan for regional development and efficiency.

This model found its origin in the works of Lowry 1964 [63]. It was first developed for planning purposes to be applied to urban area of Pittsburgh. Later various researchers such as Garin 1966 [37], Roger 1966 [90], Irwin 1965 [51], Goldner 1965 [38], Cvecine 1969 [22], Crippper 1969 [21], Batty 1970 [10], Masser 1970 [72], Putman 1975 [86], Rao 1978 [91], Hutchinson 1974[45] and Kadiyali 1991 [57] extended and used Lowry model in transport planning and development policies for regional planning with due modifications, Mathur 1992 [71].

However, the object of the model, as stated by Lowry was “the development of an analytical model capable of assigning regional activities to sub-areas of a bounded region in accordance with those principles of locational interdependence that could be reduced to quantitative form” (Lowry, 1964).

The Lowry model, incorporated in itself both forecasting and allocation procedures. It also related three elements of the regional systems together in a model, population, employment, transportation and the interaction between them was sought to be described.

In regional transport planning, therefore, the spatial distribution of basic employment is allocated exogeneously to the model, and the spatial distributions of households and population-
serving distributions of households and population-serving employment are calculated by the model. The zonal allocation rules for both households and population-serving employment are specified within the model structure. In addition, the constraints on the maximum number of households for each zone and the minimum population-serving employment thresholds for any zone of the study region are specified.

This model has no time dimension, it generates what Lowry [63] calls “an instant metropolis or region” in which the interactive sequences of the solution process are simply convenient substitutes for an analytical solution.

As described in the above context, the model based itself on the economic base theory, which suggests that the economic activity of a regional economy can be divided into two categories “basic” and “service”. The “basic” activity as defined above is export oriented, producing goods which are consumed outside the region under study and whose growth is related to national economic growth. The “service” industry on the other hand caters to the population of that region and hence its activity levels and location are dependent on the local populace.

Goldner [38] [39] made numerous beneficial modifications to the original basic model of Lowry concept and considered its treatment of time dimension. The original version features the “instant metropolis or region” and direct arrival at the regional target date equilibrium. Grecine [22] distinguishes between stable activity development patterns, and Wilson [111] partitioned non-movers from those who move their regional residence but not their jobs, from others who move jobs without changing residence, and from the most mobile group, who move both job and residence. These approaches add incremental changes over time to the existing population distribution rather than deriving at end point static equilibrium as in the original Lowry model.

In the recent past, various researchers have abandoned the constraints features in the original model (Garin, 1966 for example), while others have enriched their use. Goldner 1968 [38]
allowed zone-to-zone changes in the constraint values and modified them as a function of regional market-pressure. Cripps (1969), allowed constraints to reflect planning policy.

In their treatment over space, all the researchers started with a defined study area, partitioned into a set of zones, with zones linked to other zones by a network (Goldner 1968), but their size, shape and number may differ. The area under study varies from a small region to a big region. The network distance between zones have been measured as road distance with or without terminal time included in the study region.

In the present case therefore, we have delineated Bharuch region into eleven (11) internal and six (6) external zones as described in the earlier chapter II (Section 2.2.0) and empirically discussed in chapter IV (Section 4.2.0) for the purpose of this model to be undertaken.

The allocation mechanism has been modified from the potential model used by lowry to gravity model concept as discussed in the earlier (Section 3.6.1) of the chapter. The lowry model has proved beyond no doubt quite adoptable to different data situations, different countries, different sizes and types of regions and different planning needs while still retaining its basic chapter.

In the present case, this model can be used in regional transport planning straight away. The data (variables) considered in this case are: 1. total regional employment 2. employment in basic industries 3. employment in population-serving industries 4. the household or population sector, and 5. transportation network distance respectively. Here with, the model seeks to explain the spatial structure of a region in terms of these variables. A given level of geographical distribution of basic employment within a region is an input, and the model generates output of the rest of the region as geographical distribution and levels of retail employment and total households. Thus, if so required for a future time the model will predict location of population and non-basic employment given the rest of exogeneous factors for the model namely basic employment at that time, the transportation linkages and constraints which will exist then.
In this context, regional basic employment is defined as employment in those industries whose products or services depend on markets external to the region under study. The important assumption with respect to basic employment, however, is that it's location within a region is independent of the population and service employment distribution of that region. On the other hand, the regional location of service employment is dependent upon the population distribution of a region. Hence, typical of the industries that might be considered as basic are the various primary industries, as well as elementary schools and high school employment.

In actual practice, let us consider a region with three land-use variables. Suppose, \( P \) represents row vector of total population or household within each of the \( n \) zones, \( e \) a row vector of total employment in each zone, \( e^s \) a row vector of the population-serving-employment in each zone, \( e^b \) a row vector of the basic employment in each zone, \( H \) represents \( nxn \) Matrix of work place-to-household accessibilities, and \( S \) represents \( nxn \) Matrix of the household-to-service center accessibilities in the study region.

In this case, our problem is to determine a regional land-use allocation and demand for transportation simultaneously. In context to this, our variables can be expressed mathematically as

\[
(3.7.1.1) \quad P = e^H \\
(3.7.1.2) \quad e^s = P^s \\
(3.7.1.3) \quad e = e^b + e^s
\]

Here, \( H \) accessibility matrix zone-wise may be expanded as follows:

\[
(3.7.1.4) \quad H = [a'_{ij}] [a_j]
\]

where, \( a'_{ij} \) represents \( nxn \) square matrix of an employee working in zone \( i \) and living in zone \( j \). \( a_j \) represents \( nxn \) diagonal matrix of the inverses of the labour participation rates zone-wise, expressed either as zonal population per employment or zonal households per employment.

Conversely, \( S \) accessibility matrix zone-wise may be expanded as follows:
where, $b'_{ij}$ is $n \times n$ square matrix of the probabilities that the population in zone $j$ will be serviced by population serving employment in zone $i$, $b_j$ represents $n \times n$ diagonal matrix of the population serving employment - to population ratios.

In the previous discussion, it has been observed that zone-wise basic employment vector ($e^b$) and total employment vector ($e$) and both specified exogenously or allocated to the model and then zone-wise population-serving employment vector ($e^s$) is calculated internally within the model. In this case, an iterative procedure for calculating a stable co-distribution of population and employment zone-wise is necessary.

In actual practice, therefore, the zone-wise $a'_{ij}$ elements of the already described $H$ matrix may be estimated empirically in the following way:

$$\textit{(3.7.1.6)} \quad a'_{ij} = \frac{n_j d_{ij}^\alpha}{\sum_i n_j d_{ij}^\alpha}$$

where, $n_j$ is a measure of attractivity of zone $j$ for household location in the study region, $d_{ij}^\alpha$ represents distance/travel-time factor between zones $i$ and $j$ which reflects the manner in which the spatial separation of zones influences of the residential location choice of employment.

Relation 3.7.1.6 will be recognized as gravity type accessibility expression as already discussed in section 3.6.1 of this chapter. Similar functional form have been used in practical applications of the lowry model and this particular form which have been used are discussed later in this section.

Conversely, the $b'_{ij}$ elements may be estimated empirically in a manner similar to the already described $a'_{ij}$. In this case, it is useful to disaggregate service employment in the study area into $r$ types where the expression analogues to relation (3.7.1.6) becomes
where, $s'_i^r$ represents a measure of attraction in zone $i$ for satisfying the service-type $r$ needs of the households in the study region, while $d_{ij}^r$ is the zonewise distance/travel-time factor between zones $i$ and $j$ which reflects the manner in which the spatial separations of zones influences the type $r$ service location choices of households.

In other words, the regional distribution of activities produced by the above set of relations 3.7.2.4, 3.7.1.5, 3.7.1.6, and 3.7.1.7 should be such that the following constraint relations are satisfied in the study region:

\[
\text{(3.7.1.8)} \quad P \preceq P^c \\
\text{(3.7.1.9)} \quad e^{sr} = e^{sr} \min
\]

where, $P^c$ is a row vector of the population - holding capacities of each of the $n$ zones, $e^{sr}$ $\min$ represents a row vector of the population. Serving employment thresholds for the $r$ service employment types considered to be viable for any zone.

If relation (3.7.1.8) and (3.7.1.9) are violated the earlier relation set (3.7.1.1) to (3.7.1.3) are solved using the new matrices in the study region. One approach to this problem of developing regional distribution of activities that statistics the constraints (3.7.1.8) and (3.7.1.9) above is to use gravity model in attraction constrained case as shown in the earlier section 3.6.1 relation (3.6.1.7) of this study. This is, therefore, expressed as

\[
\text{(3.7.1.10)} \quad a_{ij}^* = \frac{n_j^*d_{ij}^\alpha}{\sum_j n_j^*d_{ij}^\alpha} \\
\text{(3.7.1.11)} \quad n_j^* = \begin{bmatrix} n_j \\ p_j \end{bmatrix} \\
\text{(3.7.1.12)} \quad b_{ij}^* = \frac{S_i^r d_{ij}^{sr}}{\sum_i S_i^r d_{ij}^{sr}}
\]

Where $S_i^r$ is equal sir for zones which $e_{ij}^{sr} \geq e_i^{sr}$.
Where, \( S_i^r = S_i^r \) for zones in which \( e_i^r \geq e_i^{r, mn} \)
\[ = 0 \] for zones in which \( e_i^r \leq e_i^{r, mn} \)

in which \( a^r \) and \( b^r \) are new estimates of \( a_i^r \) and \( b_i^r \) to be used in the next iteration of the model.

### 3.7.2 The Garin Solution Matrix:

The earlier already discussed lowry model was improved by Garin 1966 [37] in two ways, first by explicitly incorporating spatial sub-models into the framework and second, by expressing the fundamental lowry algorithm in vector and matrix format. Garin 1977 [37] showed that a more exact answers to regional transport planning can be obtained by replacing the iteration process with a matrix inversion process.

In Garin [37], given exogenous variables to the model the regional level and allocation of basic employment, the basic employees are allocated to residential zones of the study region and then population dependent on these basic employment is found out. The level of retail employment zone-wise to serve this population is determined and then allocated to service centres zone-wise the retail employment zone-wise are then allocated to residential zones. Further, increments of population and service employment are devised and allocated, until convergence in the study region is reached at.

In other words, Garin [37] proposed a formulation of the lowry model which obviates the need for the iterative solution in the study areas as discussed earlier in previous relations. In this relations in the earlier discussion extended by Garin are obtained.

\[
(3.7.1.13) \quad P^b = e^bH \\
(3.7.1.14) \quad e^1(1) = P^bS = e^b(HFAS)
\]

Relation (3.7.1.14) above calculates the population serving employment required to serve the households supported by basic employment, and the superscript (1) identified that it is the first increment of service employment in the study region.
Where $F$ is $n \times n$ diagonal matrix of labour participation ratios zone-wise, and $A$ represents $n \times n$ diagonal matrix of the population serving employment to population ratios zone-wise, and $P^b$ is basic population zone-wise.

In the present case, if $E^B$ is the regional basic employment, $P^b(i)$ basic population and $f$ is the participation rate of labour force zone-wise. This relation can be expressed as

$$(3.7.1.15) \quad P^b(i) = fE^B$$

Hence, applying zone-wise retail employment scale factor ($a$), the retail employment $E^R(i)$ to serve the regional basic population $P^b(i)$ can be derived as

$$(3.7.1.15) \quad E^R(i) = aP^b(i) = afE^B$$

Again, applying the participation rate $f$ and the basic population $P^b(i)$ related to the retail employment $E^R(i)$ can be calculated as:

$$(3.7.1.16) \quad P^b(i) = fP^b(i) = af^2E^B$$

Similarly,

$$(3.7.1.17) \quad E^R(2) = aP^b(2) = a^2f^2E^B \text{ and } E^R(m) = aP^b(m) = a^mf^mE^B$$

Thus, the total employment of the region under study can be summed up as,

$$(3.7.1.18) \quad E = E^B + E^R(1) + E^R(2) + \ldots + E^R(m)$$

$E = E^B + afE^B + a^2f^2E^B + \ldots + a^mf^mE^B$

$E = E^B (1 + a + a^2f^2 + \ldots + a^mf^m)$

3.7.2.1: Garin’s Matrix Formulation:

The interactive process used in the Lowry Model to generate retail employment can be replaced by matrix inversion process to obtain exact solution for regional transport planning.
Let us suppose that, $e^b = (E_1^b, E_2^b, \ldots, E_n^b)$, then $l x n$ vector is regional basic employment. And $e(z) = E_1(z), E_2(z), \ldots, E_n(z)$; $l x n$ vector of employment whose value has been calculated during iteration $z-1$; $e(l) = e^b$. Hence, $P(z) = P_1(z), P_2(z), \ldots, P_n(z)$; $l x n$ vector of population associated with employment vector $e(z)$. In Garin's formulation, therefore,

$$F = \text{Labour participation or activity rate diagonal matrix zone-wise of the study region.}$$

$$\begin{bmatrix}
    f_1 & 0 \\
    & \\
    & f_i \\
    & \\
    0 & f_n
\end{bmatrix}$$

(3.7.2.1.1)  $F = \begin{bmatrix}
    f_1 & 0 \\
    & f_i \\
    & \\
    0 & f_n
\end{bmatrix}$

$$A = \text{Population serving ratio, diagonal matrix zone-wise}$$

$$\begin{bmatrix}
    a_1 & 0 \\
    & a_i \\
    & \\
    0 & a_n
\end{bmatrix}$$

(3.7.2.1.2)  $A = \begin{bmatrix}
    a_1 & 0 \\
    & a_i \\
    & \\
    0 & a_n
\end{bmatrix}$

This matrix has been calculated by gravity model in production constrained case as discussed in the earlier section 3.6.1 relation 3.6.1.6 of this chapter. In other words

$$H = \text{Work to home trip probability distribution matrix}$$

$$\begin{bmatrix}
    p_{11}^{wh} & p_{12}^{wh} & p_{1n}^{wh} \\
    p_{21}^{wh} & p_{22}^{wh} & p_{2n}^{wh} \\
    p_{n1}^{wh} & p_{n2}^{wh} & p_{nn}^{wh}
\end{bmatrix}$$

(3.7.2.1.3)  $H = \begin{bmatrix}
    p_{11}^{wh} & p_{12}^{wh} & p_{1n}^{wh} \\
    p_{21}^{wh} & p_{22}^{wh} & p_{2n}^{wh} \\
    p_{n1}^{wh} & p_{n2}^{wh} & p_{nn}^{wh}
\end{bmatrix}$

Where, $p_{ij}^{wh}$ represents the proportion of trips from zone $i$ to zone $j$. In other words;

$$p_{ij}^{wh} = \frac{\text{Number of trips from zone } i \text{ to zone } j}{\text{Number of trips from zone } i \text{ to all other zones}}$$

Therefore,
\[ P_{ij}^{wh} = \frac{\sum_{j=1}^{n} \frac{N_i}{d_{ij}^\alpha}}{N_i} \]

Conversely,

\[ S = \text{home to service trip probability distribution matrix zone-wise of the study region.} \]

Therefore,

\[ S = \begin{bmatrix} P_{11}^{ha} & P_{11}^{ha} & P_{11}^{ha} \\ P_{11}^{ha} & P_{11}^{ha} & P_{11}^{ha} \\ P_{11}^{ha} & P_{11}^{ha} & P_{11}^{ha} \end{bmatrix} \]

This matrix has been calculated by gravity model in attraction constrained case as discussed in the earlier section 3.6.1 relation 3.6.1.7 of this chapter.

Where, \( P_{ij}^{ha} \) represents the regional proportion of the home to service trips from residential zone \( j \) and zone \( i \) of the study area.

Thus, \( P_{ij}^{ha} = \frac{\text{Number of trips from zone } j \text{ to zone } i}{\text{Number of trips from zone } j \text{ and all other zones}} \)

Therefore,

\[ P_{i}^{e} = \frac{E_{i}^{a} / d_{i}^{e}}{\sum_{i=1}^{n} E_{i}^{a} / d_{i}^{e}} \]

Where, \( E_{i}^{R} \) represents regional measure of attraction of zone \( i \) for retail employment in the study region; \( d_{ij}^{w} \) as stated with the earlier relations, is a zone-wise distance/travel-time factor between zones \( i \) and \( j \) which reflect regional spatial separation of zones influences of the residential location choice of employment in the study.
In other words,

\[ I = \text{unit diagonal matrix zone-wise} \]

(3.7.2.7) \[ I = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix} \]

3.7.2.8: Matrix Solution:

In the regional transport planning, Garin's solution matrix to resolve the earlier problem of allocation and demand simultaneously. In Garin, therefore, the following steps have been adopted.

Step 1: To allocate regional employment to residential location zonewise - Here the earlier relation (3.7.2.3) \( e(1)H \) gives the allocation in the area under study.

Step 2: To derive regional retail employment and allocate to service zones. This is done by multiplying the regional population vector \( P(1) \) with the population serving ratio Matrix A. The regional allocation is, therefore, done by multiplying this with the matrix \( S \).

Alternatively,

(3.7.2.9) \[ E(2) = P(1) AS \]

(3.6.2.10) \[ P(1) = e(1) HF \]

(3.6.2.11) therefore, \( E(1) = e(1) HFAS \)

(3.7.2.12) \[ P(2) = e(2) HF = e(1) HFAS.HF \]

(3.7.2.13) also, \( e(3) = P(2) AS = e(2) (HFAS)^2 \)

(3.7.2.14) then \( P(3) = e(3) HF = e(1) (HFAS)^2 HF \)

(3.7.2.15) and \( e(4) = P(3) AS = e(1) (HFAS)^3 \)

Thus, a regional successive iterations will yield the additional zone-wise employment and population in the \( x \)th iteration of
In regional transport planning, therefore, total demand for services in terms of employment and population vectors are given by:

\[(3.7.2.18)\] \[e = e(1) + e(2) + \ldots + e(z)\]

\[= e \{I + HFAS + (HFAS)^2 + \ldots + (HFAS)^Z\} + \ldots\]

In Garin [37], it has been shown that under certain conditions on the product Matrix $HFAS$ in the above matrix relations 3.7.2.18, and 3.7.2.19 will converge to the regional inverse of matrix $(I-HFAS)$ which will yield the following expressions

\[(3.7.2.20)\] \[e = e^b (I-HFAS)^{-1}\]
\[(3.7.2.21)\] \[p = e^b (I-HFAS)^{-1} \ast HF\]

Where, $I$ represents the zone-wise identity matrix in the study region.

In the present case, therefore, the condition on the zone-wise product matrix $HFAS$ in this study is that $(HFAS)^{Z-1}$ must tend to zero which will occur if the sum of the elements in each regional of HFAS is less than unity. This same constraint is already presented in the earlier section 3.4.1 relation 3.4.1.2 and 3.4.1.4 that we need to achieve in our regional transport planning.

However, Garin [37] argues that if this were not the case then an infinite amount of regional population-serving employment would be generated by a finite amount of basic employment, which is a phenomenon not observed empirically in the study region.

Garin model, has it's own limitations. One of such limitations is that the population serving employment can only be of one broad type and be dependent upon one broad home to service travel-time function. This is in contrast to the original lowry model relation which allows for large number of population serving employment types whose spatial distributions are dependent upon different home to serve travel-time-factor functions in the study region.

In regional transport planning, therefore, relation 3.7.2.20 and 3.7.2.21 could imply regional
allocation and demand for transportation which is expected for our alternative policy analysis and efficiency. In actual practice, Bharuch region has a data matrix size of $17 \times 17 = 289$ zonal cells corresponding to each landuse variable such as population, employment, basic employment and retail employment and distance matrix. These land-use variables could be specified exogenously to the model zone-wise in Bharuch region and then population serving-employment and demand for transportation are internally calculated for our alternative plans in regional efficiency and development. Empirically, the above model was tested for Bharuch region in Chapter VI. In section 7.3.0 of Chapter VII of this study, Lowry-Garin solution calibration procedures have been simplified, workable and easily understood for the present research to use.