

Estimation of O-D Trip Tables using Link volumes

A Project Report

Submitted in partial fulfillment of the requirements for the award of the degree
of

Bachelor of Technology

by

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CERTIFICATE

This is to certify that the thesis entitled **Estimation of O-D Trip Tables using Link Volumes** submitted by **Mr. Naveen Eluru** to the Indian Institute of Technology, Madras for the award of the degree of Bachelor of Technology is a bonafide record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Abstract

Road transportation plays a very significant role in the development of a nation. In a developing country like India it is even more important. The demographic characteristics of Indian population have been undergoing significant changes in the last two decades. This resulted in phenomenal growth of motor vehicles. There is great need for adopting a systematic and scientific method for planning and designing facilities for road transportation. Origin-Destination (O-D) table plays an essential role in urban planning and traffic operations. Demand and supply information in transportation planning is usually described by an O-D trip table. Since the 1970's, some cheaper and quick response theoretical methods have been proposed for estimation of O-D tables. One such model is the Linear Programming Model proposed by Sherali et al (1994). The model recognizes that due to incomplete information or due to inherent inconsistencies in the link traffic data there might not exist a trip table that can exactly duplicate the link flows. Accordingly, attempts are made to incorporate these aspects into the formulation through suitable artificial variables and objective penalties. Variations in these penalties can be used to reflect biases in selecting from alternative solutions. The present study focuses on this issue of sensitivity of the solution to the penalty component corresponding to target trip tables. The work is carried out on two sample networks and a real network. This study clearly illustrates that as the penalty component corresponding to target table increases the solution tends to move closer to the actual target table. This is established through the computed measures of closeness.

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Chapter 1

Introduction

1.1 Road Transportation

Roads have in all times been among the most influential agencies of society, and the makers of them, by enabling men readily to communicate with each other. They have been regarded as among the most effective pioneers of civilization. Roads are the pathways of industry. Wherever a line of communication between men is formed, it renders commerce practicable; and, wherever commerce penetrates, it creates a civilization and leaves a history.

Roads place the city and the town in connection, open up markets for field produce, and provide outlets for manufactures. They enable the natural resources of a country to be developed, facilitate traveling. They tend to bind together society and bring out fully the healthy spirit of industry.

The road is so necessary an instrument of social well being, that in every country it is one of the first things thought of. The country can only be effectually "opened up," by roads and until these are made, it is virtually closed.

Road transport is a vital infrastructure for economic and social development of a country. Among various modes of transport, road transport has come to occupy a dominant position in the transportation system, because of its feasibility, door-to-door services, reliability, speed and accessibility. In a predominantly developing country like India, roads play a very important role in development.

The liberalization process set in motion in the last decade has boosted the Indian economy and is still expected to grow at an increased pace in coming years.

This growth has resulted in an exponential rise in vehicular population. Because of this road transport has assumed greater importance. There is a need for adopting systematic and scientific methods for planning and designing facilities for this mode of transport. Origin-Destination trip table is an essential component of this systematic and scientific method of planning.

1.2 Origin-Destination Trip Tables

Demand and supply information in transportation planning is usually described by a trip distribution table (in short trip table). This table estimates the trips between zones of an urban area, between major activity centers and zones or between entrances and exits of National Highways. It forms the basic element of short-range and long-range transportation. There are two types of trip tables: P-A (Production-Attraction) trip tables and O-D (Origin-Destination) trip tables. Mathematically these two tables differ mainly in that a P-A trip table has no directional meaning and its cell elements represent trip interchanges, whereas an O-D trip table has directional meaning and its cell elements represent trip flows. In practice, a P-A trip table automatically satisfies flow conservation and can easily be transformed into an O-D trip table. Origin -Destination trip table is a two dimensional matrix in which the rows and columns represent origin and destinations respectively, and its cell values indicate the number of trips made from the origin to the destination in a given period of time. Origin-destination (O-D) trip tables play a very important role in transportation planning and operations. Knowledge of motorists Origin Destination (OD) travel information is necessary for a wide range of transportation planning activities. The trip table plays an essential role in urban planning and traffic operations. The information contained in the table is often used to predict traffic flows on various routes and links of an urban network, which in turn plays an important role in designing new roads and for improving existing ones, in order to carry the expected traffic. Various transportation system management actions also rely on such traffic volume information. It enables us to determine the amount of by-passable traffic that enters a town and thus establish the need for a by-pass. They are also useful in assessing the adequacy of parking facilities and to plan for future.

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1.2.1 Methods for estimating O-D matrices

Trip tables have historically been established through home interviews surveys, road-side interviews, license plate surveys, etc. These survey techniques are expensive and time consuming. Also if there is a rapid change in land-use development, the trip tables soon become obsolete and outdated. Moreover, planning agencies of small urban areas are often unable to conduct such surveys due to budgetary limitations. However, these agencies do require trip table information for many planning and management purposes. The methods used to estimate O-D matrices vary depending on their uses: static estimation methods for long-term planning and design, and dynamic estimation methods for on-line traffic control.

Static estimation methods of O-D matrices use accumulated traffic counts to set up a highly underdetermined set of equations for the unknown O-D flows. One important issue in static estimation methods is how to deal with the problem of insufficient information in estimation procedures. Traditionally, static estimation methods were based on the gravity model which reduced estimation problems of O-D matrices to calibration problems with small number of unknown parameters. Then the gravity model was extended to entropy-maximizing technique. The problem of insufficient information for determination of O-D matrices was circumvented by maximizing an objective function, entropy. Another type of

static estimation methods developed in recent decades is to include additional observation information (traffic counts, parking survey, etc.) and then combine it with priori knowledge of O-D matrices. The present study focuses on one such model proposed by Sherali et al. (1994)[\[1\]](#). It is a Linear Programming model that employs non proportional assignment assumption and finds an equilibrium solution that reproduces the observed link flows whenever such a solution exists. The present study conducts sensitivity analysis of parameters of this LP (TT) model. The remaining part of the report is organised as follows

Chapter 2 gives a brief description on the earlier work done in this area.

Chapter 3 briefly describes the main objectives of this study.

Chapter 4 describes the Linear Programming model (LP (TT)) model proposed by Sherali et al (1994).

Chapter 5 provides the details of the networks used in this study.

Chapter 6 focusses on the methodology employed in this study.

Chapter 7 presents the Results and Analysis of the work for the networks.

Chapter 8 gives the conclusions based on this study, outlines its limitations and further scope for work.

Chapter 2

Literature Review

This chapter presents a survey of theories, algorithms, techniques and methods used for estimating OD matrices. A variety of models for establishing OD trip tables based on traffic volume are addressed. The Linear Programming (LP) model, on which this study is based, is then studied in some detail. A short summary is provided in the last section that evaluates the different models. Typically, transportation models can be divided into dynamic and static steady-state representations. The results on static OD trip tables are only considered in this survey, since this is the emphasis of the present study.

2.1 Conventional Analysis and Quick Response Models

Before the 1970s, OD trip tables were obtained via statistical surveys, such as home interviews, license plate surveys and roadside surveys. The methods that use such survey data to determine real trip distributions are now called conventional analysis. Prior to World War II, information on the distribution of urban traffic was obtained using roadside interviews. Since surveys were conducted through sampling, it is impossible to determine the real trip information. Furthermore, with the evolution of society and with rapid changes in transportation demands, these surveys became harder to perform, and expensive with respect to time, manpower, money and effort. Another drawback of conventional analysis is that, as the land-use changes, these data soon become outdated. In addition,

in most cases, an assignment of this matrix to the network cannot reproduce observed flows. Three main types of models are considered in the conventional analysis: Fratar models, opportunity models and gravity models. These are evaluated by Easa (1993a)[?], and a detailed illustration of characteristics, advantages and limitations of these models are given. The emphasis on transportation system management in the early 1970s increased the need for studying small urban areas in detail. Some cheaper and quicker response theory and methods for synthesizing trip tables from more conveniently available information have been developed since then. According to the purpose of these models, they can be classified into the following subgroups: Traffic Count Based Models, Self Calibrating Gravity Models, Partial Matrix Techniques, models using GIS data, Heuristic Methods and Facility Forecasting Techniques.

2.2 Traffic Count Based Models

Among all types of easily derived data, traffic counts (link volumes in a network) perhaps contain the most important information about OD distributions. A variety of analytic models have been developed to establish OD trip tables based on traffic counts along with other information. Origin-destination (O-D) trip matrix estimation from traffic count surveys is regarded as the most economical and effective methodology in road network analysis for transport planning and traffic management. The present study focuses on this estimation of O-D trip tables using Traffic Count Based Models.

Based on the theory (or principle, or hypothesis) used, these models may be divided into the following types (Easa 1993b[?], CTR 1995[?]).

2.2.1 Gravity Based Models

These models are sometimes called Parameter Calibration models, and represent the original idea of establishing trip distributions. In these models, the entries of the OD matrix are assumed to be a function of the traffic count and other parameters. Regression techniques and the flow conservation law are applied to calibrate the parameters such that the differences between observed volumes

and established volumes are minimized. The models are divided into linear and nonlinear regression models.

2.2.2 Entropy Models

Minimum Information and Maximum Entropy models are included in this group and can be converted to a type of gravity models. In these models, the probability of a particular trip distribution occurring is assumed to be proportional to the number of the states (entropy or disorder) of the system. The derived OD table is purported to be the most likely one that is consistent with information such as length and free speed of the links contained in the link flows. The pioneers of these models, are Willumsen (1978)[3] and Van Zuylen (1978)[2]. Many improvements and combinations with other theory have been conducted since then, and a great deal of testing on these models has been performed. These results have been summarized in the review papers of Easa (1993b) and CTR (1995).

2.2.3 Equilibrium Models

These models are based on the principle of user optimization of traffic flow, called the “Equilibrium Principle” or “Wardrop’s Principle” (Wardrop 1952)[?]. The User Equilibrium Principle or user optimal assignment principle was originally used to guide the traffic flow assignment process. It requires that all routes having positive flows between any OD pair should have equal traffic cost, and this cost must not exceed the traffic cost on any other unused route between this OD pair. Mathematically, estimating the OD trip tables from link volumes can be thought of as an inverse problem of transportation assignment. Therefore, the equilibrium based OD matrix estimation problem may be described as determining an OD matrix such that, when this matrix is user-optimally assigned to the network, it reproduces the observed OD travel times. Since the correspondence between equilibrium link flow patterns and equilibrium O-D travel times for the standard equilibrium problem is “one-to-one” (Yang et al. 1994)[?], it consequently reproduces the observed link flows.

2.2.4 Statistical Models

These models produce future estimates based on prior information, employing techniques such as in Maher (1983)[?]. These models take into account inaccuracies on the observed OD flows, row and column sums and traffic counts. This group includes the constrained generalized least squares (CGLS) model (McNeil 1983)[?], and constrained maximum likelihood (CML) models (Geva 1983[?], Spiess 1987[?], Walting and Maher 1988[?], Walting and Grey 1991)[?]. Another model, called MEUSE, standing for Matrix Estimation Using Structure Explicitly (Bierlaire and Toint 1995)[?], which uses both historic data and parking data as input, can be partially included in this subgroup. Statistical models are not as popular in practice as compared with equilibrium and entropy models.

2.2.5 Neural Network Models

Muller and Reinhardt (1990)[?] introduced the neural network approach to determine O D trip table from traffic counts. In a loose sense, this approach is based on the concepts derived from research into the nature of the brain. The procedure in this approach includes “learning” and “optimization” components. The model may be mathematically described as a directed graph with three characteristics.

1. A state of variable associated with each node
2. A weight assigned to each link and
3. A transfer function defined for determining the state of each node as a function of its bias and weights of its incoming links.

Yang, Akiyama and Sasaki (1992)[?] adopted a feed forward neural network for synthesizing OD flow for a four-way intersection and a short freeway segment. Chin, Hwang and Pei (1994)[?] described a neural network model for generating OD information from flow volumes. There still exists a need for further testing these models.

2.2.6 Fuzzy Weight Models

Instead of the “all or nothing” assumption made in most models, Fuzzy Weight approaches apply some kind of “fuzziness” to the link data (Xu and Chan 1992ab)[?]. Fuzziness indicates probability, but is quite different in nature. The model is relatively new, and additional case studies and experimentation are recommended for evaluation.

The statistical estimation methods, models based on maximum entropy and network based techniques are grouped under matrix estimation techniques that rely only on link traffic counts and prior information in the form of a trip table and are easy to implement. The entropy model and the network equilibrium based techniques are based on mathematical programming and are more relevant to this study. The models proposed are based on proportional assignment assumption in which some exogenously determined coefficients specify the proportion of trips between each O-D pair that use a particular link in the network.

In contrast with proportional assignment assumption, whenever network congestion effects are prominent, a non-proportional-assignment approach based on traffic equilibrium principles becomes more appropriate. Nguyen (1977; 1984)[?] developed such an approach via two models for deriving O-D trip tables from traffic counts, both of which attempt to regenerate observed costs rather than observed flows. Turnquist and Gur (1979)[?] presented an iterative, heuristic solution technique for one such model based on Frank-Wolfe algorithm, and Gur et al. (1980)[?] imbed a similar approach in their well known LINKOD system. The LINKOD model has been extensively tested and validated by Han et al. (1981)[?], Han and Sullivan (1983)[?] and Dowling and May (1984)[?]. For all these techniques, there exist several O-D trip tables that reproduce the observed traffic volumes and so target trip tables are usually specified to guide the solution toward more likely flow patterns. Hence, a distribution assumption is utilized to extract the most likely trip table. Fisk (1989)[?] has shown that the network equilibrium approach, the maximum entropy approach and the combined distribution-assignment-formulation can be expected to produce the same results under congested network conditions, when observed link volumes correspond to

an equilibrium flow pattern. Cascetta and Nguyen (1988)[?] have also presented a unified framework for estimating or updating O-D matrices from traffic counts.

2.3 LP (TT) model

In contrast with all such nonlinear network equilibrium approaches the LP (TT) model proposed by Sherali et al. (1994)[1] employs a non proportional-assignment assumption and is a linear programming model. The LP (TT) model obtains a user equilibrium solution that reproduces the observed link flows if such a solution exists. The model recognizes that due to incomplete information or due to inherent inconsistencies in the link traffic data there might not exist a trip table that can exactly duplicate the link flows. Accordingly, attempts are made to incorporate these aspects into the formulation. Linear Programming Model as described by Sherali et al. (1994)[1] is discussed in greater detail in the following chapters.

Chapter 3

Problem Statement And Study Objectives

Estimation of O-D trip tables through convention methods is costly, time consuming and at the same time very difficult to obtain. In addition, most of these methods are conducted through sampling, and have associated sampling errors due to reliance on only a small sample of trip makers. Even if all the daily trips are recorded, the O-d table may not be stable over time due to daily variations. Moreover a slight change in the land use can result in the data becoming obsolete. This will result in resurveying, leading to further expenditures and efforts. Due to this many theoretical methods, which are fast, economical and are more responsive to the changes in land use have been proposed since the 70's.

In these mathematical models, an urban transportation system is represented by a network, which is composed of nodes and directed links, where each link is associated with a travel cost function. The travel impedance, or level of service, associated with the links representing an urban network can include many components, reflecting travel time, safety, cost of travel, stability of flow and others. The primary component of this impedance is travel time.

One among such elegant models is the Linear Programming Model as described by Sherali et al (1994). The primary decision variables in the network equilibrium formulation of LP (TT) represent the path flows for motorists traveling between OD pairs. The cost of each path flow considered by the model is a function of the sum of travel costs on the links used by this path. The model recognizes that due to incomplete information, although the individual user is driven

by the choice of a least impedance path, the actual flow may not exactly conform to a user equilibrium solution. Moreover, due to inherent inconsistencies in the link traffic data, there might not exist a trip table that can exactly duplicate the link flows. Accordingly, these features are accommodated into the model through suitable artificial variables and objective penalties. Variations in these penalties can also be used to reflect biases in selecting the amongst alternative viable O-D trip tables. The present study focuses on the influence of these penalties on the O-D matrices obtained. The main aims of this study are

1. Effect of the penalty variable corresponding to deviations from targeted trip tables, on the O-D matrix.
2. Assessing the impact of missing data (i.e. link volumes for certain links are missing) on the O-D matrix.
3. Evaluating the measures of closeness for all the solution obtained above.

For this purpose the present study focuses on three networks. The networks are discussed in detail in the chapter Case Studies.

Chapter 4

Linear Programming Model

The present study focuses on the Linear Programming Model proposed by Sherali et al(1994). The present chapter formulates the model and establishes its salient properties.

4.1 Formulation of LP (TT) Model

Given an urban road network for a particular region, let $G(N, A)$ represent the underlying digraph. Here, N is the set of nodes representing either traffic intersection points where flow is conserved or zones where trips are generated and/or where trips terminate, and A denotes the set of corresponding directed links or arcs representing the roadways existing between designated pairs of nodes. Let OD denote the set of O-D pairs that comprise the trip table to be estimated, where O is the set of possible source or origin nodes and D is the set of potential sink or destination nodes. Note that a given zone is typically both an origin as well as a destination node.

4.1.1 Preliminary Model

For introducing these concepts consider the preliminary problem of estimating trip table interchanges T_{ij} between each O-D pair $(i,j) \in OD$ comprising this table, given observed link flows $\bar{f}_a$ on each link $a \in A$. Note that an inherent assumption here is the availability of all link link flows. After this preliminary

conceptual analysis, we address other practical issues such as handling inconsistencies in flow data and accomodating prior trip table information for guiding the solution in case there exist alternative trip tables conforming with user equilibrium solutions that tend to reproduce the given link flows.

To formulate this preliminary model, let us consider the implicit enumeration of all possible paths $p_{ij}^k, k = 1, \dots, n_{ij}$, between each O-D pair $(i, j) \in OD$, where p_{ij}^k is a vector that has one component for each link $a \in A$, this component being unity if the corresponding link belongs to the particular path, and being zero otherwise. Denote x_{ij}^k as the flow on path p_{ij}^k for each $k = 1, \dots, n_{ij}, (i, j) \in OD$ and let x denote the vector of components x_{ij}^k . Then to determine a flow x that reproduces the vector $\bar{f}$ of the observed link counts ($\bar{f}_a, a \in A$), we need to find a solution to the system:

$$\sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} p_{ij}^k x_{ij}^k = \bar{f}, x \geq 0. \quad (4.1)$$

Note that the O-D trip table entries T_{ij} are related to the path-decomposed flows x_{ij}^k via the relationship

$$T_{ij} = \sum_{k=1}^{n_{ij}} x_{ij}^k \quad (4.2)$$

for each $(i, j) \in OD$.

Based on the observed flows $\bar{f}_a, a \in A$ a corresponding time -based link impedance $\bar{t}_a \equiv t_a(\bar{f}_a)$ is calculated.

It can be assumed without loss of generality that all considered links $a \in A$ carry positive flows and because multiplying $\bar{t}_a$ for all $a \in A$ by a constant leaves the problem invariant, it is assumed that $\bar{t}_a \geq 1$ and is integral for each $a \in A$. Let us denote $\bar{t}$ as the vector of components $\bar{t}_a, a \in A$.

Now, if the observed flow pattern indeed represents a network user equilibrium solution corresponding to some interchange of traffic between the designated O-D pairs, then by Wardrops (first) principle (1952), all the routes between any O-D pair that have positive flows should have equal travel costs, and this cost must not exceed the travel cost on any other unused route between this O-D pair. Notationally, let $t_{ij}^k \equiv \bar{t} \cdot p_{ij}^k$ denote the time impedance or cost on route k

between O-D pair (i, j) for each $k = 1, \dots, n_{ij}$, $(i, j) \in OD$ and let $t_{ij}^* = \text{minimum } \{t_{ij}^k, k = 1, \dots, n_{ij}\}$. Furthermore, let us define

$$K_{ij} = \{k \in \{1, \dots, n_{ij}\} : t_{ij}^k = t_{ij}^*\}, \text{ and let } \overline{K}_{ij} = \{1, \dots, n_{ij}\} - K_{ij}.$$

Then according to Wardrop's principle, if an equilibrium solution exists that reproduces the observed flows, we should be able to find a solution to equation 4.2 satisfying the condition that $x_{ij}^k > 0$ only if $k \in K_{ij}$, for each $(i, j) \in OD$. With this motivation, consider the following preliminary linear programming model.

Minimize

$$\sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} \widehat{t}_{ij}^k x_{ij}^k \quad (4.3)$$

subject to

$$\sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} p_{ij}^k x_{ij}^k = \overline{f}, x \geq 0. \quad (4.4)$$

where for each $(i, j) \in OD$,

$$\widehat{t}_{ij}^k = \begin{cases} t_{ij}^k & \text{if } k \in K_{ij} \\ M_1 t_{ij}^k & \text{if } k \in \overline{K}_{ij} \end{cases}$$

and where $M_1 > 1$ is some scalar parameter. The principal feature of this linear program is embodied by the following result.

Let $\overline{t}_{total} \equiv \sum_{a \in A} \overline{t}_a \overline{f}_a$ represent the total observed system cost. Then, the optimal objective value of the linear program is at least $\overline{t}_{total}$. Moreover, a solution x^* represents a user equilibrium solution that reproduces the observed flow vector $\overline{f}$ if and only if x^* solves the linear program with optimal objective value $\overline{t}_{total}$.

4.1.2 Modifications to accomodate inconsistent flow data

Until now, we have assumed that the observed link flow data $\overline{f}$ is consistent with respect to equation 4.2. However, due to errors in measurement and due to approximations in the network representation, there might be internal inconsistencies that might render equation 4.2, and therefore the preliminary model infeasible. Although some preprocessing may be done to make equation 4.2 feasible as in Van Zuylen and Branston (1982) for example, it is more appealing to let the model and the optimization process itself accomodate this feature. We therefore

introduce two vectors of non-negative artificial constraints, to permit positive or negative deviations in the link flow. Accordingly we penalize the objective function with the term $Me \cdot (y^+ + y^-)$, where e is a vector of $|A|$ ones, and M is a suitable penalty parameter whose value is addressed later. This gives the next Linear Programming Model (LP) as follows:

$$\text{LP: Minimize } \sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} \bar{t}_{ij}^k x_{ij}^k + Me \cdot (y^+ + y^-) \quad (4.5)$$

$$\text{subject to } \sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} p_{ij}^k x_{ij}^k + y^+ - y^- = \bar{f} \quad (4.6)$$

$$x \geq 0, y^+ \geq 0, y^- \geq 0 \quad (4.7)$$

From now on y denotes the joint vector of y^+ and y^- .

Assume that the linear program LP has a feasible solution (x, y) in which $y \equiv 0$, and consider the following three alternative values for M , where $\bar{t}_* \equiv \text{maximum}\{t_a : a \in A\}$:

$$M \geq 1 + \bar{t}_* + (|A|)\bar{t}_{total} \quad (4.8)$$

$$M \geq 1 + \bar{t}_* + t_{total} \quad (4.9)$$

$$M \geq 1 + \bar{t}_* \quad (4.10)$$

In this present study M is chosen based on the equation 4.9. In such case we have $e \cdot y^{+*} + e \cdot y^{-*} < 1$ in any optimal solution (x^*, y^*) to LP.

4.1.3 Modifications to accomodate prior trip tables

The model formulated thus far is mainly concerned with determining an O-D trip table that confirms to a user equilibrium solution that reproduces the link flows to as close an extent as possible. However, if there exist alternative optimal O-D trip tables for the linear programming model LP, we have not as yet specified any mechanism for discriminating among these tables. Moreover, by the nature of extreme point optimal solutions to LP, no more than $|A|$ O-D paths that carry positive flows are identified by the foregoing model. To rectify these shortcomings, while preserving the advantages accompanying a linear programming approach, the LP model is extended as follows.

Suppose that a partial prior (target) trip table (TT) is specified, having associated O-D flows $Q_{ij} > 0$ for $(i, j) \in \overline{OD} \subseteq OD$, where $\overline{OD}$ might represent some significant or key O-D pairs. Consider the following corresponding modification LP(TT) of LP given earlier.

$$\text{LP(TT): Minimize } \sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} \hat{t}_{ij}^k x_{ij}^k + M_e \cdot (y^+ + y^-) + M_\sigma \cdot \sum_{(i,j) \in \overline{OD}} (Y_{ij}^+ + Y_{ij}^-) \quad (4.11)$$

$$\text{subject to } \sum_{(i,j) \in OD} \sum_{k=1}^{n_{ij}} p_{ij}^k x_{ij}^k + y^+ - y^- = \bar{f} \quad (4.12)$$

$$\sum_{k=1}^{n_{ij}} x_{ij}^k + Y_{ij}^+ - Y_{ij}^- = Q_{ij} \forall (i, j) \in \overline{OD} \quad (4.13)$$

$$x \geq 0, y^+ \geq 0, y^- \geq 0, Y^+ \geq 0, Y^- \geq 0 \quad (4.14)$$

Here, for each $(i, j) \in \overline{OD}$, the deviation of the O-D trip interchange $T_{ij} \equiv \sum_{k=1}^{n_{ij}} x_{ij}^k$ from the target trip table value Q_{ij} is measured by the difference of two non-negative ("artificial") variables Y_{ij}^+ and Y_{ij}^- . The effective absolute value $(Y_{ij}^+ + Y_{ij}^-)$ of this deviation is penalized in the objective function via a penalty parameter $M_\sigma \geq \theta$. The value chosen for M_σ must naturally tradeoff the penalty imposed for deviations from the targeted trip table values with the remainder of the objective function. Because the parameter M penalizes similar deviations of the accounted link flows from the observed ones, we use $M_\sigma = \sigma M$, where $0 \leq \sigma \leq 1$. Hence we can select a value of $\sigma \in [0, 1]$ to reflect the relative degree of importance in minimizing the trip table deviations versus the link flow deviations, ranging from unimportant ($\sigma = 0$) to equally important ($\sigma = 1$). Note that as for link flows deviations we can adopt a separate penalty parameter for each O-D pair $(i, j) \in \overline{OD}$ to reflect any relative degrees of belief or biases toward reproducing different elements of the given prior trip table. Furthermore, note that the new constraints inject additional basic variables at an extremepoint optimum, thereby possibly admitting additional nonzero O-D flows. This overcomes the underspecification problem inherent to techniques that estimate O-D trip tables from link volumes.

4.2 Summary

The intent of the LP (TT) model is to determine pathflows that will approach user-equilibrium values, replicate observed flows on links, and concur with the specified prior trip table values to as much of an extent as possible. Note that an explicit statement of the linear programming model LP (TT) requires the enumeration of all possible paths between each O-D pair $(i, j) \in OD$. Although this is readily accomplished in theory, it is computationally prohibitive except for small sized networks. As an alternative, one can consider the generation of only "efficient" paths. Whereas such an approximation might be acceptable in certain applications, some caution must be exercised. To overcome such difficulties an algorithm in which the columns of LP are selectively generated only as and when needed within framework of the revised simplex method to optimally solve the problem can be used. This model is used as the basis in this study.

Chapter 5

Case Studies

5.1 Introduction

The study is applied on three road networks. Two of the sample networks used for evaluation in this work are hypothetical networks. The third is a real network. A detailed description of the network structures, the link characteristics of the sample and the real networks are given in this chapter.

5.2 Sample Network 1

The sample network 1 is a hypothetical road network. A detailed description of the network and its link characteristics are given in the following sections.

5.2.1 Network description

The sample network 1 is shown in Figure 5.1. It consists of 4 zones (1,2,3 and 4) and 6 intersection nodes (5 through 10). The network consists 12 directed links out of which one is a two-way link. The input data of the network used in the program has been shown in Table 5.1

5.3 Sample Network 2

This is also a hypothetical road network for which, user equilibrium assigned volumes are taken as observed volumes. A detailed description of the network

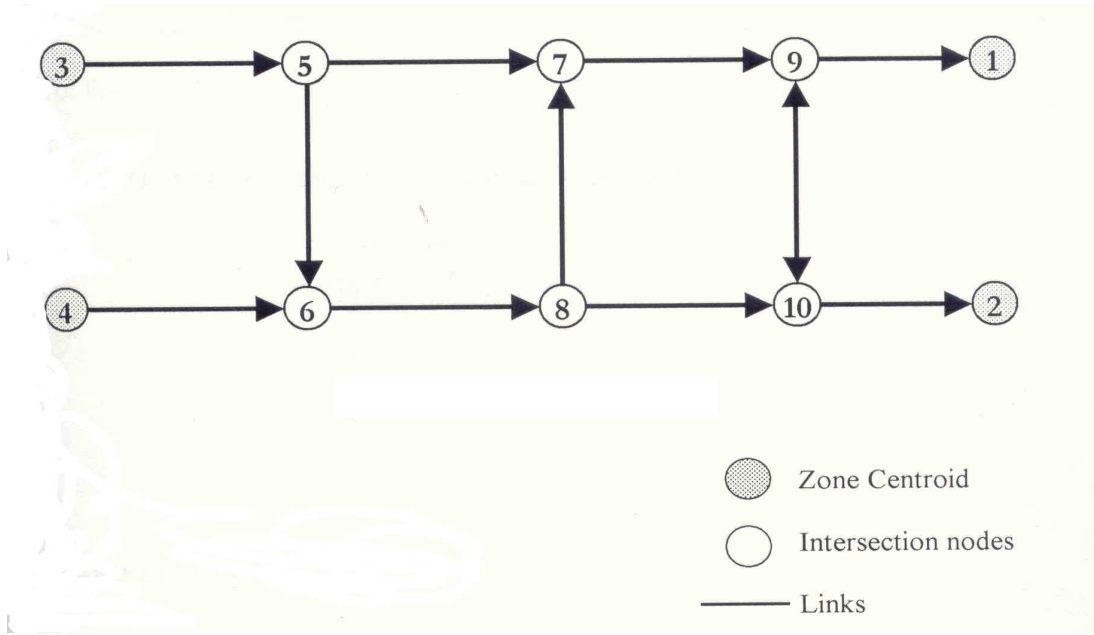


Figure 5.1: SampleNetwork 1

and its link characteristics are given in the following sections.

5.3.1 Network description

This network shown in Figure 5.2 consists of 6 zones (1 through 6). It contains 6 other intersection nodes (7 through 12). The network consists 18 directed links. The network data used as input in traffic assignment have been given in Table 5.2

5.4 Egmore Network

Egmore network, a sub area of Chennai City, is the real network considered for the study. The relevant data fore this network was obtained from a study by Kirloskar Consultants Limited (1989). This network was extracted from the Chennai City road network.

The network was chosen as the case study for this work, because of the availability of the necessary data. These include link lengths, capacities and peak

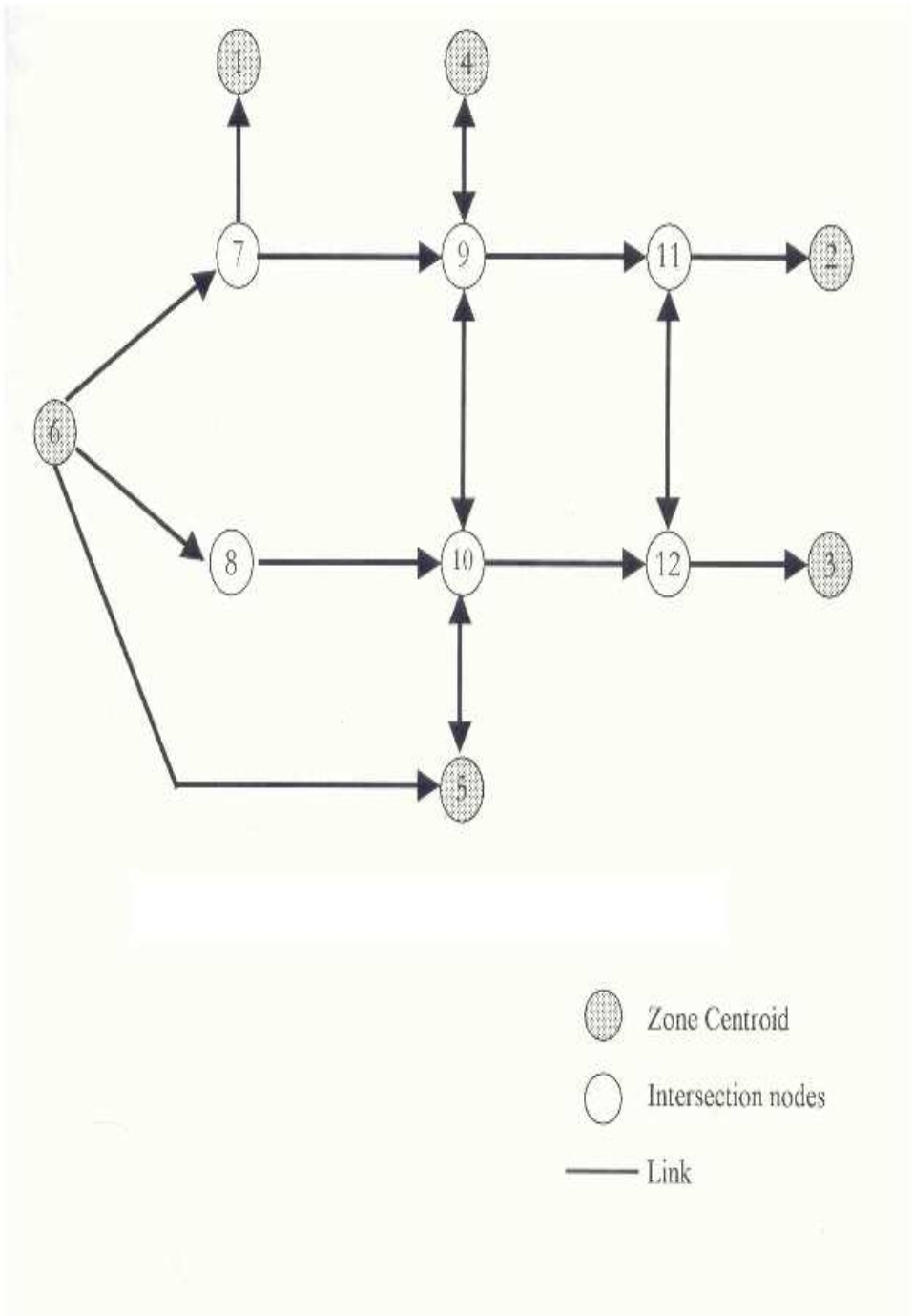


Figure 5.2: Sample Network 2

Table 5.1: Input Data for Sample Network 1

Link No	From Node	To Node	Free Flow impedance (min)	Observed Volume PCUshr
1	3	5	5	950
2	4	6	4	950
3	5	6	6	202
4	5	7	8	748
5	6	8	7	1152
6	7	9	8	856
7	8	7	6	108
8	8	10	8	1044
9	9	1	4	1100
10	9	10	6	148
11	10	2	5	800
12	10	9	6	392

hour trip table (PCUs/hr). However, data on observed volumes was not available for this network.

5.4.1 Network Description (Kirloskar Consultants Ltd., 1989)

The Egmore network is a busy commercial and residential area and it lies at the center of the Chennai Metropolitan area. The entire network area is divided into four activity zones. It consists of 92 one-way links (excluding centroid connectors) and 26 intersection nodes. The entire Chennai city road network is divided into 80 activity zones. Since many of these zones do not affect the Egmore area, only a limited number of zones in the immediate vicinity and certain important zones are considered. Fifteen zones in the immediate vicinity of the Egmore network are identified. Out of these 15 zones, 11 are external to Egmore network while the other four zones are internal zones. In the case of internal zones, zone connectors are used to provide physical connections between internal zones and the intersection nodes. In the case of the eleven zones external to the Egmore area, the centroids are moved close to the area along their respective corridors in order to give prominence to the Egmore network. For the convenience of processing

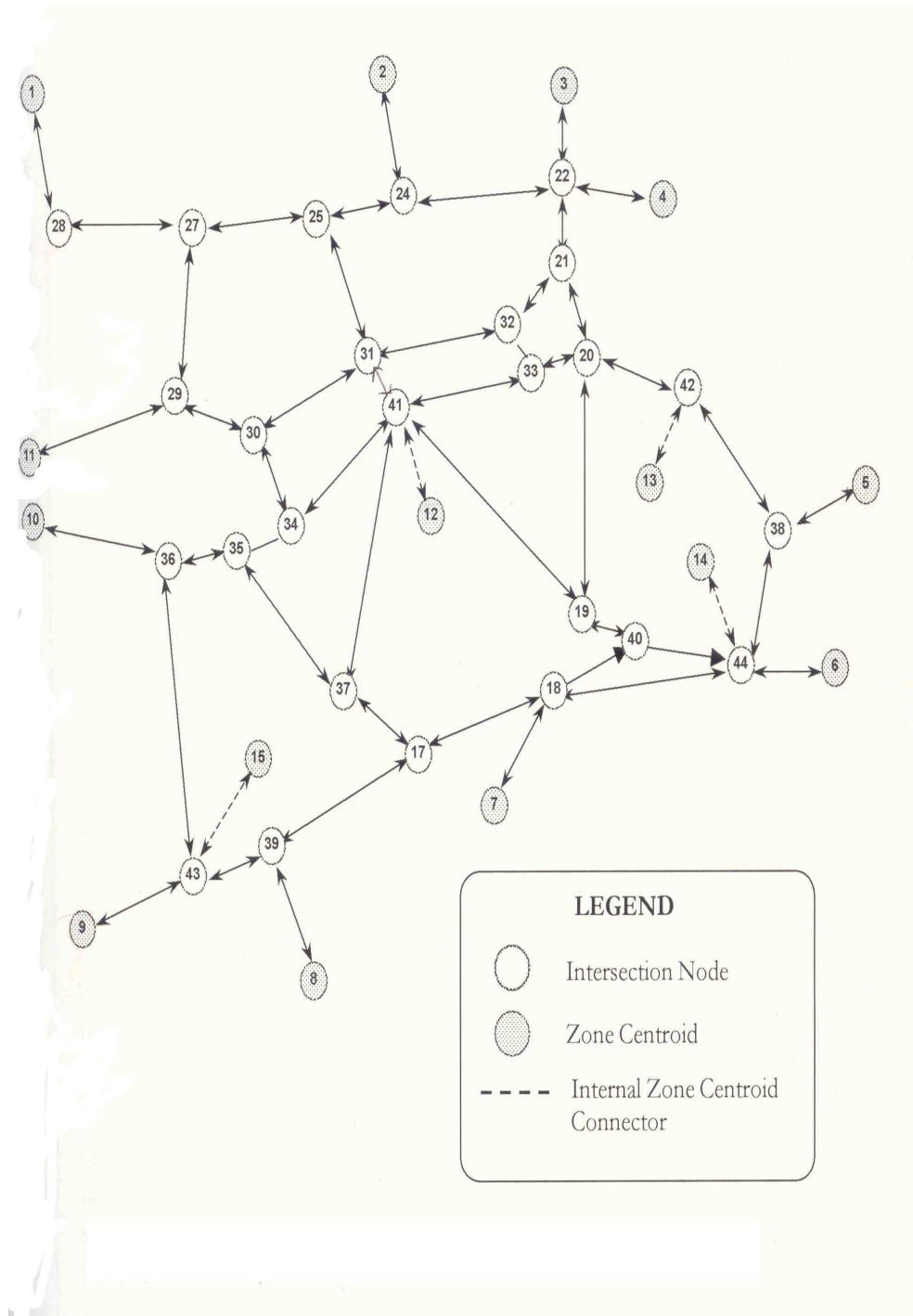


Figure 5.3: Egmore Network

Table 5.2: Input Data for Sample Network 2

LinkNo	From Node	To Node	Free Flow impedance (min)	Observed volume PCUs/hr
1	4	9	10	2400
2	5	10	10	2000
3	6	5	40	100
4	6	7	10	5000
5	6	8	10	500
6	7	1	10	500
7	7	9	20	4500
8	8	10	20	500
9	9	4	10	2000
10	9	10	10	1500
11	9	11	20	4900
12	10	5	10	1600
13	10	9	10	1500
14	10	12	20	900
15	11	2	20	4800
16	11	12	10	300
17	12	3	20	1000
18	12	11	10	200

data the network data, the external zone centroids are given the lowest numbered nodes, i.e., from 1 through 11 and the nodes numbered 12 through 15 are the internal zone centroids. This network is shown in Figure 5.3

In the data provided by the Kirloskar Consultants in Table 5.3, there was no traffic volume count for the links. The user equilibrium flows are assumed to be existing flows. These flows were obtained by Thung (2000). The trips between the zone pairs during the peak hour, expressed as vehicular trips per hour (PCU/hr) have been used in this study. The trip interchanges as used in the study by Kirloskar Consultants Limited (1989) were obtained. The trip interchanges between zone pairs, which do not pass through the networks, are not considered and dummied. The intra-zonal trips that are the trips from an origin zone to itself are not considered in this study.

5.4 Egmore Network

Table 5.3: Input Data for Egmore Network

Link No	From Node	To Node	Free Flow impedance (min)	Observed volume PCUs/hr
1	1	28	36	390
2	28	1	36	352
3	2	24	45	627
4	24	2	46	705
5	3	22	17	123
6	22	3	17	218
7	4	22	30	1151
8	22	4	31	1267
9	5	38	26	70
10	38	5	26	60
11	6	44	23	357
12	44	6	23	442
13	7	18	57	248
14	18	7	58	330
15	8	39	44	355
16	39	8	43	292
17	9	43	41	416
18	43	9	41	434
19	10	36	85	577
20	36	10	85	587
21	11	29	60	134
22	29	11	60	116
23	12	41	25	1136
24	41	12	23	660
25	13	42	21	206
26	42	13	21	264
27	14	44	22	520
28	44	14	22	530
29	15	43	25	1133
30	43	15	25	1186
31	41	19	118	329
32	19	41	115	213
33	41	33	66	460
34	33	41	67	509
35	41	37	102	389

5.4 Egmore Network

36	37	41	95	101
37	41	34	58	760
38	34	41	57	691
39	41	31	25	678
40	31	41	25	626
41	42	38	59	131
42	38	42	61	237
43	42	20	50	220
44	20	42	49	172
45	44	38	58	223
46	38	44	56	128
47	44	18	42	867
48	18	44	40	580
49	43	39	20	911
50	39	43	20	904
51	43	36	124	638
52	36	43	128	716
53	17	18	79	937
54	18	17	68	585
55	17	39	87	834
56	39	17	90	904
57	17	37	36	220
58	37	17	39	502
59	18	40	20	557
60	19	40	9	478
61	40	19	9	557
62	19	20	107	344
63	20	19	98	149
64	20	33	11	532
65	33	20	10	413
66	20	21	38	847
67	21	20	36	723
68	21	32	24	153
69	32	21	24	232
70	21	22	26	1078
71	22	21	24	876
72	22	24	73	462
73	24	22	73	471

5.4 Egmore Network

74	24	25	26	503
75	25	24	26	590
76	25	31	47	463
77	31	25	48	540
78	25	27	37	313
79	27	25	37	323
80	27	29	67	90
81	29	27	67	62
82	27	28	32	352
83	28	27	32	390
84	29	30	21	201
85	30	29	21	155
86	30	34	31	110
87	34	30	31	98
88	30	31	57	91
89	31	30	56	57
90	31	32	61	185
91	32	31	61	176
92	32	33	19	22
93	33	32	20	91
94	34	35	20	870
95	35	34	20	789
96	35	37	65	113
97	37	35	65	120
98	35	36	22	942
99	36	35	20	854
100	40	44	24	478

Chapter 6

Methodology

The focus of the present study is on evaluating the influence of the $M\sigma$ parameter on the solution trip table and on replication of link volumes obtained through the LP (TT) model proposed by Sherali et al (1994). The study also focuses on the influence of missing links on the solution obtained. Measures of closeness are also calculated for all the solutions so as to evaluate them. Hypothetical as well as real networks are used for this purpose. A detailed description of these networks has already been provided in following chapters. The software package LINDO (Linear INteractive and Discrete Optimizer) has been used to solve the LP (TT) models formulated. The present chapter discusses in detail the LINDO software and the methodology employed in each network.

6.1 Linear INteractive Discrete Optimizer(LINDO)

LINDO is designed as a flexible, friendly, and powerful linear programming system. LINDO 5.3 is the version used in the present study. It is an interactive, linear, quadratic, and integer programming system useful to a wide range of users. The main purpose of LINDO is to allow a user to quickly input a linear program (LP formulation), solve it, assess the correctness or appropriateness of the formulation based on the solution and then quickly make minor modifications to the formulation and repeat the process. LINDO allows to "program" using the mathematical statements used to define the problem, making it an easy package to learn. LINDO is command-line driven. It has a very limited set of commands,

which makes it easier to manage, and a very good help system. LINDO can be used to solve interactive linear, quadratic, general integer and zero-one integer programming programs up to 500 rows and 1,000 columns to perform sensitivity analysis and parametric programming. LINDO can be run on a UNIX workstation or a Windows computer. It can be run interactively using redirection or as a detached process in background. LINDO has been used to solve problems occurring in areas of business, industry, research and government.

6.2 General Methodology of the study

In the present study the LP (TT) model was formulated based on the input data. For this purpose all the possible O-D pairs are determined. After this, all the paths between each O-D pair are obtained. The networks 1 and 2 being small the paths could be obtained manually. But for the Egmore network paths were differently which is described in detail later. Once these paths are obtained based on the data available the travel times of each of these paths is enumerated. For every O-D pair, set of paths whose travel time is the minimum is obtained. The travel times of all the paths that do not belong to this set are doubled (setting $M1 = 2$). Distinct variables are assigned to each of these paths. The calculation of M is also carried out based on the method recommended in Sherali et al (1994). Once this is done the formulated model is loaded into the LINDO for solving. The model is initially solved with the correct trip table information that is available in the data. It is used to obtain solutions for various Trip Table values. For every value of this target table a sensitivity analysis on parameter $M?$ is carried i.e. the value of $M?$ is varied from 0 to M . All the results obtained are tabulated. On the same model for one of these trip table values the effect of missing links (interior) is also carried out. This is carried out in the following steps

1. The effect of every individual link is obtained.
2. The links are chosen in pairs and results are obtained. These pairs are chosen such that they form consecutive links on a path.
3. For all the above solution the measures of closeness namely MAE, RMSE, ? are calculated as described in the previous chapters.

The methodology is described in the form of a flow chart in Figure 6.1 . Sample Formulation The following section in detail describes the formulation of the LP (TT) mode for the Sample Network 2. No. of Links = 18 Total No. of paths = 29 The variable $x_{i,j,k}$ represents the flow in i th path from node j to k $a_{i,j}$ represents vector of positive deviations on the link from node i to node j $b_{i,j}$ represents vector of negative deviations on the link from node i to node j $c_{i,j}$ represents vector of positive deviations from targeted trip tables $d_{i,j}$ represents vector of negative deviations from targeted trip tables The LP (TT) model is proposed as a minimization problem which minimizes the total travel time.

6.3 Sample calculations

1. *Travel times of an O-D pair* Consider O-D pair 6-2. The paths for this O-D pair are

- (a) 6-7-9-11-2 $x_{1_6_2}$ Travel time = 70
- (b) 6-8-10-12-11-2 $x_{2_6_2}$ Travel time = 80
- (c) 6-5-10-12-11-2 $x_{3_6_2}$ Travel time = 100
- (d) 6-8-10-9-11-2 $x_{4_6_2}$ Travel time = 80
- (e) 6-7-9-10-12-11-2 $x_{5_6_2}$ Travel time = 90
- (f) 6-5-10-9-11-2 $x_{6_6_2}$ Travel time = 100

Clearly the path $x_{1_6_2}$ has the minimum travel time. All the remaining travel times are scaled up by a factor M_1 chosen as 2 in this study. So for instance in the objective function the travel time component of $x_{6_6_2} = 200$.

2. *Calculation of M*

M in this study is taken as atleast $1 + t^* + t_{total}$

$$t_{total} = \sum t_{afa} = 10 \times 2400 + 10 \times 2000 + 40 \times 100 + 10 \times 5000 + 10 \times 500 + 10 \times 500 + 20 \times 4500 + 20 \times 500 + 10 \times 2000 + 10 \times 1500 + 20 \times 4900 + 10 \times 1600 + 10 \times 1500 + 20 \times 900 + 20 \times 4800 + 10 \times 300 + 20 \times 1000 + 10 \times 200$$

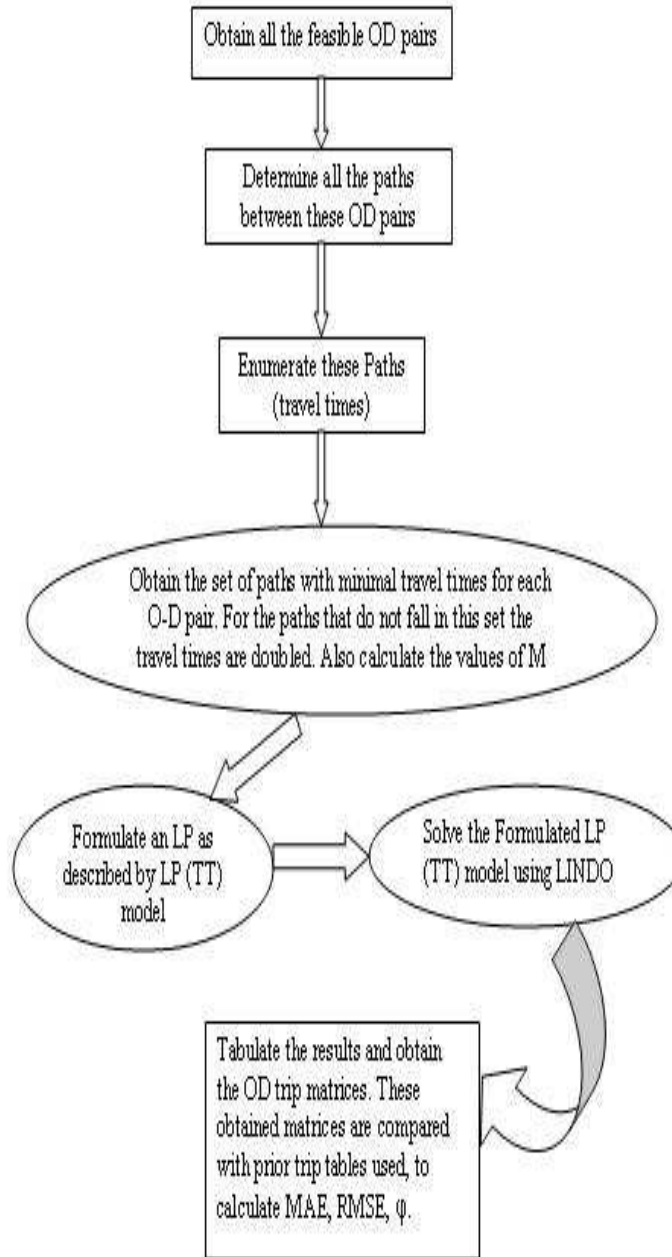


Figure 6.1: Methodology of the Study

$$= 5, 11,000.$$

$$M = 1 + 40 + 5, 11,000$$

$$= 5, 11, 041.$$

After obtaining all the values required for the formulation of the model, the LP (TT) model is formulated as follows:

1. Firstly the objective function is obtained.
2. Secondly the constraints are obtained.

Objective Function

The objective function consists of 3 components

1. Costs corresponding to flows
2. Penalty on link errors
3. Penalty on deviations from trip table

costs corresponding to flows

$$\begin{aligned} & 20 \text{ x1}_6_1 + 50 \text{ x1}_4_2 + 140 \text{ x2}_4_2 + 60 \text{ x1}_5_2 + 60 \text{ x2}_5_2 + 70 \text{ x1}_6_2 \\ & + 160 \text{ x2}_6_2 + 200 \text{ x3}_6_2 + 160 \text{ x4}_6_2 + 180 \text{ x5}_6_2 + 200 \text{ x6}_6_2 + \\ & 60 \text{ x1}_4_3 + 60 \text{ x2}_4_3 + 50 \text{ x1}_5_3 + 140 \text{ x2}_5_3 + 160 \text{ x1}_6_3 + 160 \text{ x2}_6_3 + \\ & 180 \text{ x3}_6_3 + 70 \text{ x4}_6_3 + 180 \text{ x5}_6_3 + 220 \text{ x6}_6_3 + 30 \text{ x1}_5_4 + 40 \text{ x1}_6_4 + \\ & 100 \text{ x2}_6_4 + 140 \text{ x3}_6_4 + 30 \text{ x1}_4_5 + \\ & 100 \text{ x1}_6_5 + 40 \text{ x2}_6_5 + 40 \text{ x3}_6_5 + \end{aligned}$$

penalty on link errors

$$511041 \text{ a6}_7 + 511041 \text{ b6}_7 + \dots + 511041 \text{ a10}_5 + 511041 \text{ b10}_5 +$$

penalty on deviations from trip table

$$51104.1 \text{ c6}_1 + 51104.1 \text{ d6}_1 + \dots + 51104.1 \text{ c6}_5 + 51104.1 \text{ d6}_5$$

Constraints Formulation

The constraints of this model could be grouped into 2 types

1. Link constraints
2. Trip Table constraints

sample link constraints

For the link connecting 6 and 7 the link volume constraint can be written as follows:

$$x1_6_1 + x1_6_2 + x5_6_2 + x1_6_3 + x2_6_3 + x1_6_4 + x1_6_5 + a6_7 - b6_7 = 5000$$

Similarly for link connecting 7 and 9:

$$\text{link7_9) } x1_6_2 + x5_6_2 + x1_6_3 + x2_6_3 + x1_6_4 + x1_6_5 + a7_9 - b7_9 = 4500$$

sample trip table constraints

For the O-D pair 6 and 1 the trip atble constraint is as follows:

$$x1_6_1 + c6_1 - d6_1 = 600$$

similarly for O-D pair 6 and 2:

$$x1_6_2 + x2_6_2 + x3_6_2 + x4_6_2 + x5_6_2 + x6_6_2 + c6_2 - d6_2 = 600$$

6.4 Egmore Network

Egmore is a sub-area in Chennai city. It is a larger network. In the earlier networks it was possible to obtain all the paths between each O-D pair. But this being a large network the number of paths between each O-D pair is very large. Enumerating all these paths and then using these in the LP formulation is impossible. So in the present study between each O-D pair five paths are chosen. These paths represent the first five shortest paths between the O-D pair. Obtaining even five paths between each O-D pair is not easy. So a computer program which makes use of Gentic Algorithms is used.

6.4.1 Genetic Algorithm

Obtaining the n^{th} shortest path is an NP complete problem. So to obtain solutions to such problems Genetic Algorithms(GA) are very helpful. GA does not guarantee you the optimal solution but ensures that the solution is pretty close to the optimum. In this network to obtain the first five shortest paths a GA has been used. In this program a generation with a population of 10 is randomly generated. In this process initially a node is selected and all the nodes connecting to it are checked if they are visited or unvisited. The person can move only from a node to an unvisited node. The selection of an unvisited node is done randomly. This process begins at the origin node and ends at the destination node. This process is continued 10 times to generate the initial population. Once this population is obtained crossovers are undertaken to obtain solutions for the next generation. For this, two parents are chosen through a roulette wheel process. These parents are checked for a common node. If a common node exists then the paths on either side of the common node are swapped to obtain two distinct offsprings. If a common node does not exist the process is repeated. This yields ten new offsprings. This process is carried for ten generations. At the end of every generation the solution for the best five distinct paths is updated. Hence at the end of 10 generations we have the best 5 paths between any O-D pair. The Algorithm is presented in the flow chart 6.2. Once these paths were obtained the same mode of formulation as explained in the Sample Network case has been carried out. All the travel time calculation, setting up of the model has been done with help of a program. With nearly 1500 variables doing this manually would be time consuming. In this model the sensitivity analysis of the value M has been carried out. The measures of closeness for these solutions are obtained.

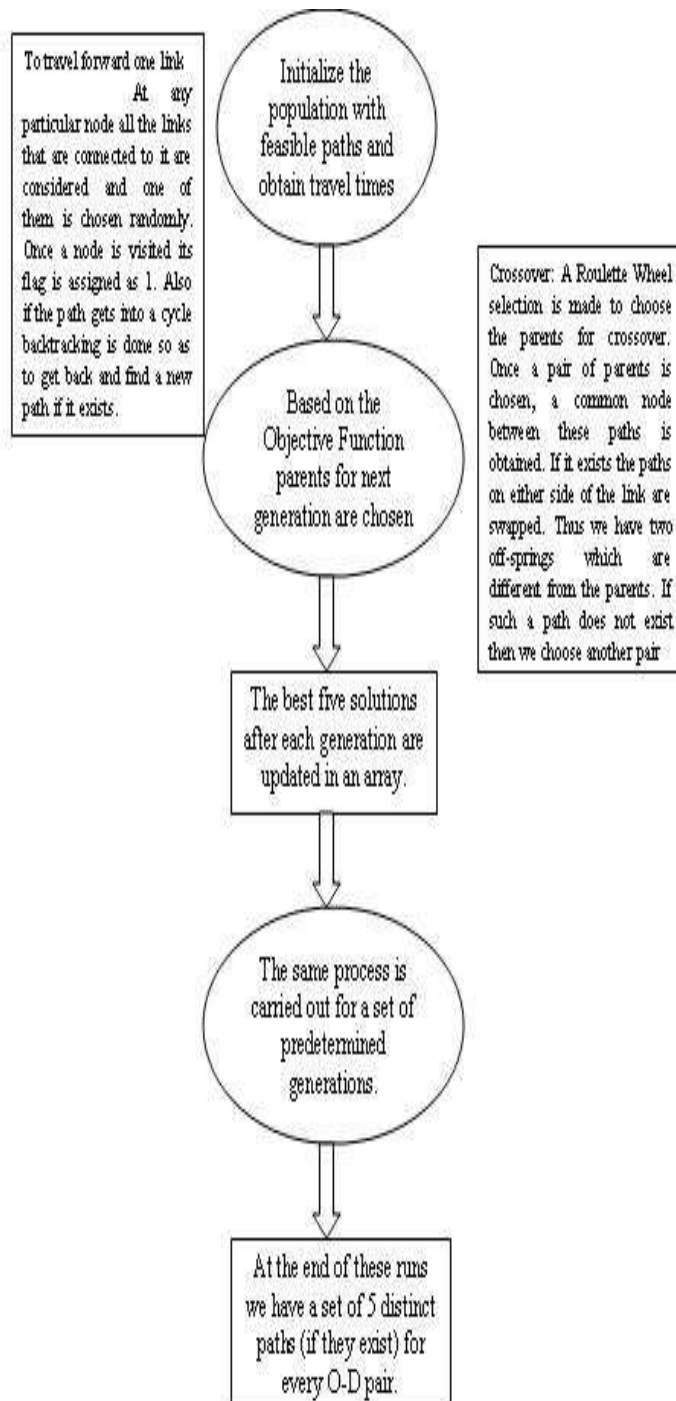


Figure 6.2: GA Methodology for Egmore Network

Chapter 7

Results and Analysis

7.1 General

LINDO models formulated were run on all the three networks as explained in the previous chapter. This chapter discusses all the results that are obtained on the two Sample Networks and the Egmore Network. The present chapter discusses the results of Sample Network 1, Sample network 2 and Egmore Network in order. In each Network the results are presented in the following order

1. Results pertaining to varying O-D trip table values. In this the value of M_s is also varied for a particular O-D trip table value. Different solutions obtained for the same trip table values for different M_s values are clearly marked. Also the measures of closeness are evaluated. The solutions are displayed based on the notation described earlier.
2. Results pertaining to missing link volumes are presented. Measures of closeness are also presented.

Table 7.1: Solution obtained using the LINDO model

Path	100	200	300	400	500	600
x13-1	600	600	600	600	600	600
x23-1	0	0	0	0	0	0
x33-1	0	0	0	0	0	0
x13-2	148	148	148	148	148	148
x23-2	202	202	202	202	202	202
x33-2	0	0	0	0	0	0
x14-1	392	392	392	392	392	392
x24-1	108	108	108	108	108	108
x14-2	450	450	450	450	450	450
x24-2	0	0	0	0	0	0
TOTAL	1900	1900	1900	1900	1900	1900

Table 7.2: Table with O-D Details for trip table value ranging from 100 to 600

Destination $\Rightarrow$		
Origin $\downarrow$	1	2
3	600	350
4	500	450

MAE = 0 MAE = 0%
 RMSE = 0 RMSE = 0%
 Phi = 0

Table 7.3: LINDO Details of links relaxed for target tables 600

Path	Actual	5_6_8	5_7_9	6_8_10	7_9_10	8_10_9	All internal
x13-1	600	600	600	600	600	600	600
x23-1	0	0	0	0	0	0	0
x33-1	0	0	0	0	0	0	0
x13-2	148	148	148	148	148	148	0
x23-2	202	202	202	202	202	202	350
x33-2	0	0	0	0	0	0	0
x14-1	392	392	392	392	392	392	0
x24-1	108	108	108	108	108	108	500
x14-2	450	450	450	450	450	450	450
x24-2	0	0	0	0	0	0	0
TOTAL	1900	1900	1900	1900	1900	1900	1900

Table 7.4: LINDO Details of links relaxed for target tables 600

Path	Actual	3-5 5-6 4-6 6-8	3-5 5-6 4-6 6-8 8-10	3-5 7-9 5-6 4-6 6-8 8-10
x13-1	600	600	600	600
x23-1	0	0	0	0
x33-1	0	0	0	0
x13-2	148	148	148	148
x23-2	202	52	52	52
x33-2	0	0	0	0
x14-1	392	392	392	392
x24-1	108	108	108	108
x14-2	450	600	600	600
x24-2	0	0	0	0
TOTAL	1900	1900	1900	1900

Table 7.5: O-D Trip Table Details of the relaxed links 1

Destination⇒		
Origin↓	1	2
3	600	200
4	500	600

MAE = 0 MAE = 0%
RMSE = 0 RMSE = 0%
Phi = 0

Table 7.6: O-D Trip Table Details of the relaxed links 2

Destination⇒		
Origin↓	1	2
3	600	350
4	500	450

MAE = 19.29 MAE = 4.06%
RMSE = 106.06 RMSE = 22.33%
Phi = 325.32

7.2 Sample Network 1

7.2.1 Results

7.2.2 Analysis

Sample Network 1 being a very small network the number of feasible paths is very small. So no changes occur in solutions obtained by varying the Trip Table values. Even the solution obtained with missing link information has little variations. Variations are seen only when relaxation is employed on a large path.

7.3 Sample Network 2

7.3.1 Results pertaining to OD Target Values

Table 7.7: LINDO Details of links relaxed for various target table values

Path	200(1)	200(2)	400(1)	600(1)	800(1)	1000(1)	1000(2)	983	Smallinfo	Corr.table
x16-1	500	500	500	500	500	500	500	500	500	500
x14-2	600	600	800	800	900	1000	1000	983	787	600
x24-2	—	—	—	—	—	—	—	—	—	—
x15-2	1200	—	1000	800	600	800	500	783	1304	1500
x25-2	200	200	200	200	200	200	200	200	200	200
x16-2	2800	4000	2800	3000	3100	2800	3100	2834	2509	2500
x26-2	—	—	—	—	—	—	—	—	—	—
x36-2	—	—	—	—	—	—	—	—	—	—
x46-2	—	—	—	—	—	—	—	—	—	—
x56-2	—	—	—	—	—	—	—	—	—	—
x66-2	—	—	—	—	—	—	—	—	—	—
x14-3	300	300	200	200	300	300	300	300	113	300
x24-3	100	100	200	400	400	400	400	400	391	400
x15-3	300	300	300	300	300	300	300	300	309	300
x25-3	—	—	—	—	—	—	—	—	187	—
x15-4	200	1400	400	600	800	700	1000	717	—	—
x16-3	—	—	—	—	—	—	—	—	—	—
x26-3	—	—	—	—	—	—	—	—	—	—
x36-3	—	—	—	—	—	—	—	—	—	—
x46-3	300	300	200	—	—	—	—	—	—	—
x56-3	—	—	—	—	—	—	—	—	—	—
x66-3	—	—	100	100	—	—	—	—	—	—
x16-4	1700	500	1600	1400	1100	1300	1000	1283	1991	2000
x26-4	—	—	—	—	—	—	—	—	9	—
x36-4	100	100	—	—	100	—	—	—	—	—
x14-5	1400	1400	1200	1000	800	700	700	717	1109	1100
x16-5	—	—	100	100	300	400	400	383	—	—
x26-5	200	200	300	500	500	500	500	500	491	500
x36-5	—	—	—	—	—	100	100	100	100	100
TOTAL	9900	9900	9900	9900	9900	10000	10000	10000	10000	10000

Table 7.8: O-D Details for trip table value = 200(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	600	400	—	1400	2400
5	—	1400	300	200	—	1900
6	500	2800	300	1800	200	5600
Total	500	4800	1000	2000	1600	9900

MAE = 209.09 MAE = 23%
RMSE = 250.45 RMSE = 27.55%
Phi = 2140.3

Table 7.9: O-D Details for trip table value = 200(2)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	600	400	—	1400	2400
5	—	200	300	1400	—	1900
6	500	4000	300	600	200	5600
Total	500	4800	1000	2000	1600	9900

MAE = 645.45 MAE = 71%
RMSE = 896.97 RMSE = 98.67%
Phi = 8537.24

7.3.2 Results pertaining to Missing Link information

Table 7.10: O-D Details for trip table value = 400(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	800	400	—	1200	2400
5	—	1200	300	400	—	1900
6	500	2800	300	1600	400	5600
Total	500	4800	1000	2000	1600	9900

MAE = 245.45 MAE = 27%
RMSE = 290.77 RMSE = 31.98%
Phi = 2225.1

Table 7.11: O-D Details for trip table value = 600(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	800	600	—	1000	2400
5	—	1000	300	600	—	1900
6	500	3000	100	1400	600	5600
Total	500	4800	1000	2000	1600	9900

MAE = 263.64 MAE = 29%
RMSE = 372.95 RMSE = 41.02%
Phi = 2456.58

Table 7.12: O-D Details for trip table value = 800(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	900	700	—	800	2400
5	—	800	300	800	—	1900
6	500	3100	—	1200	800	5600
Total	500	4800	1000	2000	1600	9900

MAE = 354.55 MAE = 39%
RMSE = 492.67 RMSE = 54.20%
Phi = 3607.03

Table 7.13: O-D Details for trip table value = 1000(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	700	—	2000
6	500	2800	—	1300	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 327.27 MAEC = 36%
RMSE = 430.64 RMSEC = 47.37%
Phi = 3157.13

Table 7.14: O-D Details for trip table value = 1000(2)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	700	300	1000	—	2000
6	500	3100	—	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 436.36 MAEC = 48%
RMSE = 590.84 RMSEC = 64.99%
Phi = 4542.66

Table 7.15: O-D Details for trip table value = 983(1)

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	983	700	—	717	2400
5	—	983	300	717	—	2000
6	500	2834	—	1283	983	5600
Total	500	4800	1000	2000	1700	10000

MAE = 330.36 MAEC = 36.34%
RMSE = 436.30 RMSEC = 47.99%
Phi = 3195.81

Table 7.16: O-D Details for trip table value with small errors table

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	787	504	—	1109	2400
5	—	1504	496	—	—	2000
6	500	2509	—	2000	591	5600
Total	500	4800	1000	2000	1700	10000

MAE = 72.91 MAEC = 8.02%
RMSE = 116.95 RMSEC = 12.87%
Phi = 778.84

Table 7.17: O-D Details for trip table value as the Correct Information Table

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	600	700	—	1100	2400
5	—	1700	300	—	—	2000
6	500	2500	—	2000	600	5600
Total	500	4800	1000	2000	1700	10000

MAE = 0 MAEC = 0%
RMSE = 0 RMSEC = 0%
Phi = 0

7.3 Sample Network 2

Table 7.18: Details with single link relaxed.

Path	Actual	10_12	11_12	12_11	10_9	7_9	8_10	9_10	9_11
x16-1	500	500	500	500	500	500	500	500	500
x14-2	1000	1000	1000	1000	1000	1000	1000	1000	1000
x24-2	0	0	0	0	0	0	0	0	0
x15-2	800	800	500	500	800	500	500	800	500
x25-2	200	200	200	200	200	200	200	200	200
x16-2	2800	2800	3100	3100	2800	3100	3100	2800	3100
x26-2	0	0	0	0	0	0	0	0	0
x36-2	0	0	0	0	0	0	0	0	0
x46-2	0	0	0	0	0	0	0	0	0
x56-2	0	0	0	0	0	0	0	0	0
x66-2	0	0	0	0	0	0	0	0	0
x14-3	300	300	300	300	300	300	300	300	300
x24-3	400	400	400	400	400	400	400	400	400
x15-3	300	300	300	300	300	300	300	300	300
x25-3	0	0	0	0	0	0	0	0	0
x15-4	700	700	1000	1000	700	1000	1000	700	1000
x16-3	0	0	0	0	0	0	0	0	0
x26-3	0	0	0	0	0	0	0	0	0
x36-3	0	0	0	0	0	0	0	0	0
x46-3	0	0	0	0	0	0	0	0	0
x56-3	0	0	0	0	0	0	0	0	0
x66-3	0	0	0	0	0	0	0	0	0
x16-4	1300	1300	1000	1000	1300	1000	1000	1300	1000
x26-4	0	0	0	0	0	0	0	0	0
x36-4	0	0	0	0	0	0	0	0	0
x14-5	700	700	700	700	700	700	700	700	700
x16-5	400	400	400	400	400	400	400	400	400
x26-5	500	500	500	500	500	500	500	500	500
x36-5	100	100	100	100	100	100	100	100	100
TOTAL	10000	10000	10000	10000	10000	10000	10000	10000	10000

Table 7.19: Details with two links relaxed.

Path	Actual	10_12_11	10_9_10	10_9_11	11_12_11	7_9_10
X16-1	500	500	500	500	500	500
x14-2	1000	1000	1000	1000	1000	1000
x24-2	0	0	0	0	0	0
x15-2	800	500	800	500	500	800
x25-2	200	200	200	200	500	200
x16-2	2800	3100	2800	3100	2800	2800
x26-2	0	0	0	0	0	0
x36-2	0	0	0	0	0	0
x46-2	0	0	0	0	0	0
x56-2	0	0	0	0	0	0
x66-2	0	0	0	0	0	0
x14-3	300	300	300	300	600	300
x24-3	400	400	400	100	100	100
x15-3	300	300	300	300	0	300
x25-3	0	0	0	0	0	0
x15-4	700	1000	1000	1000	1000	700
x16-3	0	0	0	0	0	0
x26-3	0	0	0	0	0	0
x36-3	0	0	0	0	0	0
x46-3	0	0	0	300	300	300
x56-3	0	0	0	0	0	0
x66-3	0	0	0	0	0	0
x16-4	1300	1000	1000	1000	1000	1300
x26-4	0	0	0	0	0	0
x36-4	0	0	0	0	0	0
x14-5	700	700	700	1000	700	1000
x16-5	400	400	700	400	700	400
x26-5	500	500	200	200	200	200
x36-5	100	100	100	100	100	100
TOTAL	10000	10000	10000	10000	10000	10000

Table 7.20: Details with two links relaxed.

Path	Actual	7_9_11	8_10_12	8_10_9	9_10_12	9_11_12
x16-1	500	500	500	500	500	500
x14-2	1000	1000	1000	1000	1000	1000
x24-2	0	0	0	0	0	0
x15-2	800	800	800	500	800	500
x25-2	200	200	200	200	200	200
x16-2	2800	2800	2800	3100	2800	3100
x26-2	0	0	0	0	0	0
x36-2	0	0	0	0	0	0
x46-2	0	0	0	0	0	0
x56-2	0	0	0	0	0	0
x66-2	0	0	0	0	0	0
x14-3	300	300	300	300	300	300
x24-3	400	400	400	100	400	400
x15-3	300	300	300	300	300	300
x25-3	0	0	0	0	0	0
x15-4	700	700	700	1000	700	1000
x16-3	0	0	0	0	0	0
x26-3	0	0	0	0	0	0
x36-3	0	0	0	0	0	0
x46-3	0	0	0	300	0	0
x56-3	0	0	0	0	0	0
x66-3	0	0	0	0	0	0
x16-4	1300	1300	1300	1000	1300	1000
x26-4	0	0	0	0	0	0
x36-4	0	0	0	0	0	0
x14-5	700	700	700	1000	700	700
x16-5	400	400	400	400	400	400
x26-5	500	500	500	200	500	500
x36-5	100	100	100	100	100	100
TOTAL	10000	10000	10000	10000	10000	10000

Table 7.21: Details with three links relaxed.

Path	Actual	7_9_10_12	7_9_11_12	8_10_12_11	8_10_9_11
X16-1	500	500	500	500	500
X14-2	1000	1000	1000	1000	1000
X24-2	0	0	0	0	0
X15-2	800	800	800	500	800
X25-2	200	200	200	200	200
X16-2	2800	2800	2800	3100	2800
X26-2	0	0	0	0	0
X36-2	0	0	0	0	0
X46-2	0	0	0	0	0
X56-2	0	0	0	0	0
X66-2	0	0	0	0	0
X14-3	300	300	300	300	300
X24-3	400	400	400	100	400
X15-3	300	300	300	300	300
X25-3	0	0	0	0	0
X15-4	700	700	700	1000	700
X16-3	0	0	0	0	0
X26-3	0	0	0	0	0
X36-3	0	0	0	0	0
X46-3	0	0	0	300	0
X56-3	0	0	0	0	0
X66-3	0	0	0	0	0
X16-4	1300	1300	1300	1000	1300
X26-4	0	0	0	0	0
X36-4	0	0	0	0	0
X14-5	700	700	700	1000	700
X16-5	400	400	400	400	400
X26-5	500	500	500	200	500
X36-5	100	100	100	100	100
TOTAL	10000	10000	10000	10000	10000

Table 7.22: Details of all links relaxed.

Path	Actual	All links
X16-1	500	500
X14-2	1000	1000
X24-2	0	0
X15-2	800	0
X25-2	200	1000
X16-2	2800	2800
X26-2	0	0
X36-2	0	0
X46-2	0	0
X56-2	0	0
X66-2	0	0
X14-3	300	0
X24-3	400	700
X15-3	300	0
X25-3	0	0
X15-4	700	1000
X16-3	0	0
X26-3	0	0
X36-3	0	0
X46-3	0	300
X56-3	0	0
X66-3	0	0
X16-4	1300	1000
X26-4	0	0
X36-4	0	0
X14-5	700	700
X16-5	400	700
X26-5	500	200
X36-5	100	100
TOTAL	10000	10000

Table 7.23: Table with O-D Details for trip table value = 1000 With LINK 10_12 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	700	—	2000
6	500	2800	0	1300	1000	5600
Total	500	4800	1000	2000	1700	10000

$$\text{MAE} = 327.27$$

$$\text{MAEC} = 36\%$$

$$\text{RMSE} = 430.64$$

$$\text{RMSEC} = 47.37\%$$

$$\text{Phi} = 3157.13$$

The solution remains same when links 10_9, 9_10 are relaxed individually.

Table 7.24: Table with O-D Details for trip table value = 1000 With LINK 11_12 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	700	300	1000	—	2000
6	500	3100	0	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

$$\text{MAE} = 436.36$$

$$\text{MAEC} = 48\%$$

$$\text{RMSE} = 590.84$$

$$\text{RMSEC} = 64.99\%$$

$$\text{Phi} = 4542.66$$

The solution remains same when links 12_11, 7_9, 8_10, 9_11 are relaxed individually.

7.4 Egmore

Table 7.25: Table with O-D Details for trip table value = 1000 With LINKS 7_9 and 9_11 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	700	—	2000
6	500	2800	0	1300	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 327.27

MAEC = 36%

RMSE = 430.64

RMSEC = 47.37%

Phi = 3157.13

The solution is same when links (8_10, 10_12) , (9_10,10_12), are relaxed.

Table 7.26: Table with O-D Details for trip table value = 1000 With LINKS 8_10 and 10_9 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	400	—	1000	2400
5	—	700	300	1000	—	2000
6	500	3100	300	1000	700	5600
Total	500	4800	1000	2000	1700	10000

MAE = 436.36

MAEC = 48%

RMSE = 581.53

RMSEC = 63.97%

Phi = 4328.05

The solution is same when links (10_9, 9_11) are relaxed.

Table 7.27: Table with O-D Details for trip table value = 1000 With LINKS 9_11 and 11_12 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	700	300	1000	—	2000
6	500	3100	0	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 436.36

MAEC = 48%

RMSE = 590.84

RMSEC = 64.99%

Phi = 4542.66

The solution is same when links (10_12, 12_11) are relaxed

Table 7.28: Table with O-D Details for trip table value = 1000 With LINKS 10_9 and 9_10 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	1000	—	2000
6	500	2800	0	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 381.81

MAEC = 42%

RMSE = 527.43

RMSEC = 58.02%

Phi = 3681.86

Table 7.29: Table with O-D Details for trip table value = 1000 With LINKS 11_12 and 12_11 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	0	1000	—	2000
6	500	2800	300	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 436.36

MAEC = 48%

RMSE = 542.72

RMSEC = 59.7%

Phi = 5392.99

Table 7.30: Table with O-D Details for trip table value = 1000 With LINKS 7_9 and 9_10 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	400	—	1000	2400
5	—	1000	300	700	—	2000
6	500	2800	300	1300	700	5600
Total	500	4800	1000	2000	1700	10000

MAE = 327.27 MAEC = 36%
 RMSE = 417.79 RMSEC = 45.96
 Phi = 2942.5

Table 7.31: Table with O-D Details for trip table value = 1000 With LINKS 7_9, 9_10 and 10_12 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	700	—	2000
6	500	2800	0	1300	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 327.27 MAEC = 36%
 RMSE = 430.64 RMSEC = 47.37%
 Phi = 3157.13

The solution is same for the links (7,9,11,12) and (8,10,9,11).

Table 7.32: Table with O-D Details for trip table value = 1000 With LINKS 8_10, 10_9 and 9_11 Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	400	—	700	2400
5	—	700	300	1000	—	2000
6	500	3100	300	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 490.90 MAEC = 54%
 RMSE = 604.53 RMSEC = 66.5
 Phi = 4934.39

Table 7.33: Table with O-D Details for trip table value = 1000 With ALL intermediate LINKS Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	0	1000	—	2000
6	500	2800	300	1000	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 436.36 MAEC = 48%

RMSE = 542.72

RMSEC = 58.7

Phi = 5392.99

Table 7.34: Table with O-D Details for trip table value = 1000 with no LINK Relaxed

To	1	2	3	4	5	Total
From	-----	-----	-----	-----	-----	-----
4	—	1000	700	—	700	2400
5	—	1000	300	700	—	2000
6	500	2800	0	1300	1000	5600
Total	500	4800	1000	2000	1700	10000

MAE = 327.27 MAEC = 36%

RMSE = 430.64 RMSEC = 47.37

Phi = 3157.13

Table 7.35: O-D Matrix for Egmore Network for $M_s = 0.1$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	265	0	53	0	0	0	3	0	0	17	52	0	0	0
2	22	-	0	399	0	0	5	0	0	12	6	0	23	0	160
3	0	0	-	123	0	0	0	0	0	0	0	0	0	0	0
4	172	104	0	-	0	0	0	0	113	0	0	292	149	159	162
5	0	27	0	33	-	0	0	0	0	0	0	0	10	0	0
6	0	48	0	251	0	-	0	0	0	0	0	0	0	0	58
7	0	0	18	162	0	0	-	0	0	0	0	0	0	0	68
8	0	0	0	0	0	0	0	-	24	0	0	32	0	122	177
9	0	0	182	0	3	0	27	0	-	0	93	45	0	34	32
10	45	6	0	1	12	64	56	63	0	-	0	90	0	18	212
11	0	0	0	0	0	0	0	0	0	34	-	39	0	0	61
12	67	79	0	91	0	153	31	0	205	338	0	-	0	1	171
13	0	0	6	53	30	26	0	1	7	0	0	11	-	14	0
14	0	69	0	101	15	72	32	40	65	22	0	13	6	-	85
15	46	107	12	0	0	127	179	185	20	181	0	76	18	182	-

Table 7.36: O-D Matrix for Egmore Network for $M_s = 0.2$ M

Destination⇒															
Origin↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	277	0	42	0	0	0	0	0	0	16	55	0	0	0
2	33	-	0	403	0	0	5	0	0	0	7	0	33	0	146
3	0	0	-	119	0	0	0	0	0	0	0	4	0	0	0
4	172	154	0	-	0	0	0	0	117	24	0	235	139	148	162
5	0	19	0	31	-	0	0	0	0	0	0	0	10	10	0
6	0	23	0	229	0	-	0	0	0	32	0	0	0	0	73
7	0	0	25	162	0	0	-	0	0	0	0	0	0	0	61
8	0	5	0	0	0	0	0	-	0	0	0	51	0	122	177
9	0	0	158	0	3	0	0	2	-	0	63	45	0	96	49
10	34	26	0	1	10	64	54	66	0	-	0	124	0	18	180
11	0	9	0	0	0	0	0	0	0	36	-	39	0	0	50
12	67	53	0	91	0	163	31	0	245	291	0	-	0	16	179
13	0	15	6	51	32	26	0	1	7	0	5	18	-	14	31
14	0	25	17	90	15	62	46	38	65	22	0	13	47	-	79
15	46	100	12	47	0	127	193	185	0	181	25	76	34	106	-

Table 7.37: O-D Matrix for Egmore Network for $M_s = 0.3$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	263	0	56	0	0	0	0	0	0	16	55	0	0	0
2	40	-	0	385	0	0	5	0	0	0	7	0	53	1	136
3	0	0	-	109	0	0	0	0	0	0	0	14	0	0	0
4	172	188	0	-	0	0	0	0	93	25	0	236	118	157	162
5	0	9	0	34	-	0	0	0	0	0	0	0	10	17	0
6	0	28	0	209	0	-	0	0	0	47	0	0	0	0	73
7	0	0	25	138	0	0	-	0	0	0	0	6	0	0	79
8	0	23	0	0	0	0	0	-	0	0	0	33	0	122	177
9	0	0	158	0	3	0	47	0	-	0	51	45	0	112	0
10	27	42	0	10	12	64	42	39	0	-	0	143	0	18	180
11	0	9	0	0	1	0	0	0	0	23	-	39	0	0	62
12	67	25	0	128	0	163	31	0	220	284	7	-	0	16	195
13	0	22	6	48	29	26	0	1	7	5	5	0	-	14	43
14	0	20	17	90	15	49	65	38	65	22	0	13	47	-	79
15	46	77	12	59	0	140	140	214	49	181	30	76	36	73	-

Table 7.38: O-D Matrix for Egmore Network for $M_s = 0.4$ M

Destination⇒															
Origin↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	118	0	168	0	0	30	0	0	0	19	55	0	0	0
2	67	-	0	358	0	26	5	0	0	3	7	36	23	0	102
3	0	0	-	58	0	0	0	0	0	0	0	20	16	28	0
4	172	258	81	-	0	0	0	0	111	88	0	97	124	114	106
5	0	9	0	34	-	0	0	0	0	0	0	0	10	17	0
6	0	22	0	149	0	-	0	0	0	38	0	0	3	0	145
7	0	0	25	37	0	0	-	0	0	0	0	31	0	76	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	0	3	0	68	59	-	8	4	45	7	47	134
10	0	42	0	43	12	64	0	0	16	-	0	197	5	18	180
11	0	9	10	23	2	17	0	0	2	0	-	39	0	5	27
12	67	113	0	128	1	163	31	9	233	242	19	-	0	16	114
13	0	0	6	49	27	26	0	1	7	5	10	18	-	14	43
14	0	19	17	90	15	18	97	38	65	22	0	13	47	-	79
15	46	91	38	131	0	127	99	185	0	181	58	76	28	73	-

Table 7.39: O-D Matrix for Egmore Network for $M_s = 0.5$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	120	0	168	0	0	34	0	0	0	11	55	2	0	0
2	52	-	0	341	1	25	5	0	0	22	7	82	23	0	69
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	172	258	36	-	0	0	0	0	123	79	23	86	107	106	162
5	0	9	0	33	-	0	0	0	1	0	0	0	10	17	0
6	0	17	0	74	0	-	0	0	0	67	0	54	0	0	145
7	3	0	25	24	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	91	3	0	52	34	-	0	21	45	7	50	71
10	0	42	0	102	12	64	7	0	0	-	0	107	5	18	220
11	12	9	0	23	2	17	0	0	0	0	-	39	0	5	27
12	67	95	0	128	4	163	31	34	238	211	19	-	16	16	114
13	0	14	6	44	23	26	0	1	7	5	5	18	-	14	43
14	0	11	17	90	15	20	102	38	65	22	0	13	47	-	79
15	46	107	93	92	0	127	99	149	0	181	30	76	24	73	-

Table 7.40: O-D Matrix for Egmore Network for $M_s = 0.6$ M

Destination⇒															
Origin↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	116	0	168	0	0	39	0	0	0	12	55	0	0	0
2	56	-	0	348	0	27	5	0	0	23	7	36	23	0	102
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	172	258	32	-	0	0	0	0	105	73	0	116	117	116	162
5	0	9	0	33	-	0	0	0	0	0	0	0	10	17	1
6	0	0	0	71	0	-	0	0	0	67	0	74	0	0	145
7	0	0	25	32	0	0	-	0	0	0	0	31	2	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	102	3	0	38	22	-	0	43	45	7	42	73
10	0	42	0	95	12	64	18	42	3	-	0	103	0	18	180
11	11	9	0	23	2	17	0	0	1	0	-	39	0	5	27
12	67	116	0	128	4	163	31	4	254	216	19	-	0	16	118
13	0	9	6	48	24	26	0	1	7	5	5	18	-	14	43
14	0	16	17	90	15	18	99	38	65	22	0	13	47	-	79
15	46	107	98	72	0	127	99	185	0	181	30	76	39	73	-

Table 7.41: O-D Matrix for Egmore Network for $M_s = 0.7$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	113	0	168	1	0	34	0	0	0	16	45	7	6	0
2	51	-	0	334	9	26	5	0	0	16	7	79	23	0	77
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	172	258	36	-	0	0	0	0	149	84	25	86	75	104	162
5	0	9	0	24	-	0	0	0	3	2	0	0	10	17	5
6	0	0	0	69	0	-	0	0	0	67	0	68	8	0	145
7	16	0	25	11	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	110	3	0	28	18	-	0	14	45	23	49	85
10	0	42	0	107	12	64	16	16	0	-	0	106	5	18	191
11	0	9	10	23	2	17	0	0	0	0	-	39	0	5	29
12	67	110	0	128	4	163	46	34	210	210	19	-	6	16	114
13	0	23	6	44	14	26	0	1	7	5	5	18	-	14	43
14	0	12	17	90	15	19	102	38	65	22	0	13	47	-	79
15	46	107	83	100	0	127	99	185	0	181	30	76	26	73	-

Table 7.42: O-D Matrix for Egmore Network for $M_s = 0.8$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	101	0	168	11	0	41	0	0	0	29	24	7	9	0
2	38	-	0	300	9	27	5	0	0	29	7	92	23	3	94
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	172	258	48	-	0	0	0	0	149	17	25	86	46	97	162
5	0	9	0	26	-	0	0	0	3	0	0	0	10	17	5
6	0	0	0	62	0	-	0	0	0	67	0	70	13	0	145
7	22	0	25	5	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	124	3	0	26	9	-	0	1	45	37	49	81
10	0	42	0	107	12	64	14	25	0	-	0	113	3	18	180
11	0	9	10	23	2	17	0	0	0	0	-	39	2	5	27
12	67	120	0	128	4	163	40	34	210	199	19	-	2	16	114
13	7	23	6	44	4	26	3	1	7	5	5	18	-	14	43
14	0	13	17	90	15	18	102	38	65	22	0	13	47	-	79
15	46	107	71	109	0	127	99	185	0	181	30	76	29	73	-

Table 7.43: O-D Matrix for Egmore Network for $M_s = 0.9$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	71	0	168	11	8	61	0	0	0	29	10	7	9	0
2	10	-	0	264	9	27	5	0	0	29	7	96	23	5	96
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	172	258	29	-	0	0	0	0	127	117	25	86	46	96	162
5	11	9	0	13	-	0	0	0	3	0	0	0	10	17	5
6	8	22	0	28	0	-	0	0	0	67	0	74	13	0	145
7	22	0	30	0	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	138	3	7	29	0	-	0	1	45	26	46	79
10	0	42	0	107	12	64	0	34	12	-	0	103	5	18	180
11	0	9	10	23	2	17	0	0	0	0	-	39	2	5	27
12	67	136	0	128	4	163	31	34	220	166	19	-	0	16	114
13	7	23	3	44	4	26	3	1	7	5	5	18	-	14	43
14	9	19	17	90	15	3	102	38	65	22	0	13	47	-	79
15	46	94	85	117	0	126	99	185	0	181	30	76	20	73	-

Table 7.44: O-D Matrix for Egmore Network for $M_s = 1$ M

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	80	0	168	11	10	57	0	0	0	29	19	7	9	0
2	34	-	0	302	9	27	5	0	0	29	7	96	23	2	94
3	0	0	-	58	0	0	0	0	0	0	0	21	16	28	0
4	23	258	38	-	0	0	0	0	136	104	25	86	46	96	162
5	0	9	0	25	-	0	0	0	3	1	0	0	10	17	5
6	0	9	0	50	0	-	0	0	0	67	0	73	13	0	145
7	22	0	25	5	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	135	3	0	29	0	-	0	1	45	30	51	81
10	0	42	0	107	12	64	4	34	0	-	0	111	5	18	180
11	0	9	10	23	2	17	0	0	0	0	-	39	2	5	27
12	67	126	0	128	4	163	31	34	223	177	19	-	0	16	114
13	7	23	6	44	4	26	3	1	7	5	5	18	-	14	43
14	4	19	17	90	15	8	102	38	65	22	0	13	47	-	79
15	46	107	81	106	0	127	99	185	0	181	30	76	23	73	-

Table 7.45: OD Matrix used for the study

Destination⇒															
Origin⇓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	0	0	168	11	18	65	0	0	0	0	55	7	9	57
2	0	-	0	264	9	27	5	34	0	41	7	96	23	19	102
3	0	0	-	0	0	0	25	0	5	4	8	21	16	28	16
4	172	258	0	-	0	0	0	0	149	157	25	86	46	96	162
5	11	9	0	0	-	0	0	0	3	11	0	4	10	17	5
6	18	22	0	0	0	-	0	0	0	67	18	74	13	0	145
7	22	5	25	0	0	0	-	0	0	0	0	31	7	79	79
8	0	23	0	0	0	0	0	-	0	0	0	32	1	122	177
9	0	0	41	286	3	0	0	0	-	0	0	45	7	34	0
10	0	42	79	107	12	64	0	0	0	-	0	70	5	18	180
11	0	9	10	23	2	17	0	0	0	0	-	39	2	5	27
12	67	188	28	128	4	163	31	34	205	99	19	-	40	16	114
13	7	23	6	44	4	26	3	1	7	5	5	18	-	14	43
14	9	19	17	90	15	0	102	38	65	22	4	13	47	-	79
15	46	107	12	157	0	127	99	185	0	181	30	76	40	73	-

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