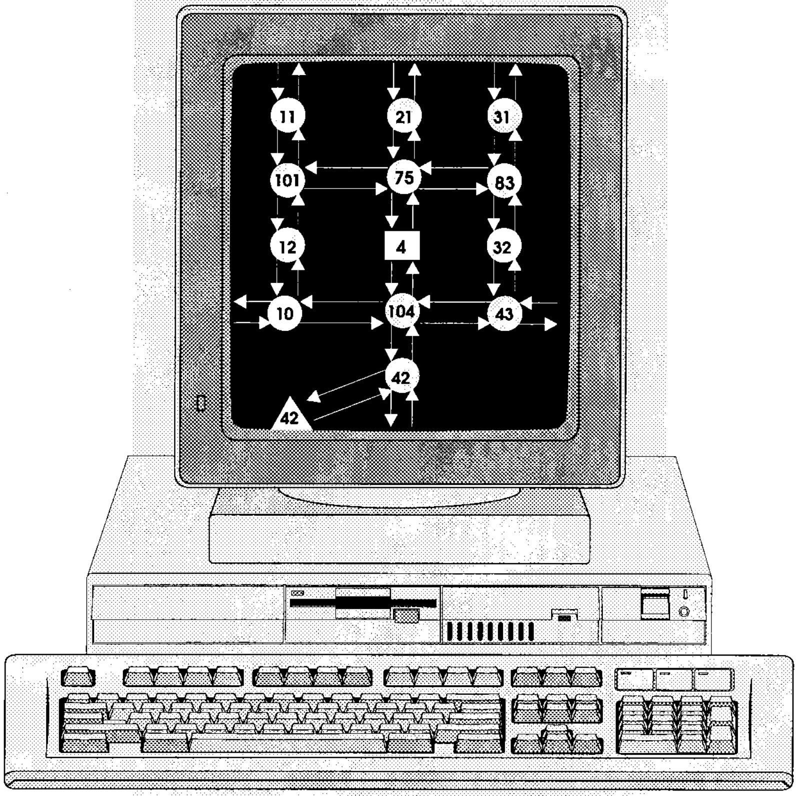
INTERIM REPORT

REVIEW AND EVALUATION OF MODELS THAT PRODUCE TRIP TABLES FROM GROUND COUNTS



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Abstract

This research effort was motivated by the desires of planning agencies to seek alternative methods of deriving current or base year Origin-Destination (O-D) trip tables without adopting conventional O-D surveys that are expensive, time consuming and labor intensive. This study had two objectives: (1) to conduct a review of existing approaches and models that produce trip tables from ground counts, and to select a few models for testing and evaluation, and (2) to perform a detailed testing of selected models based on application to both hypothetical and real networks, and to conduct performance evaluation and sensitivity analyses of these models.

Two models, namely, The Highway Emulator (THE), and the Linear Programming (LP) model developed at Virginia Tech, were chosen for comprehensive testing and evaluation. For test purposes, these two models were applied to the following three case studies: (1) Sample Network, (2) Purdue University Network, and (3) Pulaski Town Network. While the first network was a hypothetical one, the other two were real networks. Different cases of target table information and combinations of percentage available target cells and link volume information were used in the tests. These tests enabled a comprehensive evaluation of the performance and sensitivity analyses of the models. The test results were judged by two criteria: (1) the closeness of the model output tables to the "correct" or "surveyed" tables, and (2) the replication of observed link volumes by the models.

The test results led to the following key conclusions:

1. In general, the LP model results have proven to be superior, both in terms of closeness of modeled trip tables to the "correct"/"surveyed" tables, and in terms of replicating observed link volumes, for all the case studies. The exception to this is the structural target case, when THE produced better results, in terms of closeness of output tables to the "correct"/"surveyed" tables. This is based on the assumption that the "correct"/"surveyed" trip tables used for the case studies were in fact "correct"/"true".

2. THE model performed superior to the LP model for the structural target case (almost all the cases), where the target contains 1/0 cell values, 1 for those cells which represent O-D interchanges that are feasible, and 0 for those that are not. This has practical implications in that if a region does not have a prior table available as target, then a structural target could be used.

3. A word of caution must be noted with regard to conclusion # 2 above. While one would be tempted to use THE with a structural target for applications where a prior table is not available, it must be noted that the modeled results

of both THE and LP turned out to be poor when compared with the "correct"/"surveyed" tables for all the cases, even though THE results were better than those of LP.

However, these conclusions are based on tests on specific and limited number of networks, and under the assumption that the data used in testing and evaluation were accurate enough. The adoptability of these models and the use of one model versus the other must be decided based on the above facts, and in the context of error rates reported in this study. However, this study has highlighted the value of using such theoretical models for trip table estimation without performing conventional surveys.

Key words: Origin-Destination (O-D) Trip Tables, Traffic Volumes, Theoretical Models, Evaluation, The Highway Emulator (THE), Linear Programming Model

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\- R. Sivanandan

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CHAPTER 1.0

INTRODUCTION

1.1 Background

An origin-destination (O-D) trip table is a two-dimensional matrix of elements whose cell values represent the number of trips made between various O-D zone pairs in a given region. Conventionally, the information presented in the O-D trip table is established through extensive surveys of the travelers. These surveys include home interviews, license plate surveys, and road side surveys. These survey techniques are expensive, time-consuming, and labor intensive. Also, most of these methods are conducted through sampling, with associated sampling errors. Even if all the trips on a particular day are recorded, the O-D table so determined may not be stable over time, due to variations from day to day (Willumsen, 1978). There are other inherent drawbacks associated with conventional techniques. One common problem is changes in travel patterns due to changes in influencing factors. For instance, as the land use develops or changes rapidly, so will the trip table. The previously established trip table becomes outdated, leading to re-surveying and further expenditures.

Many planning agencies, such as the Transportation Planning Division (TPD) of Virginia Department of Transportation (VDOT) and many smaller planning organizations, are often unable to conduct such surveys due to budgetary, time, and manpower restrictions. Nevertheless, these agencies require trip table information for planning purposes and for testing traffic operations alternatives. This necessitates obtaining trip tables through cheaper and quicker means. This was a motivating factor for the development of theoretical approaches for synthesizing trip tables using available information in the form of link traffic counts. Furthermore, a trip matrix obtained through conventional survey relies on only a small sample of trip makers, whereas the link counts method may constitute nearly the entire sample, thus utilizing greater information. Review of these theoretical approaches and evaluation of a few selected models are the focus of this report.

1.2 Problem Statement

Advances in trip table synthesis have opened a new avenue for estimating O-D trips from ground counts. Essentially, it can be viewed as the reverse procedure from the conventional traffic assignment step. Several approaches have been developed to perform this function. The central idea in all these approaches is to use the information available in the link volume data to derive a trip table that will replicate the observed link volumes as closely as possible, and in certain cases to be as consistent as possible to prior information. Almost all the approaches and models are theoretical in nature. Basically, almost all of the earlier models are static, and do not capture the time-varying nature of O-D flows. Recently, there has been interest in estimating dynamic O-D flows at intersections and for linear networks. Several approaches have been proposed to perform this function. However, static methods are better established than their dynamic counterparts, and are of greater interest in planning applications.

Since all these models use different approaches, and have different assumptions and data requirements, their solutions and performance may often be different. Some models require more extensive data than others. While some classes of models require user input for parameter values, others employ assumptions within the models. However, all the assumptions may not reflect reality. It was also observed that where some models produce good results for a specific application, some models do not. An evaluation of the models was needed, in terms of validity, applicability, performance and other characteristics. This was the basic motivation for this research effort.

1.3 Research Objectives

This research effort was initiated with two major objectives in mind:

1. To review theoretical O-D trip table estimation models, and select a few models for evaluation.
2. To evaluate the strengths and weaknesses of the selected models.

1. *Review of O-D Estimation Models and Selection:* Several approaches and models to estimate trip tables from ground counts have evolved over time. Different assumptions and theoretical bases have been employed in these models. Many of the models have been translated into usable computer programs. A comprehensive survey of the literature and other sources was conducted and two models, The Highway Emulator (THE) and the Linear Programming (LP) models, were selected for evaluation. Details of these models are contained in Chapter 2.0.

2. *Evaluation of Selected Models:* The key objective of this research was to evaluate the selected set of models that were available as usable computer programs and were operational. The evaluation was comprehensive in nature, including sensitivity analysis and examination of related issues. A conventional O-D survey was conducted by VDOT for a case study, in order to perform a meaningful evaluation of the selected models by comparing their results with those of the surveyed table.

1.4 Scope

The scope of the project was to evaluate The Highway Emulator (THE) and the Linear Programming (LP) models. THE was developed by Bromage (1988, 1991), and the LP was developed at Virginia Tech (Sivanandan, 1991; Sherali, Sivanandan and Hobeika, 1994). THE has already found some popularity, and is being used by some transportation agencies. Some initial comparisons of this model with the linear programming model showed superiority of the latter. Thus, it was found worthwhile to perform an in-depth evaluation. The evaluation was comprehensive in nature, and included a variety of criteria that affect the practical applications of the models by planning agencies. A total of three networks were chosen for case studies. These were a sample network, Purdue University network, and Pulaski town network. The selected models were evaluated by testing them extensively using these case studies. While the data for sample network was obtained from literature (Gur et al., 1980), Dr. John Fricker of Purdue University provided the relevant data for the Purdue network. The necessary data for the Pulaski network was provided by VDOT (TPD).

1.5 Methodology

To fulfill the objectives of this research effort, the following three major tasks were performed: (1) review of literature on trip table estimation approaches/models, (2) selection of models for evaluation, and (3) evaluation of the selected models using the case studies.

1. Literature Review on Trip Table Estimation Models: Review of literature on the existing models and approaches was systematically carried out. This review included the examination of the theoretical basis of various models,

their characteristics and assumptions. Past test results of these models were also reviewed.

2. Selection of Models for Evaluation: Since the objective of this research was to evaluate the models for recommendations on their use for planning purposes, only static models were selected. In selecting the models, careful consideration was given to factors like:

    (i) Model's data requirements
    (ii) Nature of assumptions within the model
    (iii) Performance of the models based on past tests
    (iv) Existing popularity and use of the model, and its extent of usage
    (v) Availability and accessibility of software package for testing the model

3. Evaluation of Models Using Case Studies: As mentioned earlier, three case studies were considered after consultation with VTRC and VDOT (TPD). These were: (1) a sample network, (2) Purdue University network, and (3) Pulaski town network.

The selected models were then applied to these case studies, and several runs were made to evaluate the performance of the models. Extensive testing was done to ascertain the sensitivity of the models to various factors. In order to evaluate the resulting trip tables from the models, certain criteria were adopted. The ability of the models to replicate the observed link volumes, and the closeness of the derived table to the true/surveyed one were the criteria. These criteria were then measured through appropriate statistical error rates.

1.6 Organization of This Report

Chapter 2.0 is the survey of approaches for estimating O-D trip tables from traffic counts. Chapter 3.0 summarizes the selection of models and case studies. Chapters 4.0 through 6.0 contain the detailed discussions of test results on the three case study networks, namely the Sample, Purdue and Pulaski networks. Chapter 7.0 presents the summary findings and conclusions.

CHAPTER 2.0

SURVEY OF APPROACHES FOR ESTIMATING O-D TRIP TABLES FROM TRAFFIC COUNTS

2.1 Introduction

The early 1970's saw the dawn of theoretical approaches for estimating O-D trip tables using link traffic counts. The interest in these approaches was kindled by a need for a shift in planning philosophy from long term to intermediate and short term, necessitated by limitations in budget, time and manpower resources. Since then, different approaches to accomplish this task have evolved, incorporating various desirable features and refinements. Many prominent approaches are nonlinear, and are based on the general framework of trip table estimation utilizing link volumes.

Early approaches to this problem relied on linear or nonlinear regression analysis to construct demand models assuming a gravity-type flow pattern, for estimating trip table entries. These models, however, required data on zone-specific variables like population, employment etc. A later group of models based their estimation of trips on the network traffic equilibrium approach, with the aim of accounting for congestion effects. Yet another group attempted to extract a most likely trip table consistent with link volumes, through maximum entropy or minimum information approaches. Another group of models utilizes statistical techniques to produce future estimates based on prior information. Recent research has attempted techniques such as neural networks and fuzzy weights to solve this problem. The interest in the problem continues, as is evident by reports of enhancements and refinements to the above approaches.

2.2 Classification of Models

Willumsen (1978) presents a detailed review of methods for estimating an origin-destination matrix from traffic counts. A comprehensive and more recent review of these models is provided by O'Neill (1987) in her Ph.D. dissertation. Since then, newer approaches such as the linear programming approach (Sivanandan, 1991; Sherali et al.,1994), the neural network and fuzzy weighted approaches have been developed. Here, we adopt O'Neill's classification scheme, and we have added a new category of recent approaches. We confine our remarks to a brief review of the relevant literature. For further details and a critical discussion of these models, the reader is referred to O'Neill's dissertation and the specific documents. The recently developed linear programming approach has been included in the matrix estimation models.

The O-D estimation models can be classified as:

1. Parameter Calibration Models
    a. Linear
    b. Non-Linear
2. Matrix Estimation Models
    a. LINKOD Type
    b. Maximum Entropy - Minimum Information Type
    c. Statistical Estimation Type
    d. Linear Programming Model
3. Recent Approaches
    a. Neural Network Approach
    b. Fuzzy Weighted Approach

Different model variations have been proposed in the sub-classes of the above categorization. These approaches/models are briefly elaborated below.

2.3 Parameter Calibration Models

2.3.1 Conceptual Framework

The underlying concept in these models is to combine an assignment assumption with a distribution assumption to produce a consistent trip table.

If a travel demand model is assumed to be of the form:

$$t_{ij} = f(O_i, D_j, c_{ij}, \beta) \qquad [2.1]$$

where,

O_i, D_j	are explanatory variables,
c_{ij}	is a measure of travel cost or impedance,
β	is a vector of parameters,

then, by substitution, the general equation for trip table estimation, $v_a = \sum_i \sum_j p_{ij}^a t_{ij}$ takes the form:

$$v_a(\beta) = \sum_i \sum_j p_{ij}^a f(O_i, D_j, c_{ij}, \beta) + e_a \qquad [2.2]$$

where, v_a is the volume of traffic on link *a*, $p^a{}_{ij}$ is the proportion of trips between origin *i* and destination *j* using link *a*, and t_{ij} is the number of trips between zones *i* and *j*, and e_a is an error term.

These modeled link volumes are then compared with the observed volumes through regression analysis. The aim is to calibrate parameters to minimize the difference between the observed and estimated volumes. In notational form, the problem reduces to the following:

$$\min_{\beta} F(v, v(\beta)) \qquad [2.3]$$

where F is some measure of distance between observed and estimated link volumes. These parameters are then substituted in the equation [2.1] for t_{ij} to estimate the trip matrix.

As cited earlier, these models are either linear or non-linear, based on the regression type employed.

2.3.2 Linear Parameter Calibration Models

O'Neill (1987) reviews models formulated by Low (1972), Overgaard and Jensen and Neilsen (reviewed in Bendtsen, 1974), Holm et al. (1976), and Gaudry and Lamarre (1979). All models, except the one developed by Holm et al. (1976), adopt proportional all-or-nothing assignment, with other differences among the models attributable to variable definition and parameter selection.

Low's (1972) model obtains trip probabilities using the following equation:

$$t_{ij}^{n} = O_i \, D_j / c_{ij}^{s} \qquad [2.4]$$

where

O_i, D_j are zone specific explanatory variables,

$1/c_{ij}^{s}$ is a separation factor with parameter s,

t_{ij}^{n} is a trip probability using definition n for O_i, D_j and s.

Here, O_i, D_j and s can be defined in different ways to yield different trip tables. Each trip matrix is assigned to the network using the all-or-nothing assignment to produce trip probability factored volumes, x_n. These volumes are then compared to selected existing traffic counts with the aim of calibrating the following multiple regression equation:

$$v_a = c + \sum_i b_i x_i \qquad [2.5]$$

where c and b_i are parameters to be estimated.

These equations are then used as a volume forecasting model. In addition to forecasting, the model could also be used for replicating the present pattern of trips.

The models by Overgaard, and Jensen and Nielsen, when compared to Low's model, offer slight differences in zonal generation coefficients, explanatory variables, etc. Following Jensen and Nelson's model of iteratively determining the exponent in the gravity model, Holm et al. (1976) further developed this procedure by adopting Smock's (1962) iterative traffic assignment algorithm, thus incorporating capacity restraints into the solution. Gaudry and Lamarre (1979) developed a simple linear model accounting for heteroscedasticity of residuals. Another model in this category is based on a procedure parallel to Low's, developed by Neumann et al. (1983). Here, area-wide, all-purpose trip production rates are developed from traffic counts. The drawback of Low's, and most other methods, is the requirement of estimation of external trips to the study area, which are to be subtracted from observed counts.

2.3.3 Non-linear Parameter Calibration Models

Robillard (1975) and Hogberg (1976) investigated this type of model. Robillard's model uses the proportional assignment technique and hence does not consider capacity restraints. The problem of estimating an O-D table is shown to be equivalent to a general non-linear problem. The measure of closeness suggested in choosing an O-D matrix is given by

$$c(v_a, v_a(\beta)) = \sum_a (v_a - v_a(\beta))^2, \qquad [2.6]$$

where,

v_a is observed flow on arc a,

$v_a(\beta)$ is assigned traffic volume on arc a.

By employing a distribution assumption, the O-D matrix is then evaluated. A trip table so obtained is viewed as a nonlinear least squares estimate of an O-D matrix. However, this class of method is shown to be equivalent to a linear regression problem. It is also shown through an example, that the solution is not unique. Consequently, a distribution assumption is used to evaluate the O-D matrix.

Hogberg's (1976) model is a parameter calibration model of the nonlinear regression type, solved by means of a least-squares algorithm to get estimates of trips between origin-destination interchanges. The all-or-nothing assignment is employed here. In this model, the distance between districts, the number of inhabitants, and the number of employees in each district are used as exogenous variables. Three journey types are used in the gravity-type distribution model. Only a partial set of link counts is mandatory. Willis (1977) proposes an alternative nonlinear model for estimating an O-D matrix. This model accommodates a wider range of variables.

2.4 Matrix Estimation Models

2.4.1 General

Here, trip tables are extracted directly from known information without calibrating parameters as in parameter calibration models. Assumptions on how trips are distributed are utilized to overcome the problem of underspecification that arises when the number of known volume counts on links are fewer than the number of unknown trip interchanges.

The general relationship for the determination of O-D trip table entries is used here to form a feasible region, over which a functional form of a distribution assumption is optimized. O'Neill gives a general framework for these types of models, as shown below:

$$\min F(T,T^*) \qquad [2.7]$$

subject to:

$$v_a = \sum_i \sum_j p_{ij}^a t_{ij} \qquad [2.7a]$$

where, T represents the matrix of interest and T^* represents a reference matrix.

The reference matrix may be a target matrix, an outdated matrix, or even a structural matrix. Additional constraints could be added to the above problem, if required. In some matrix estimation approaches, in order to obtain a feasible solution, the constraints must be consistent. This is violated when the link volumes do not conserve flow. For various reasons, it is very likely that observed link volumes may not conserve flow. However, ways of eliminating inconsistencies in traffic counts have been provided by Van Zuylen and Willumsen (1980), Van Zuylen (1981), Van Zuylen and Branston (1982), and Barbour and Fricker (1989). The differences among the matrix estimation models can be attributed to the source of their derivation - whether derived as mathematical programming optimization models or developed from principles of econometric analysis. Another source of difference is the combination of distribution assumption, assignment assumption, and measure of distance employed. Data on target or prior trip table and observed link volumes on some or all network links are required by these models.

2.4.2 Types of Models

O'Neill (1987) classifies papers relating to matrix estimation techniques into three groups:

Group I:	LINKOD and related models
Group II:	Minimum information/Maximum entropy theory based models
Group III:	Statistical estimation models

The linear programming model developed at Virginia Tech can also be viewed as a matrix estimation model, and is hence classified here as the fourth group:

Group IV:	Linear programming model

The LINKOD-type models aim at deriving a solution that satisfies equilibrium assignment concepts. The maximum entropy/minimum information models, on the other hand, emphasize distribution assumptions. While trip distribution and traffic assignment are treated separately in these models, Erlander et al. (1979), and Fisk and Boyce (1983) propose combined distribution and assignment models. The Group III models attempt to consider the stochastic nature of the data in future estimates. All the above models use prior information in the form of a trip table to guide the solution. The linear programming model represents a non-proportional-assignment, user-equilibrium motivated, finitely convergent model for estimating O-D trip tables from available link volumes, based on linear programming principles.

2.4.3 Group I: LINKOD and Related Models

A comprehensive review of the development of this group of models and a critical discussion of the various related aspects is provided by O'Neill. This group of models is suitable for congested area analysis. In these models, the solution tends to approach the given prior information, which is made the target. However, adjustments are made to reproduce observed link volumes. Here, the main interest is in extracting an equilibrium trip table that is as close to the target as possible. Presented below are the formulations proposed by Nguyen (1977), that form the basis for this type of model. He exploits Wardrop's (1952) user-equilibrium principle for route choice and formulates a deterministic network equilibrium approach. He proposes two models stated as optimization problems.

In the first model, an O-D trip matrix is obtained by solving the following problem:

$$\min F(v) = \sum_{a} \int_{0}^{v_a} f_a(x)dx \qquad [2.8]$$

subject to:

$t_{ij} - \sum_r h_{r_{ij}} = 0, \forall i, j$ (zonal conservation of flow) [2.8a]

$h_{r_{ij}} \geq 0, \forall r, i, j$ (nonnegativity constraint) [2.8b]

$t_{ij} \geq 0, \forall i, j$ (nonnegativity constraint) [2.8c]

$v_a = \sum_r \sum_i \sum_j d_{ar_{ij}} h_{r_{ij}}, \forall a$ (analogous to general relationship) [2.8d]

$\sum_a f_a(v^*_a) v^*_a - \sum_i \sum_j u^*_{ij} t_{ij} = 0$ [2.8e]

(observed total travel cost = est. total travel cost)

where,

$f_a(x)$= volume-delay function for link *a*,

t_{ij} = travel demand between origin *i* and destination *j*,

h_{rij} = flow on route r connecting origin *i* and destination *j*,

$$d_{arij} = \begin{cases} 1 & \text{if link a is on route r between } i \text{ and } j \\ 0 & \text{otherwise} \end{cases}$$

v_a^* = observed link flow, and

u_{ij}^* = observed inter-zonal accessibility (travel time on any used route between zone *i* and zone *j* due to the equilibrium assumption).

Here, the observed link flows are explicitly considered. Giving a modified Frank-Wolfe algorithm for solving the problem, Nguyen suggests that this model is more appropriate for small networks, where observed traffic counts on all links can be easily obtained. Where this is not the case, or where large number of origins and destinations may render the solution procedure less efficient, he proposes an alternate formulation.

The alternate formulation, as given below, considers only observed inter-zonal accessibilities, thus relaxing the requirement on the need for all link counts.

$$\min F(v,T) = \sum_{a} \int_{0}^{v_a} f_a(x)dx - \sum_{i}\sum_{j} u^{*}_{ij} t_{ij} \qquad [2.9]$$

subject to:

constraints as in equations [2.8a][2.8b][2.8c] and [2.8d].

This model is suitable for large networks, and there is substantial reduction in input data, as claimed by Nguyen. Based on tests on a small problem, the author concludes that both of the above models produce trip tables that closely reproduce observed volumes when assigned to the network using user-equilibrium principle. A major deficiency of this approach is that the problem can have more than one solution that can reproduce the traffic patterns. This necessitates the use of a distribution assumption to identify the most likely table among the alternative solutions.

Nguyen's theoretical model became operational during the course of a Federal Highway Administration project in which the LINKOD system of models (Turnquist and Gur, 1979; Gur et al., 1980) were developed. The LINKOD system is comprised of two major components: SMALD and ODLINK SMALD (Kurth et al., 1979), a small area trip distribution model determines a trip table for a sub-area. This table is used to overcome the underspecification problem of Nguyen's formulation. It is used as the initial (target) table, which is corrected by the ODLINK model, such that the corrected table when assigned using an equilibrium principle, will replicate observed volumes on network links. An alternate approach for selecting the most likely trip table among optimal solutions is proposed by Nguyen (1984).

Turnquist and Gur (1979) and Gur et al. (1980) propose an enhanced and efficient iterative heuristic solution procedure for Nguyen's second model, again employing a modified Frank-Wolfe algorithm. This procedure, incorporated in the LINKOD system, also includes a heuristic method for correcting the initial trip table. Gur et al. (1980) have conducted tests of the LINKOD system on a sample network. The authors of the LINKOD model conclude that the algorithm has many desirable properties, including the capability to move towards a reasonable solution even when the starting table does not contain information about the solution table. Also, the table produced by the model approximates observed flows very closely. The computer effort required is reported to be only modest. The LINKOD model has been extensively tested and verified by Han et al. (1981), Han and Sullivan (1983) and Dowling and May (1984). A modification of the LINKOD model to handle partial traffic counts has been considered by many authors, including Nguyen (1984). The issue is identified as a case for further research. Most researchers of LINKOD models conclude that the performance of the model depends primarily on data requirements.

2.4.4 Group II: Minimum-Information/Maximum Entropy Theory Based Models

The above approaches for estimating a trip table from link counts, like the parameter calibration models and the network equilibrium based approaches, force the solution trip table to conform a gravity type pattern, or cause them to be as close to a prior trip table as possible. Van Zuylen and Willumsen (1980) criticize this by saying that these approaches do not make full use of the information contained in the link volumes. Since prior trip table information is used by other approaches to also take care of the underspecification problem, Van Zuylen and Willumsen suggest that this could be solved by introducing minimum external information. Following this idea, the authors have put forward two concepts - information minimization and entropy maximization approaches. The original models in these categories were proposed by Van Zuylen (1978) and Willumsen (1978), respectively. In the information minimizing approach, an attempt is made to choose a trip table that adds as little information as possible to the knowledge contained in the general equation for trip table estimation from link counts.

Based on the theory of information minimization, Van Zuylen (Van Zuylen and Willumsen, 1980) has derived a multi-proportional model for estimating a trip table, as follows:

$$\min F(v) = \sum_a \sum_i \sum_j t_{ij} p_{ij}^a \ln[(t_{ij} v_a^*) / (v_a t_{ij}^*)] \qquad [2.10]$$

subject to general relationship for trip table estimation [2.7a]

where,

t_{ij}^* = prior (or old) trip matrix,

$v^*_a = \sum_i \sum_j t^*_{ij} \, p^a_{ij}$,

and other notations are as defined earlier.

On similar lines, Willumsen (Van Zuylen and Willumsen, 1980) proposed a maximum entropy approach to solve the problem. This approach is more popular, and is detailed below. It is based on Wilson's (1970) application of the concept of entropy to the O-D trip matrix. Here, the most likely trip matrix is defined as the one having the greatest number of micro-states associated with it. Attempting to maximize the number of ways of selecting a trip matrix, Willumsen formulates the problem as:

$$max\, F(T) = -\sum_{i}\sum_{j}(t_{ij}\, ln\, t_{ij} - t_{ij}) \qquad [2.11]$$

subject to Eqn [2.7a], the general O-D matrix estimation relationship.

Where information contained in the prior matrix is to be used, the above formulation becomes,

$$max\, F(T, T^{*}) = -\sum_{i}\sum_{j} t_{ij}(ln\, t_{ij} / t_{ij}^{*} - 1), \qquad [2.11a]$$

subject to Eqn.[2.7a].

The derived table would be the most likely that is consistent with information contained in the link flows.

Both the above approaches are shown to reduce to a multi-proportional problem. In particular, the maximum entropy approach reduces to solving the following optimality conditions:

$$t_{ij} = t_{ij}^{*} \prod_{a} X_{a}^{p_{ij}^{a}}, \qquad [2.12]$$

where,

$$X_{a} = (\sum_{ij} t_{ij})^{1/L} . e^{-\lambda_{a}}, \qquad [2.12a]$$

and where L denotes the number of counted links, and λ_a is the Lagrange multiplier corresponding to the count on link a constraint. Van Zuylen and Willumsen (1980) also give an algorithm for solving the above problem [2.12], based on Murchland's (1977) algorithm for the multi-proportional problem. It is further indicated that the coverage of the problem has not been satisfactorily proved. Counts on all the links are not necessary. However, a complete set of counts is expected to yield better results. It is to be noted that both the above formulations require information on link usage proportions.

O'Neill (1987) summarizes the conditions to be satisfied by the maximum entropy model, in order for an estimated trip table to reproduce observed volumes fully, as: (1) consistency of link volumes (flow conservation), (2) consistency of prior trip table with observed flows and route choice proportions, and (3) consistency of route choice assumption with observed flows.

Many researchers (Hall et al., 1980; Van Zuylen, 1981; Van Vilet and Willumsen, 1981; Willumsen, 1982; Bell, 1983; Nguyen, 1984) have conducted tests or have proposed improvements on this type of model. Of particular interest is the attempt to consider the effects of congestion, through equilibrium assignment. Willumsen (1982) proposed and tested a heuristic model that includes the equilibrium principle. Bromage (1988), while at Central Transportation Planning Staff (CTPS) in Boston, programmed the maximum entropy model, incorporating a capacity restraint procedure for the assignment step, as a module in the software package, "The Highway Emulator (THE)." This program was enhanced by Beagan (1990), also of CTPS, to include an equilibrium assignment option, as proposed by Hall et al. (1980). Further refinements were made to THE by Bromage (1991 and after). A recently refined version of the trip table estimation module of THE was obtained from Mr. Bromage for use in this research. Hammerslag and Immers (1988) suggest some possibilities for improvement for this group of models. Fisk (1988) has shown how to combine the maximum entropy and the user-optimal assignment into one problem. It is also shown by Fisk (1989) 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 satisfy equilibrium flow pattern. In a recent approach, Brenninger-Gothe, Jornsten, and Lundgren (1989) present a multiobjective programming formulation using entropy function, for estimating O-D matrices, where efficient points are sought which compromise between the separation of the solution from the observed traffic counts versus that from the prior target O-D matrix. O'Neill (1987) concluded that the maximum entropy models require further verification and refinements.

2.4.5 Group III: Statistical Estimation Models

The models in this category attempt to estimate trip tables directly from prior estimates, using statistical techniques. The two techniques employed to achieve the objectives in this group of models are Bayesian inference methods and least squares estimation techniques. These models consider the stochastic nature of data.

Criticizing the maximum entropy or minimum information approaches as being prone to giving little weight to the prior information, Maher (1983) points out the need for incorporating the measure of degree of belief in prior estimates. Based on Bayesian statistical inference, he proposes a method that allows the flexibility of placing different degrees of belief in the prior information, for estimating a posterior trip table. This method, however, is based on a proportional assignment assumption, and requires that these proportions be known beforehand. In the category of least squares estimation approaches, Carey et al. (1981), McNeill and Hendrickson (1985), and Cascetta (1984) have proposed model formulations. Cascetta (1984) proposes a generalized least squares estimator for the trip table matrix, by combining the estimation with traffic counts through an assignment model. The hypothesis here is that the direct or model estimators used for this purpose are unbiased, and that there are negligible misspecification errors in the assignment model. Tests on real data are not known to have been carried out.

Thus, the advantage of Group III models lies in their consideration of stochastic nature of data and the problem. However, these models need to be further tested, especially on real data. Also, the equilibrium assignment principle needs to be incorporated into these models, to account for congestion. O'Neill (1987) has combined the equilibrium assignment concept, that is applicable in urban analysis, with the incorporation of stochastic nature of data, into the trip table estimation process to produce a heuristic model. Here, the equilibrium proportion estimation method, and the assignment model have been combined with the trip matrix estimation process through statistical techniques. The two steps, one associated with each component technique, are iteratively solved to get an acceptable solution. O'Neill has concluded based on tests on a small network, that the model cannot be rejected, but that further tests need to be conducted.

2.4.6 Group IV: Linear Programming Model

With the objective of overcoming certain weaknesses of earlier models, a new linear programming approach was developed at Virginia Tech. A detailed description of the development this model and preliminary test results are presented in the Ph. D. dissertation of Sivanandan (1991) and in the paper by Sherali, Sivanandan, and Hobeika (1994). The model is a non-proportional-assignment, user-equilibrium motivated, linear programming model for estimating O-D trip tables from available data on link traffic volumes. The model is designed to determine a traffic equilibrium network flow solution that reproduces the link volume data, if such a solution exists. The model's solution also has a tendency to match a specified prior target trip table as closely as possible.

The linear programming model is formulated as below (Sherali et al., 1994):

$$\text{Minimize} \sum_{(i,j)\in OD} \sum_{k=1}^{n_{ij}} \tilde{t}_{ij}^{k} x_{ij}^{k} + Me\cdot(y^{+} + y^{-}) + M_{\sigma} \sum_{(i,j)\in\overline{OD}} (Y_{ij}^{+} + Y_{ij}^{-}) \qquad [2.13a]$$

$$\text{subject to} \quad \sum_{(i,j)\in OD} \sum_{k=1}^{n_{ij}} p_{ij}^{k} x_{ij}^{k} + y^{+} - y^{-} = \bar{f} \qquad [2.13b]$$

$$\sum_{k=1}^{n_{ij}} x_{ij}^{k} + Y_{ij}^{+} - Y_{ij}^{-} = Q_{ij} \qquad \forall (i,j)\in\overline{OD} \qquad [2.13c]$$

$$x \geq 0, \quad y^{+} \geq 0, \quad y^{-} \geq 0, \quad Y^{+} \geq 0, \quad Y^{-} \geq 0. \qquad [2.13d]$$

where,

OD is set of origin-destination (O-D) pairs comprising the trip table

$\overline{OD}$ is some key O-D pairs for which target trip values are specified

(i,j) is O-D pair from origin i to destination j

k is path identifier between different O-D pairs

n_{ij} is number of paths between O-D pair (i,j)

$\tilde{t}_{ij}^{k}$ is weighted impedance on route k between O-D pair (i,j)

$$\tilde{t}_{ij}^{k} = \begin{cases} t_{ij}^{k} & \text{if } k \in K_{ij} \\ M_{1} t_{ij}^{k} & \text{if } k \notin K_{ij} \end{cases}$$

t_{ij}^{k} is impedance on route k between O-D pair (i,j)

K_{ij} is set of paths between O-D pair (i,j) whose path costs are equal to the shortest path for the O-D pair (i,j)

x_{ij}^{k} is flow on path p_{ij}^{k}, for each $k = 1,\ldots,n_{ij}$, $(i,j)\in OD$

e is vector of ones

y^{+} (y^{-}) is vector of positive (negative) deviations in link flows

$Y^+ (Y^-)$ is vector of positive (negative) deviations from targeted trip table values

p_{ij}^k is k^{th} path between O-D pair $(i,j) \in OD$

$\bar{f}$ is vector of observed link volumes

Q_{ij} is Prior (target) trip table value for O-D pair $(i,j) \in \overline{OD}$

M_1 and M_σ are scalar penalty parameters.

A modified column generation solution technique has been presented to optimally solve the above problem. The model incorporates several desirable features, as elaborated in Chapter 3.0. The preliminary test results indicated the superiority of this model over the maximum entropy and LINKOD models (Sherali et al., 1994).

The above model had a limitation in that it required the specification of volume information for all the links of the network. Since this may not be always available, the model was enhanced recently, adding the capability to estimate O-D trip tables even when only a "partial set" of link volume information is available. The proposed approach formulates a sequence of linear programs to approximate a fundamentally nonlinear optimization problem that is employed to estimate O-D flows, given incomplete network flow information (Narayanan, 1995).

The linear programming model was chosen as a candidate for further evaluation in this study.

2.5 Recent Approaches

2.5.1 Introduction

There have been several attempts recently to apply newer concepts to derive O-D trip tables. These include use of neural networks, fuzzy weights, etc. to account for the uncertainty of the surveyed data. Two of these approaches are briefly elaborated below.

2.5.2 The Neural Network Approach

Neural network models are algorithms for cognitive tasks, such as learning and optimization, which are in a loose sense based on concepts derived from research into the nature of the brain.

Chin, Hwang and Pei (1994) have described a neural network model for generating origin-destination information for traffic circles based on observed flow volumes on approaching and existing legs. There has been some previous research in this area, wherein Yang, Akiyama and Sasaki (1992) adopted a feed forward neural network model for synthesizing O-D flows for a four-way intersection and a short freeway segment. Based on simulation results, Yang et al. showed that a back propagation based method was able to estimate turning movement ratios with high tracking ability and stability. The Chin et al. model, however, might depend on the geometry of the network and the availability of link traffic volumes. More data from different traffic circles are needed to further verify the findings of this study. The inference drawn in their case was that, if the model could “learn” the “rules” based on simulated data and make inferences regarding actual information collected from streets, then it would be an actual intelligent model.

2.5.3 The Fuzzy Weighted Approach

Another recent development has been the fuzzy weight approach towards developing the origin destination table. Xu and Chan (1993) designed an experiment to compare probabilistic multi-path against all-or-nothing (i.e., single path) traffic assignment in O-D estimation algorithms. The theory states that the link count is no longer viewed as a precise, infallible piece of fact. In fact, imprecision is explicitly recognized and is attributable to counting errors or causal factors such as obstruction to traffic flow. Such imprecision is modeled by the subordinate function which quantifies the level of “fuzziness” of the above data.

This fuzzy mathematics is used to take the error of link counting into consideration, rather than using a single infallible value of each link count. An algorithm is then suggested through the inclusion of the fuzzy weights and probabilistic assignment during volume allocation.

The Eastern Highway Corridor network was used as case study to evaluate this model. Later, it was concluded based on the results obtained, that the FWA, as it is popularly referred to, yielded a more accurate O-D estimates in all studies when compared with regular O-D estimation algorithms. The same can be said about probabilistic assignment, which was found to yield better accuracy when compared with all-or-nothing assignments. Even so, the authors recommend additional case studies and experimentation to support the controlled experimentation reported in this case.

2.6 Summary of Literature Review

The above review of different approaches to synthesize trip tables from link counts has exposed the complexities associated with the problem, and the attempts by various approaches to overcome them. Each of the approaches/models seems to have certain strengths and weaknesses. A brief summary of these is presented below.

Parameter calibration models use zone specific variables, such as information on population, employment, etc., in formulating the demand model. All of these referenced models employ all-or-nothing traffic assignment, with the exception of one model. The use of these models is unattractive, since they require considerable data, which, furthermore, may become outdated as changes in land use take place. This raises the issue of reliability of data for use in a model. Another drawback of parameter calibration models is that they fail to incorporate the equilibrium assignment principle, which is relevant in congestion related contexts.

In the category of matrix estimation models, although the LINKOD type models incorporate the desired equilibrium assignment concept, their nonlinear nature renders them infinitely convergent, leading to the issue of the computational effort required for deriving acceptable solutions. The minimum information/maximum entropy models, on the other hand, pose restrictions on data requirements (such as consistency of flows), in addition to being theoretically complex. Yet, this approach has found wide use. The maximum entropy approach as incorporated in The Highway Emulator (THE) was one of the candidates for evaluation in this study. The linear programming model has yielded encouraging results based on preliminary tests, and was the other candidate for evaluation in this study. The limitations of these models are discussed in Chapter 3.0.

The statistical estimation models possess the desirable quality of considering the stochastic nature of the data and the problem. However, they have not been well-tested, and further work needs to be done in accounting for congestion considerations. The neural networks approach and the fuzzy set approach, which have been the latest developments in this field, though promising, still need to be verified by testing on real networks.

CHAPTER 3.0

SELECTION OF MODELS AND CASE STUDIES

3.1 Models Selected

To determine the extent of usage of the different approaches/models that estimate O-D trip tables using link volumes, and the experiences of users of computer programs that have incorporated these models, several transportation professionals in government and private organizations were contacted and interviewed. These individuals had either developed the programs themselves or had applied them to case studies. Based on this investigation, the following three models were considered for the selection process. All the three models were available as computer programs, and were known to have been used for real applications.

- Maximum Entropy Model
- LINKOD/Network Equilibrium Model
- Linear Programming Model

The concept of maximum entropy has been incorporated in several computer programs, such as The Highway Emulator (THE), TMODEL2, and TRIPS. It was learned through personal communications that of the three, the THE model is popular, and has been or is being used for several applications. The Center for Transportation Research had previous experience in using THE, and the developers of the latest version (4.0), Mr. Ed Bromage (now with Louis Berger and Assoc., Inc., Boston) and Mr. Dan Beagan (CTPS, Boston) were cooperative and helpful in providing us the new version (Bromage, 1991). Hence, THE was selected for evaluation in this research. An enhanced version of the trip table estimation program (within THE) recently provided by Mr. Ed Bromage was used for test purposes. The LINKOD model (network equilibrium approach) has not proved to be very successful, as per the comments of several professionals who have had experience in using it. While computer programs have been developed incorporating this approach, difficulties were reported in applying it to actual studies. The linear programming model (LP) developed at Virginia Tech was readily available for testing, with further refinements and enhancements. It also proved to be superior to THE and LINKOD models based on preliminary tests (Sherali et al., 1994).

Based on the above, the following two models were selected for application to case studies, and for detailed evaluation:

- The Highway Emulator (THE) model
- The Linear Programming (LP) model

3.1.1 The Highway Emulator (THE) Model

THE model (Bromage, 1991) is a microcomputer highway traffic simulation model for modeling of individual communities, corridors, sections of counties and analysis of small sections of major cities. Two distinct modeling approaches are incorporated in THE. The first utilizes the traditional four step urban transportation planning methodology. The second utilizes the maximum entropy algorithm for estimating trip tables from link traffic volumes. It extracts a most likely trip table that will produce observed traffic counts. The trip table estimation program is based on the maximum entropy formulation and algorithm detailed by Van Zuylen and Willumsen (1980). A maximum entropy algorithm is one which attempts to define a trip table with the maximum degree of disorder or random exchange between zones. Besides regional and sub regional modeling efforts, this model can be applied to estimate origin-destination tables for traffic circles, one way streets in a CBD, freeways, toll roads and other limited access facilities.

3.1.1.1 Trip Table Estimation Procedure

The program first assigns a seed trip table to the specified network. While the assignment is in progress the program creates a link use probability file. These probabilities are used to make adjustments to the trip exchange matrix in order to duplicate the observed volumes. The next step is the actual application of the trip table estimator algorithm. The algorithm is iterative and may take up to one hour for each iteration, for large networks. The output of the trip table estimation program is a new trip table which closely duplicates the observed traffic counts for the given probabilities. The above steps are repeated to satisfy the number of calibration iterations. For microcomputer applications, with respect to handling large networks, the trip table estimation program can handle a maximum of 300 traffic zones and up to 500 links (Bromage, 1991). From personal communication with Mr. Bromage, it is understood that it can handle greater number of links.

3.1.1.2 Data Requirements

THE requires the following data as input for running the trip table estimation program:

Node numbers at each end
Link length in miles
Free flow speed on the link
Link delays (if any)
Whether link is one way or two way
Any additional impedance (such as a zone connector terminal time)
Hourly capacity for each direction
Link volumes (preferably for all links, but partial counts also accepted)
Prior (target) trip table, if desired to guide the solution (a structural table could also be used)

The network coding is based on traditional methods, and is outlined in NCHRP Report # 187. It is also consistent with FHWA's UTPS coding scheme. It must be noted that it cannot accept a node with more than four connections. In such cases, dummy links are needed. However, turn links can be coded. In terms of user parameters to be supplied, THE requires the specification of number of iterations for maximum entropy process, assignment and calibration. However, default values for these can also be used. These values for the tests were chosen based on judgement.

3.1.1.3 Model Restrictions

The Highway Emulator has several restrictions while running the trip table estimation program. While some of the restrictions are minor and/or internal to the model, certain others have implications for data collection and manipulation. These are briefly described below (Bromage 1991).

Balanced flow at nodes: The THE manual states that for the trip table estimation program, it is necessary to provide balanced traffic counts, except for roadway segments intersected by traffic zone connectors. This means that the total traffic volume entering an intersection node must be equal to the total volume exiting it; flow must be conserved. While this is a restriction, was learned from Mr. Bromage that the model can still be run without balanced flows. However, this may affect the quality of the results. Also the volume of traffic at one end of a link must be the same as that at the other end.

Assignment to Produce Observed Counts: Another constraint for THE's trip table estimation program, as stated in the manual, is that the assignment of the estimated trip table must produce the observed volumes. The algorithm works by adjusting a seed trip table slightly in order to match the observed volumes. If a trip table cell has some or all of its volumes assigned to a network link for which there exist observed volumes, then that cell is adjusted so that the above-mentioned constraint is met. However, we learned from the model developer that there may be instances where this is not possible, in which case the model will still work and the algorithm will attempt to match the observed volumes as closely as possible.

Counts on links: The THE manual states that "the trip table program works very well if traffic counts are available for every network link, including those that connect traffic zones. Unfortunately, traffic volume data is usually known on only a fraction of the network links which comprise the highway network. Without traffic count data on zone connectors and on virtually every network link, the trip table estimation program will take great liberty in defining what volume should be on the zone connector." The manual recommends that the trip table estimation program should be used in conjunction with a gravity model distribution in situations where traffic volume data is not known for traffic zone connectors.

Mr. Bromage explained that the model can still be run in the absence of such complete information. However, complete volume information is very desirable for obtaining superior quality results.

3.1.2 The Linear Programming (LP) Model

This new approach to estimating trip tables from ground counts has been developed at Virginia Tech (Sherali et al., 1994). The model employs the non-proportional assignment assumption, and finds a user equilibrium solution which reproduces the observed link flows whenever such a solution exists. 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. However, if there does exist a user equilibrium solution that reproduces the link flows, the model, with suitable penalty parameters, will determine such a solution along with the corresponding O-D trip table. Additionally, due to the potentially large number of alternative paths to be considered between the different O-D pairs, an efficient column generation technique that utilizes shortest-path subproblems in order to determine an optimal solution to the linear programming model has been developed. The model is also designed to handle the situation in which a prior target trip table is specified, and it is required to find a solution that, in addition to the foregoing considerations, has a tendency toward reproducing this table as closely as possible.

This model has been programmed in FORTRAN for computer runs. One of the weaknesses of the original linear programming model was that it required the specification of volume data on all the links of the network. This data, however, is hard to obtain for real networks. Realizing the constraint, the model was enhanced to accommodate missing volume data, and to estimate O-D tables even when only partial sets of link traffic counts are available. This enhancement was also programmed for computer applications (Narayanan, 1995).

The notation "LP" is used in this report to refer to linear programming models in general, and not to the specific formulation named "LP" by Sivanandan (1991) and Sherali et al. (1994). Several versions and different formulations of the model evolved during the development and enhancement of the approach. Thus, more than a single version or formulation has been used in this research.

3.1.2.1 Data Requirements

The linear programming model (LP) requires the following data input for running the trip table estimation program:

Zones, nodes and link numbers (traditional network coding method)

Hourly capacities, free-flow speeds and lengths of links (alternatively, if current travel times on links are known, it will suffice)
Whether link is one way or two way
Link volumes (preferably for all links, but partial counts also accepted)
Prior (target) trip table data (optional) (a structural target could also be used)
Any link delays and additional impedance, if appropriate, may be included in the current link travel times.

For this model, the user also needs to input a value for a parameter to reflect the relative degree of importance in minimizing the trip table deviations (modeled vs. targeted) versus the link flow deviations (modeled vs. observed). These parameter values for the tests were chosen based on judgement.

3.1.2.2 Model Restrictions

The LP model accommodates inconsistencies in link volumes and does not require balanced flows at nodes. However, the model will yield better results in the absence of such discrepancies. It can also accept more than four links joining at a node.

Counts on Links: The original version of the model required that traffic count data on all the network links be given as input. However, during the course of the research, the model was enhanced to overcome this restriction, and can now estimate O-D tables with partial set of volume data. But superior results can be expected with more complete volume information.

Network Size: The limitation of the LP model with regard to network size arises mainly due to limitations in allocating array sizes in the computer program. The array sizes in the model are influenced by the number of constraints of the optimization program, which are based on the number of links and the number of

O-D interchanges to be targeted. However, since this restriction is compiler and computer based, it can be overcome through the use of an enhanced compiler and a powerful computer. Also, the computation time for model runs tend to grow rapidly with an increase in network size.

3.2 Case Studies

Considerable effort was expended in attempts to obtain real data sets for evaluation of the selected models. Several officials from FHWA, state DOTs and local governments were contacted. Many of these officials were met in person, either in their offices or at technical meetings and conferences. This effort led to identification of several data sets for possible consideration for evaluation. These networks were: (1) Norfolk CBD, (2) Conway, Arkansas, (3) Albemarle county and Charlottesville city network, and (4) Northern Virginia network (portion of beltway). The network details and/or data sets were obtained for these networks through contacts. Networks were investigated in detail to see if they could be used as case studies for evaluating the models. It was concluded that none of the above networks were suitable for use, mainly because these networks could not provide the required data for a more meaningful evaluation of the models.

Finally, the following three networks were chosen as case studies.

(1) Sample Network

While the objective of this research work was to test the models on real data sets, there are distinct advantages to testing on sample networks, which offer features ideal for evaluating several aspects of the models' performance. For this purpose, detailed testing and analysis of the models was performed on a small sample hypothetical test network (Gur et al., 1980) which was selected for its useful features. This network had 6 zones, 6 intersection nodes and 18 links. Further details about the network are provided in Chapter 4.

(2) Purdue University Network

Through personal contact and correspondence with the researcher (Dr. J. D. Fricker of Civil Engineering) at Purdue University, network and data sets were obtained for the Purdue University campus. This was a real network for which 100% link volumes and a prior trip table believed to be "reasonable good" by Purdue researchers were available. Since the provided network structure could not be directly used for our modeling purposes, it had to be restructured and recoded and the data had to be modified and input to suit our model application. This network had 16 zones, 43 intersection nodes and 130 links. More details about the network are provided in Chapter 5.

(3) Pulaski Town Network

This case study was suggested by the Virginia Department of Transportation (VDOT). The study of the Pulaski network was important as a more realistic validation, because a surveyed trip table was available (provided by VDOT) for comparison purposes. VDOT also provided us with 24 hour volume data (collected at 15 minute intervals) for the network. VDOT's interest was in obtaining both the 24 hour and the peak hour trip table through the models. It must be noted that the volume information was made available only for approximately 75% of the links. Most of the remaining 25% of the links constituted centroid connectors, representing abstract links for which actual volumes cannot be obtained. This adds another realistic element in the evaluation of the models. The Pulaski test network consisted of 32 zones, 57 intersection nodes and 230 links.

3.3 Evaluation Criteria

To compare the test results of the two models, two measures of closeness are used in judging the results. The first measure is based on the replication of link volumes by the solution trip table. This is accomplished by comparing the output link volumes with the observed volumes. The second measure is the closeness of the solution table to the target table. These two criteria are obvious choices, since the objective of the problem of the trip table estimation is to determine a table that replicates observed link volumes, and is as close to the target table (if provided) as possible.

3.3.1 Replication of Observed Link Volumes

One of the most important measures of the quality of the trip table is its ability to replicate observed volumes on the network links. This is a measure of how consistent the solution trip table is with the observed link volumes. The modeled volumes for both THE and LP were obtained as byproducts of trip table estimation procedures. For cases where less than 100% observed volumes were used (even though 100% volume data may have been available), the replication criteria was applied only to links for which observed volumes were provided as input.

The Percentage Root Mean Square Error (% RMSE) and Percentage Mean Absolute Error (% MAE) were chosen as measures of error rate to compare the closeness of modeled volumes to the observed volumes. These measures are defined as follows:

$$\%RMSE = \sqrt{\frac{\sum_{a \in A_v}(V^a_{assign} - V^a_{obs})^2}{n}} * \frac{100 * n}{\sum_{a \in A_v} V^a_{obs}}$$

$$\%MAE = \frac{\sum_{a \in A_v} | V^a_{assign} - V^a_{obs} |}{\sum_{a \in A_v} V^a_{obs}} * 100$$

where,

V^a_{assign} = assigned volume on link a.

V^a_{obs} = observed volume on link a.

n = number of links with available volumes

A_v = set of links with available volumes

The smaller the values of these measures, the better is the replication of observed link volumes. Ideally, values of zero for each of these measures mean perfect replication.

3.3.2 Closeness of Estimated Trip Tables to the "True" or "Correct"/ "Reasonably Good"/ "Surveyed" Tables

The validity of a solution trip table can best be evaluated by comparing how close it is to the "true" or "correct" (if known) trip table. However, the purpose of these models is to establish a trip table when it is currently not available. Hence, the use of a "true" or "correct" trip table is of interest mainly for evaluation purposes. Another major issue is how to obtain this "true" / "correct" table. For several reasons, obtaining such a table may be impossible. However, as a compromise, one can use a table obtained through a survey (if available) or one that is believed to be "reasonably good."

There are various measures of closeness for comparing trip matrices. Smith and Hutchinson (1981) evaluate different goodness of fit statistics for trip distribution models and conclude that the PHI-statistic (ϕ) is one of the most appropriate to test the goodness of fit of alternative trip distribution models. The mean absolute error statistic has also been reported as a useful indicator. Consequently, the %RMSE, %MAE and ϕ are used in the analysis for trip table comparisons. These measures of closeness are defined below:

$$\% RMSE = \sqrt{\frac{\sum (t_{ij} - t_{ij}^*)^2}{n_{OD}}} * \frac{100 * n_{OD}}{\sum t_{ij}^*}$$

$$\% MAE = \frac{\sum |t_{ij} - t_{ij}^*|}{\sum t_{ij}^*} * 100$$

$$\phi = \sum \max(1, t_{ij}^*) \left| \ln \frac{\max(1, t_{ij}^*)}{\max(1, t_{ij})} \right|$$

(Note: The above definition of ϕ has been slightly modified from Smith and Hutchinson (1981)).

where,

t_{ij}^* = true/correct/reasonably good/surveyed number of trips for O-D interchange (i, j)

t_{ij} = estimated or modeled number of trips for O-D interchange (i, j)

n_{OD} = number of feasible O-D interchanges

Since the above statistics are measures of error in estimation, the smaller the values of these measures, the closer are the tables under comparison (modeled) to the evaluation (correct/surveyed etc.) table. Ideally, values of zero for each of these statistics would mean that the estimated table is the same as the evaluation table.

Chapter 4.0

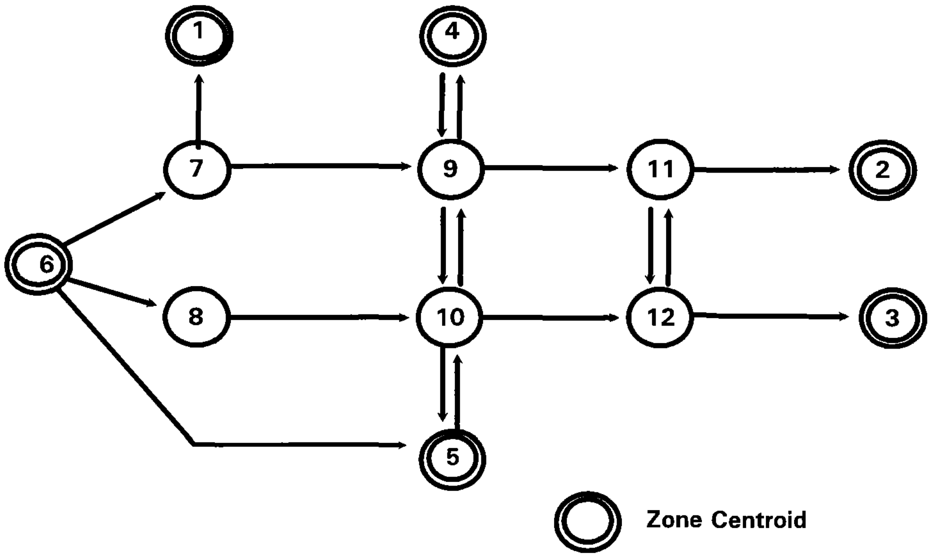
Evaluation of Models Using Sample Network Data

4.1 Introduction

This chapter and the following two chapters present the details of application of the two models, THE and LP, on the three networks. The details of the tests on the sample network are presented in this chapter. Chapter 5 deals with test results for a real network, which represents a one square mile area of Purdue University in West Lafayette, Indiana. The application of the models on the real network of Pulaski, Virginia is presented in Chapter 6.

4.2 The Sample Network

The sample network chosen for the tests is a hypothetical network called the “corridor network,” reflecting a travel corridor (Gur et al., 1980). This network was used extensively for tests while developing the LINKOD system of models. The network consists of 6 zones, 6 intersection nodes and 18 links. Although it is a hypothetical network, it has multiple routes between some O-D pairs and multiple equilibrium solutions, thus presenting an opportunity to apply and test the equilibrium concepts that account for congestion effects. Another desirable feature of this network is that the conservation of flow is satisfied at all intersection nodes, as required by some models. Finally, due to its small size, it is ideal for performing extensive tests without having to expend too much computational effort. This network and its attributes are shown in Figure 4-1.



Link Number	Beginning Node	Ending Node	Observed Volume
1	4	9	2400
2	5	10	2000
3	6	5	100
4	6	7	5000
5	6	8	500
6	7	1	500
7	7	9	4500
8	8	10	500
9	9	4	2000
10	9	10	1500
11	9	11	4900
12	10	5	1600
13	10	9	1500
14	10	12	900
15	11	2	4800
16	11	12	300
17	12	3	1000
18	12	11	200

Fig 4-1: Sample Network and its Characteristics (Source: Gur et al., 1980)

4.3 Model Tests

The LP and THE models were tested separately for several cases of availability of link volumes and prior trip table information. The models were then judged based on their ability to match the prior table as closely as possible, and at the same time their capability to replicate the observed volumes. A model will be judged good if it can achieve both the above objectives. For the measures of closeness, %MAE, %RMSE and PHI statistics were used for the table comparisons, and %MAE and %RMSE for the volume comparisons. These measures are defined in Chapter 3.0.

4.3.1 Target Trip Tables

A target trip table is a useful device that resolves the underspecification of the O-D table estimation problem in the presence of multiple optima (alternate solution trip tables). Here, the solution table is guided toward that which is closest to the target table. Different target tables can, however, be used, leading to different possible solutions. A prior table could be a structural table, with zeros and ones in the cells, to ensure that the final table retains a similar structure, or it could be a “no-prior-information” table with all feasible interchanges assigned the same value of trips. Better still, the target table could be one that is somewhat close to the “correct” solution, based on an older table or on some historical data or estimation process. Finally, the “correct” trip table can also be used as target, for testing the models from the perspective of academic interest. The accuracy of the final solution will naturally depend on which target table is provided. The following target trip tables were used for this case.

a) Structural Target Trip Table: This represents a table which has 1 or 0 as cell values, depending on whether the O-D interchange corresponding to the cell is feasible or not, respectively. This target trip table is used when there is no prior trip table information available.

b) "No-Prior-Information" Target Trip Table: The no-prior-information trip table has a uniform value of 983 trips for all feasible O-D interchanges. This table is reported to match the total observed vehicle hours traveled on the network.

c) "Relatively Small Errors" Target Trip Table: The relatively small errors target trip table is one that is somewhat close to the "correct" solution, but still does not reproduce observed flows on links when assigned to the network.

d) "Correct" Trip Table as Target: This is a precise user equilibrium solution that replicates link flows. This target is of only theoretical interest.

Tables b), c) and d) were used by Gur et al. (1980) in testing the LINKOD system. For each of these three tables, the sensitivities of the models to partial target table information were tested by providing different percentages (ranging from 45% to 100%) of target table information. Since the network and the total number of O-D interchanges are small, cells for which the information was assumed missing were determined arbitrarily.

4.3.2. Missing Volume Cases

Generally, volume data for all the links of a network may not be available. This leads to the need for studying the sensitivity and performance of models when only partial link volume information is available. For the sample network, six cases (50%, 60%, 70%, 80%, 90% and 100%) available volumes were tested. The data for these cases were generated by assuming that volume information on some links were missing. These links were arbitrarily determined, because of the nature of the network and due to its small size.

4.3.3 Summary of Test Cases

In summary, 78 cases were tested for each of the models. These cases, arising out of a combination of different percentages of target trip table and link volume information availability, are shown in the following table. IBM compatible personal computers were used for the test runs.

Table 4.1: Summary of Test Cases for Sample Network

Target Table	% Available Target Info.	% Available Link Volumes						Total Cases
		50%	60%	70%	80%	90%	100%	
Struct.(0/1)	100% cells	●	●	●	●	●	●	6
No Prior Information	45% cells	●	●	●	●	●	●	6
	64% cells	●	●	●	●	●	●	6
	82% cells	●	●	●	●	●	●	6
	100% cells	●	●	●	●	●	●	6
Small Errors	45% cells	●	●	●	●	●	●	6
	64% cells	●	●	●	●	●	●	6
	82% cells	●	●	●	●	●	●	6
	100% cells	●	●	●	●	●	●	6
Correct Table	45% cells	●	●	●	●	●	●	6
	64% cells	●	●	●	●	●	●	6
	82% cells	●	●	●	●	●	●	6
	100% cells	●	●	●	●	●	●	6
Total Cases		13	13	13	13	13	13	78

4.4 Discussion of Model Results

Extensive model runs for different combinations of available information in the form of link volumes and prior trip tables were used to analyze and verify the performance of the models and their sensitivity to different levels of data. This exercise was worthwhile from a theoretical perspective. Since it was created artificially, the sample network satisfies many ideal characteristics, such as conservation of flows at each node, presence of network equilibrium flows, and availability of a "correct" trip table solution that is also fully consistent with network volumes. A detailed discussion of results for various cases are presented below (Narayanan, 1995).

As shown in table 4-1, four cases of target were used for test purposes. The discussions below are structured around these four cases, and highlight the performance of the LP and THE models. For this case, a model is judged based on its ability to match the "correct" table (which is known) as closely as possible, and at the same time its capability to replicate the observed volumes. A model will be judged good if it can achieve both objectives. The discussion of results presented below centers around these two criteria.

(a) Structural Table as Target/Seed: This kind of target/seed trip table is used when no prior trip table information is available. In this case, the least amount of information is provided in the form of target. Both THE and LP were run with this target for the six cases (50%, 60%, 70%, 80%, 90% and 100%) of available link volumes. The resulting trip tables were then compared with the correct trip table. Also, the modeled volumes were compared with observed volumes to test how well the models are able to replicate the volumes.

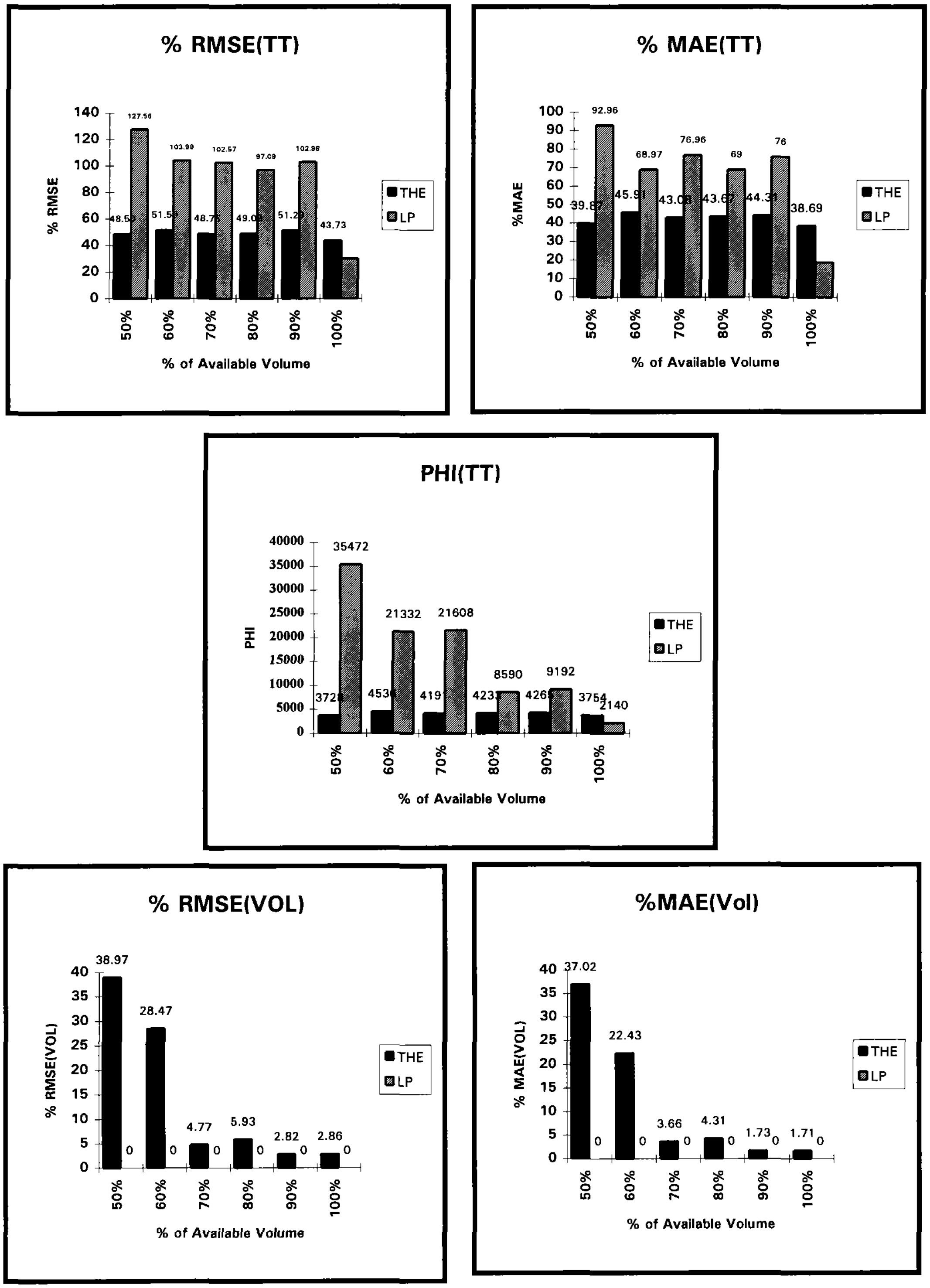
The results of comparisons for both the models (Figure 4-2) show that in general, The Highway Emulator yielded trip tables that were closer to the "correct" trip table, as compared to the LP model tables. This is highlighted by %RMSE (TT), %MAE(TT), and PHI (TT) statistics.

For the LP model, the %RMSE of the deviations from the correct trip table values varies from 30%-128%, which is to be expected when the target table contains almost no information. The mean absolute error percentages for trip table deviations also are high, as expected. While increasing the availability of link volume information seems in general to decrease the measures of error rates, the test results show that a statement on the monotonicity of the decrease cannot be made. While the decrease of the measures of error rates, with increasing knowledge of link volumes, is perceptible for the MAE and RMSE statistics, it is not as dramatically visible as the φ statistic's variation. The largest error rate as measured by this statistic, occurs when only 50% of the link volumes are available. Increasing the availability of link volumes rapidly decreases this error rate. Another noteworthy observation is that the available link volumes are perfectly replicated for all six cases of available volumes, as indicated by the zero values for the %MAE and %RMSE.

In contrast to the performance of the LP model, THE performs much better for the structural target table input. The RMSE, MAE and φ for trip table deviations are significantly lower for most cases, now ranging only between 44%-52%, 39%-46% and 3728-4536, respectively. However, unlike the linear programming approach, the replication of observed volumes is not perfect for any case of available link volume percentages. In fact, for the 50% and 60% available link volume cases, the RMSE and MAE for link volume deviations are significantly high.

Figure 4-2: Trip Table (Modelled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Structural



The above results lead to the following conclusions. THE yields superior results for the 70%, 80%, 90% and 100% available link volume cases. This conclusion is based on the facts that the trip table error statistics for THE are significantly lower, while its link volume replication is quite good. However, for the 50% and 60% available link volume cases, this model is unable to replicate observed link volumes satisfactorily. In contrast, the linear programming approach performs exceptionally well for all the cases of available link volumes, with respect to link volume replication. It replicates link volumes exactly with zero error. However, the error statistics for the output trip tables show that its performance, in general, is not comparable to that of THE. It must be added that the performance of either model for the 50% and 60% link volumes is questionable in this case, because of the high values for trip table errors for the linear programming model and unsatisfactory replication of observed link volumes by THE. Thus, in the context of the two performance criteria, namely the closeness of the output trip table to the "correct" trip table, and replication of observed link volumes, neither model is consistently superior to the other. On the other hand, if the models are to be purely judged on the basis of the quality of output trip table, then THE's results are superior for most cases. However, note that for the 100% link volume availability, the linear programming approach is superior.

(b) "No-Prior-Information" Table as Target/Seed: This target trip table is one in which all feasible interchanges carry a uniform value of 983 trips. Four different no-prior-information trip tables were used as target tables for the tests discussed in this section. Each cell with information in all four trip tables carries the same number of trips. The tables only differ in the number of cells that contain such information. The number of cells with information for the four cases were 5, 7, 9 and 11 (which corresponds to the total number of feasible interchanges). The motivation here was to test the sensitivity of these models to the extent of information provided in the target table. The table with 5 cells represents a case where approximately 45% of the cells contain information. And the other tables correspond to approximately 64%, 82%, and 100% cells containing information.

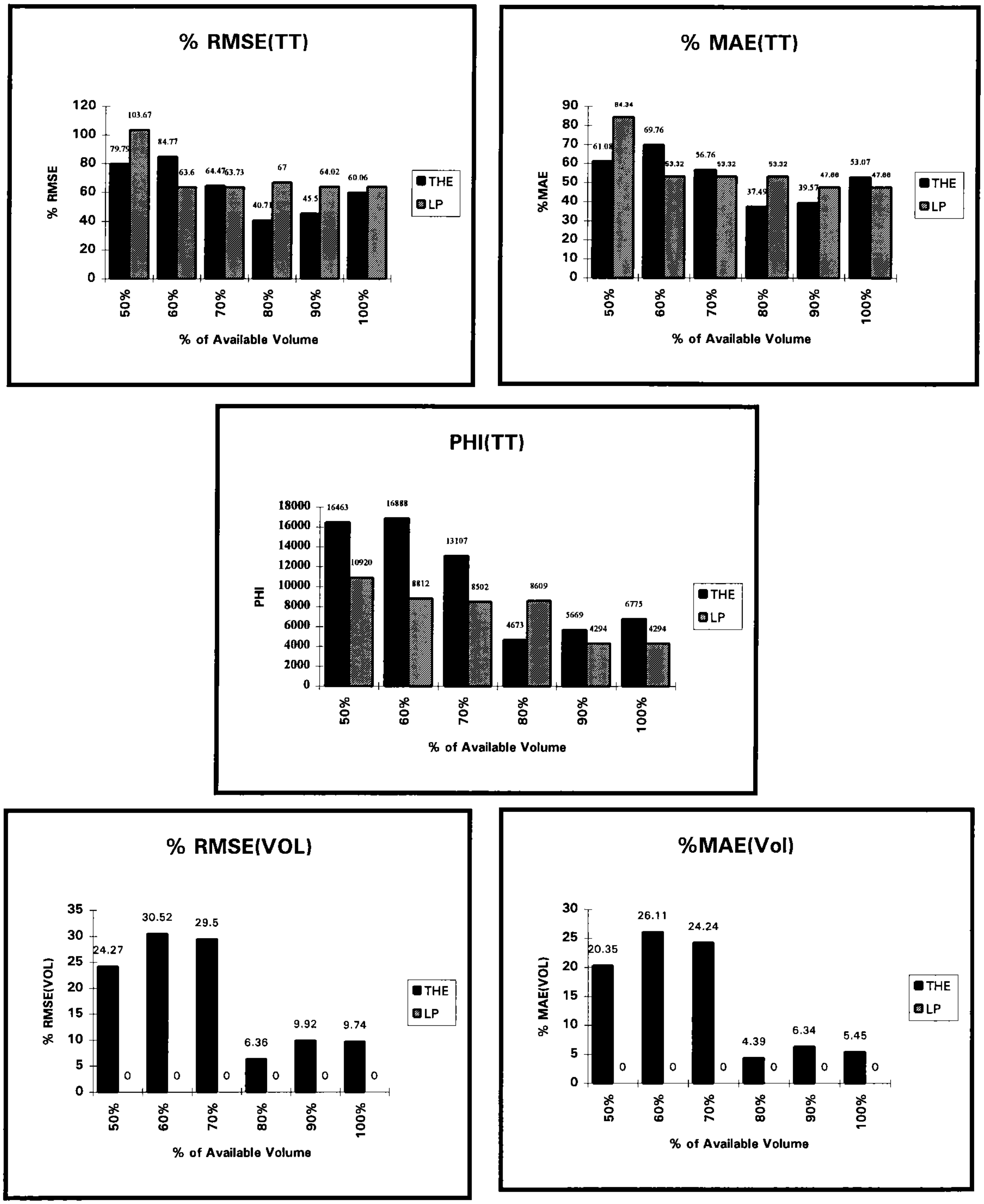
For LP, when there are only 45% of cells with information, the performance of the model is generally seen to improve with increasing information on link volumes (Figure 4-3). The RMSE error rate for the output trip table ranges from 64% to 104%, mostly lower compared to the structural target trip table case. The MAE and ϕ deviations follow a similar trend.

Examining THE's results, for every case of available link volumes, the structural table input yielded lesser values for trip table errors than this case of no-prior-information target (45% cells). The RMSE and MAE statistics for trip table errors are also mostly higher than the corresponding values obtained for the structural trip table case. Link volume replication was also inferior to the structural target case.

Several interesting observations can be made, comparing the results of the LP and THE models. Again, the replication of available volumes is perfect for the linear programming approach. For THE, the RMSE and MAE statistics for link volume replication range from 6%-31% and 4%-26%, respectively. The RMSE (TT) are lower for THE for all but the cases of 60% and 70% volume availability. However, if the φ error statistic were used to judge the performance, the linear programming model can be taken to be generally superior to THE (φ for LP is lower for all cases except the 80% link volume case).

Figure 4-3: Trip Table (Modeled vs. Correct) & Volume (Modelled vs. Observed) Comparisons

Network: Sample **Target** No-Prior-Info 45%



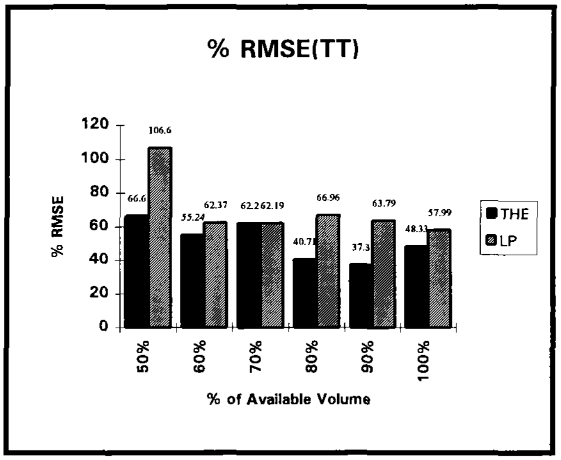
When two more cells of uniform value (983) are introduced into the target trip table, which makes a total of 64% cells with information, the performance of both models seems to improve, if judged by the ϕ statistics (Figure 4-4). Again, a clear monotonic decrease in the trip table error statistics with increasing link volume information cannot be observed, especially for THE model results. With regard to volume replication, LP proves to be superior again, with perfect replication.

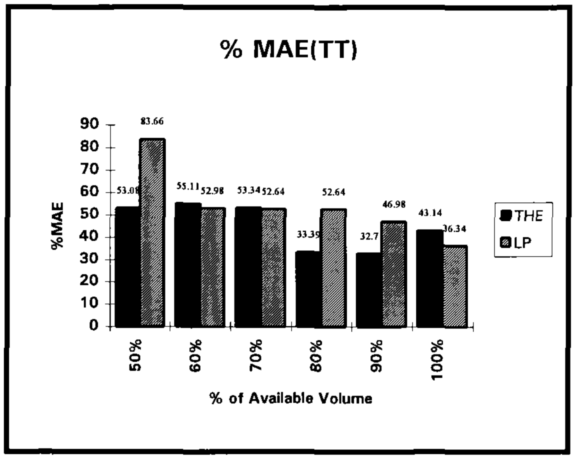
A comparison of the two approaches allows us to draw conclusions similar to that made for the previous case. For the 80% and 90% volume availability cases, one may conclude, based on trip table error statistics, that the performance of THE is superior to LP. Although the link volume replication for THE for these cases is not exact, the error rates are quite low.

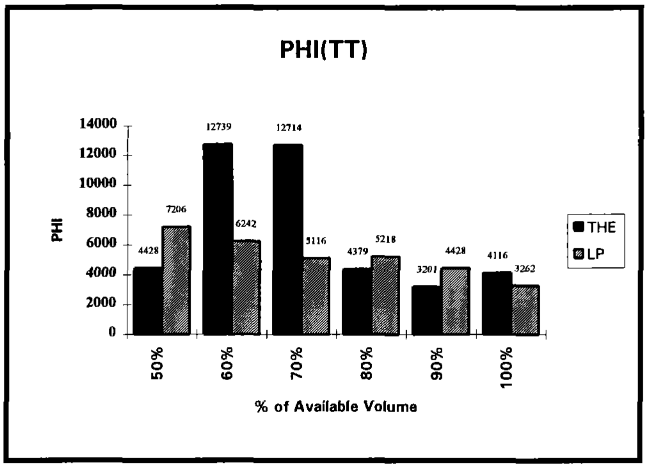
When additional cells are provided with information in the target table, the output tables of both models seem to improve in general, with some exceptions. (Figures 4-5 and 4-6). Again, the LP model replicates link volumes perfectly, while THE is unable to do so. However, for the available volume ranges of 70% to 100%, error rates for THE are quite low.

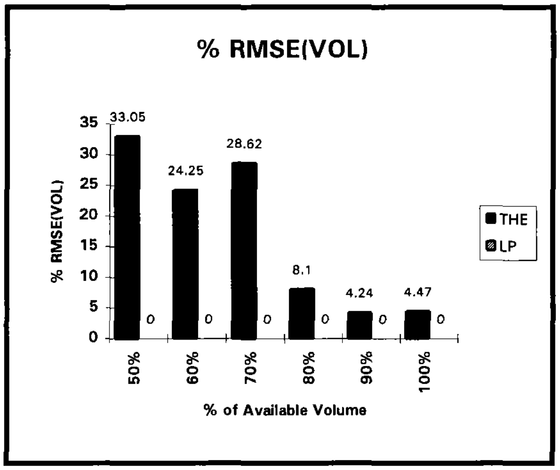
Figure 4-4: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** No-Prior-Info 64%









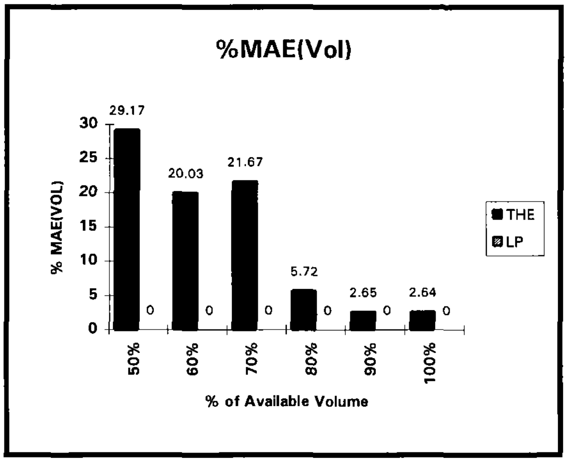


Figure 4-5: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** No-Prior-Info 82%

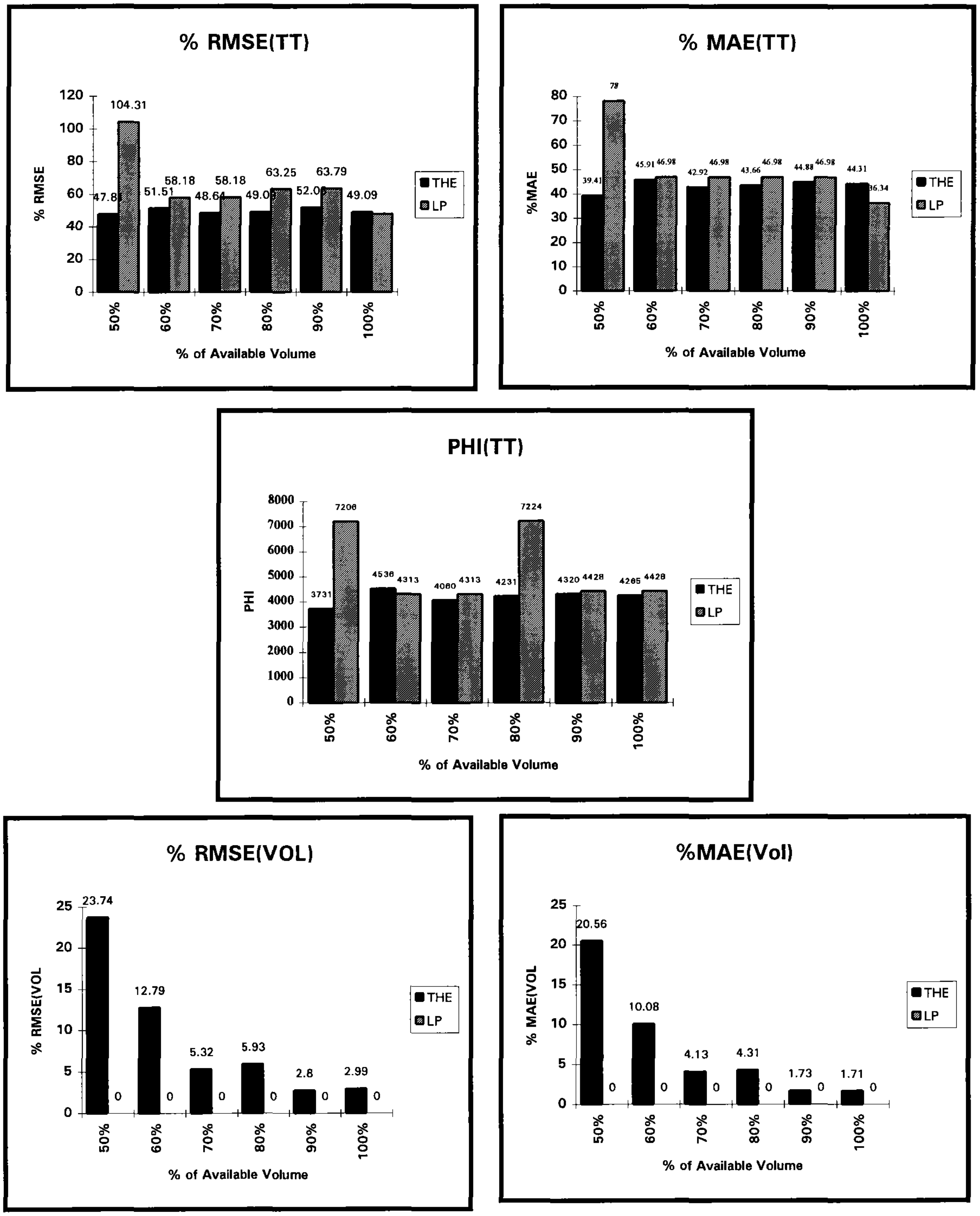
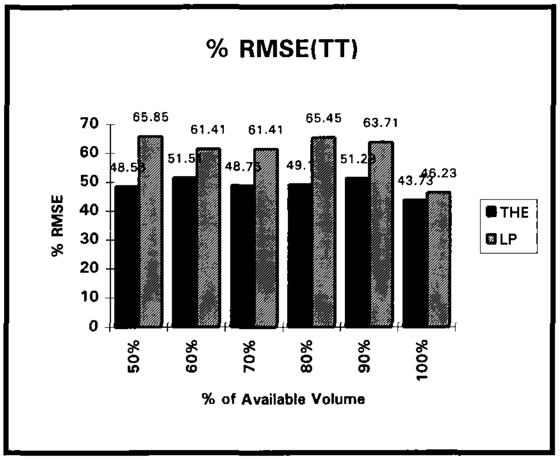
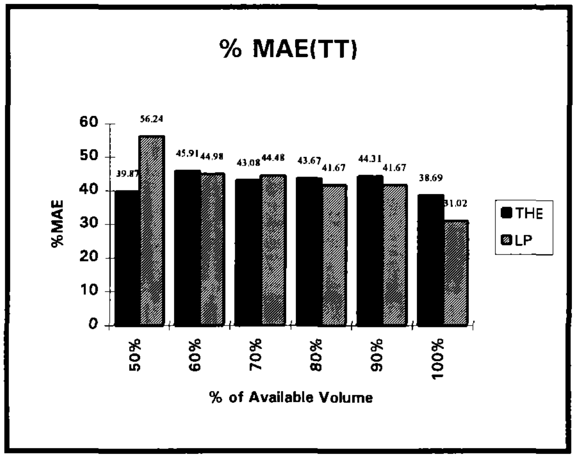
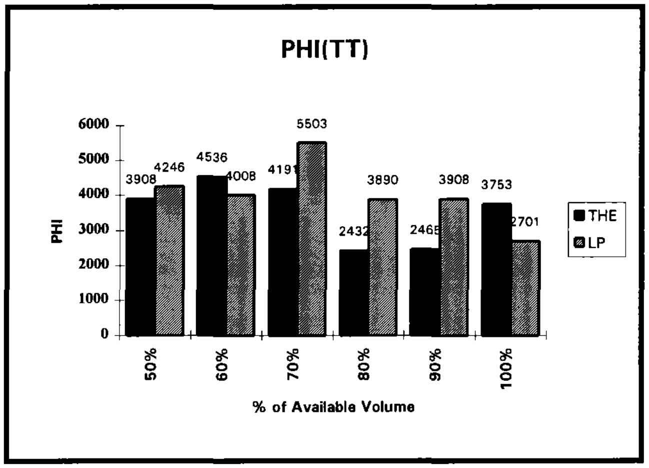


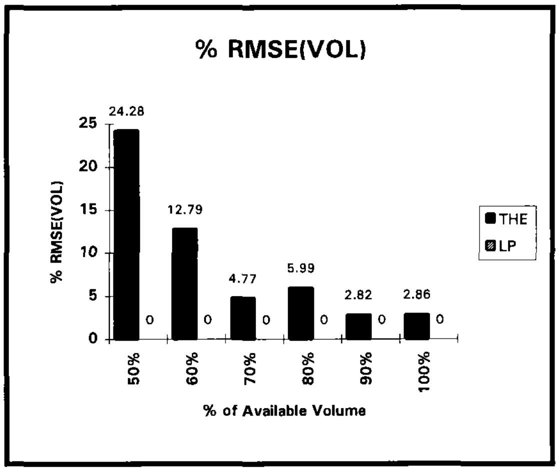
Figure 4-6: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

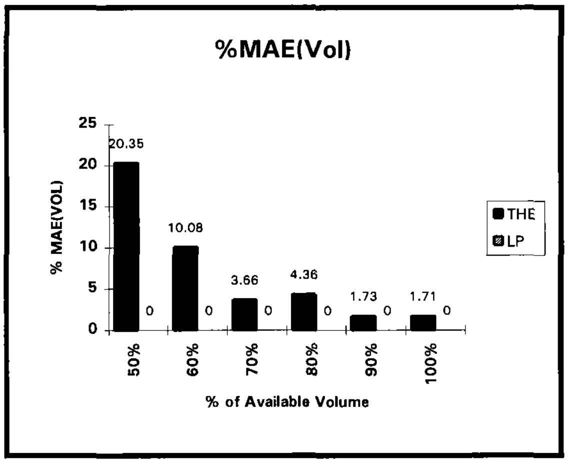
Network: Sample **Target** No-Prior-Info 100%


% RMSE(TT)


% MAE(TT)


PHI(TT)


% RMSE(VOL)

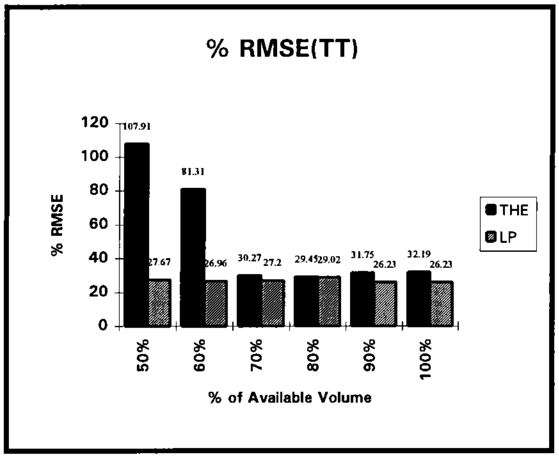

%MAE(Vol)

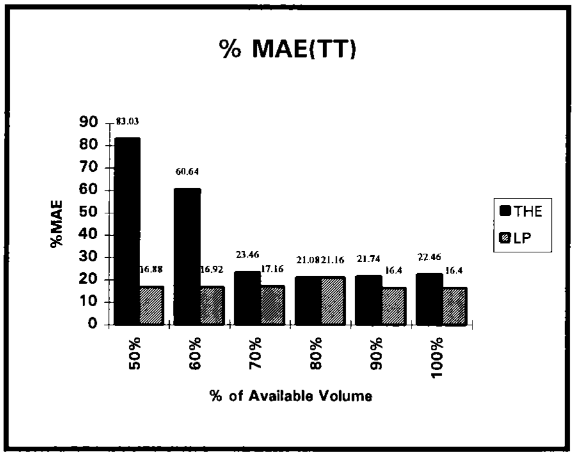
(c) "Small Error" Trip Table as Target: These trip tables have cell values that are relatively close to the correct trip table. Again, we used varying extents of information in the target tables, ranging from 45% to 100% of the cells with such information.

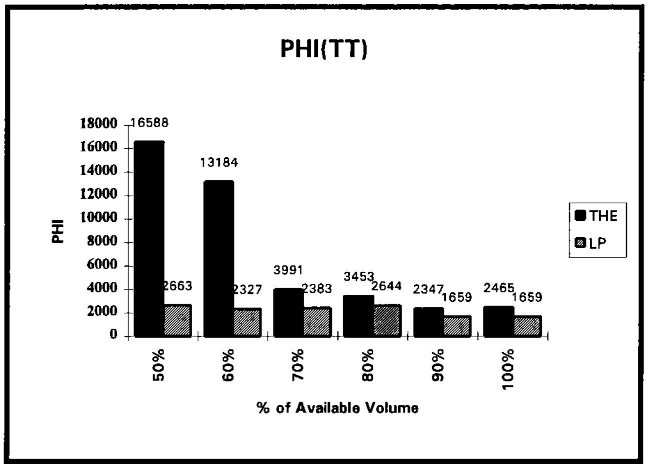
The charts depicting the statistics for comparison of modeled versus correct trip tables and modeled versus observed volumes for the 45%, 64%, 82% and 100% cell information are shown in figures 4-7, 4-8, 4-9 and 4-10, respectively. Analyzing the numbers shown in these figures, based on arguments similar to the "no-prior-information" case, it can be concluded that the LP model clearly performs superiorly to THE in this case, with regard to both the criteria of closeness of modeled table to the correct one, and the replication of observed volumes. All the error statistics are lower for the LP model for each case and for every percentage of available volumes considered.

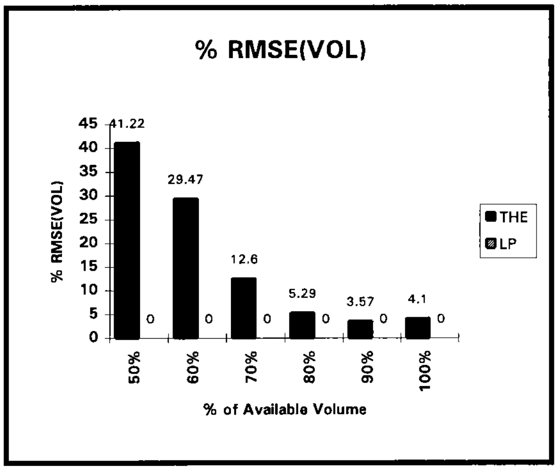
Figure 4-7: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Small Error 45%









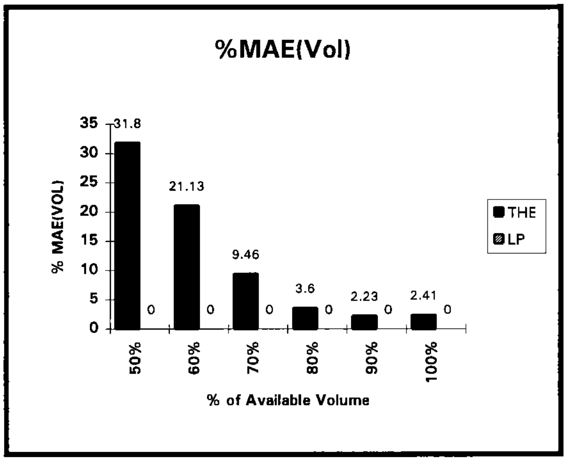


Figure 4-8: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Small Error 64%

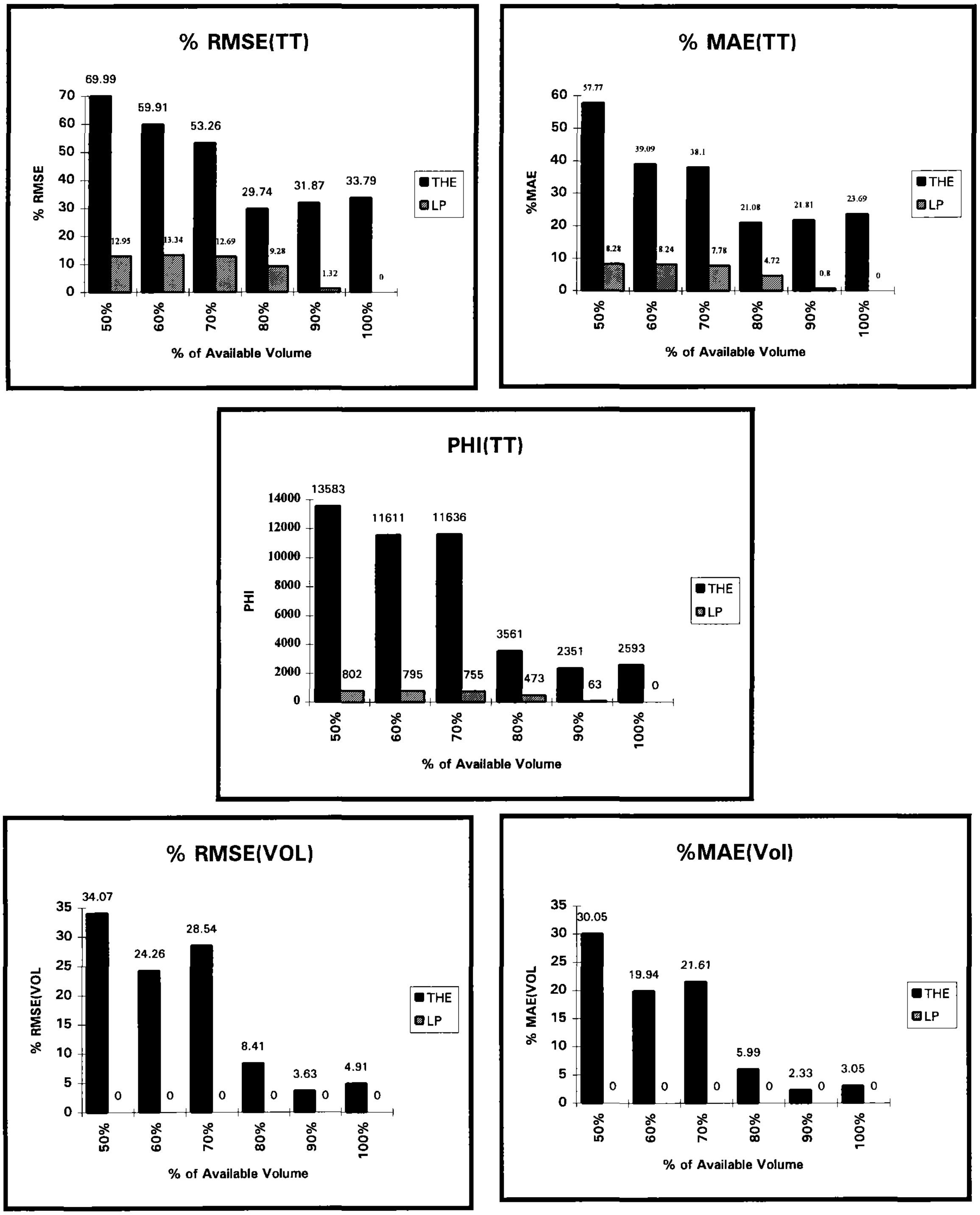
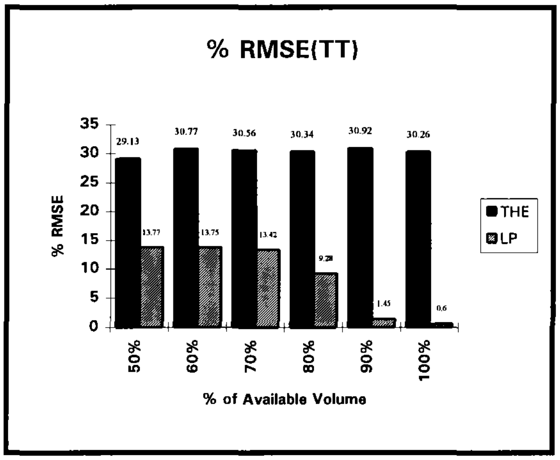
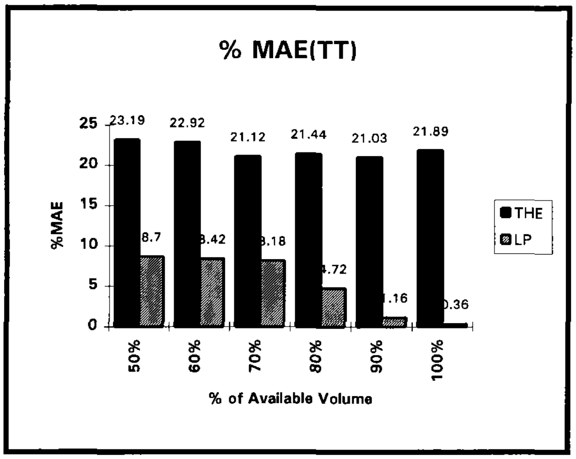
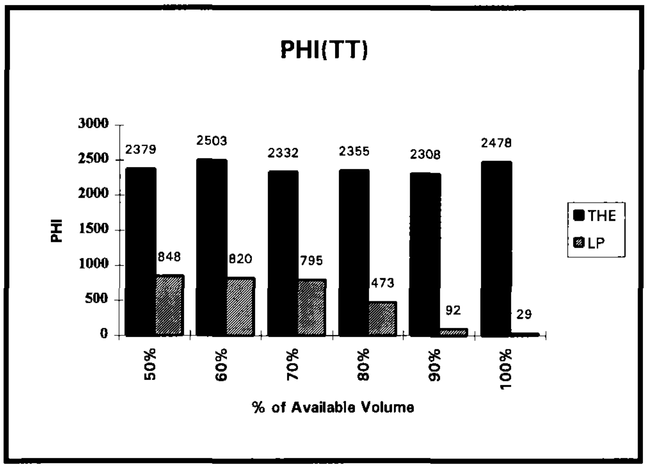


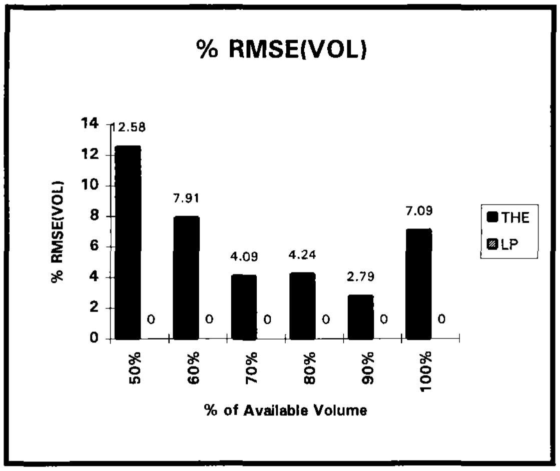
Figure 4-9: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Small Error 82%


% RMSE(TT)


% MAE(TT)


PHI(TT)


% RMSE(VOL)

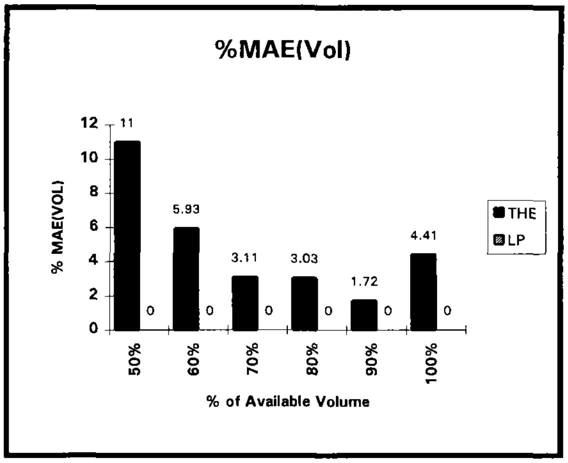
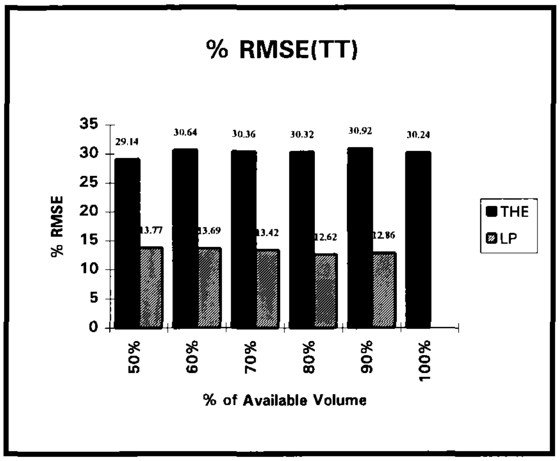
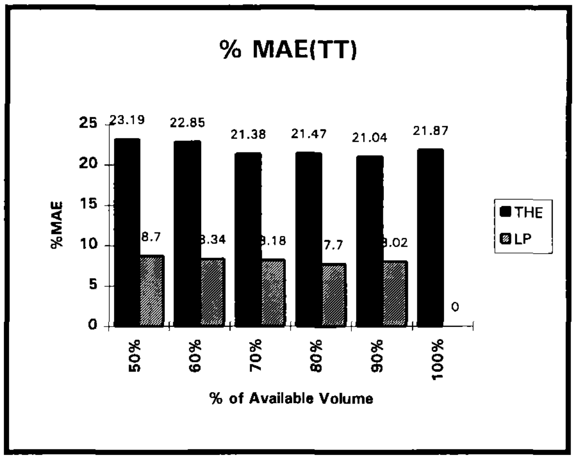
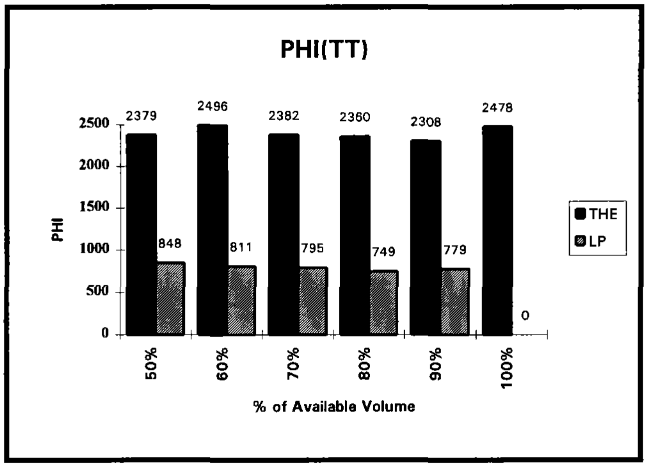

%MAE(Vol)

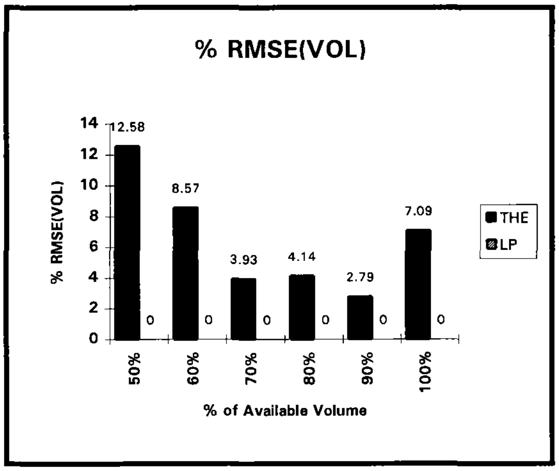
Figure 4-10: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

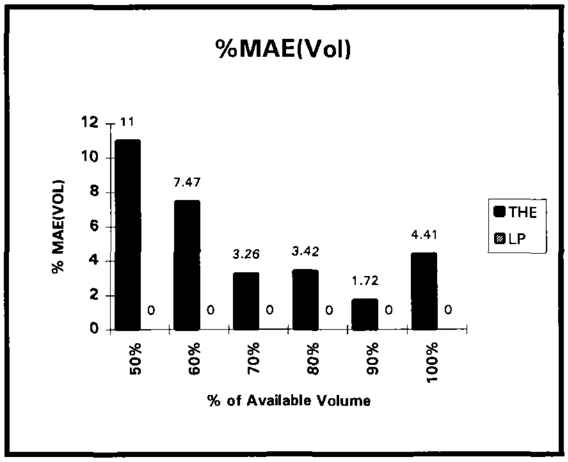
Network: Sample **Target** Small Error 100%


% RMSE(TT)


% MAE(TT)


PHI(TT)


% RMSE(VOL)


%MAE(Vol)

(d) "Correct" Trip Table as Target: This case is purely of theoretical interest, since the "correct" trip table for a real network is almost impossible to obtain, and the need for use of theoretical O-D estimation models does not arise if such a table is available. However, in this hypothetical test case, the availability of a "correct" table facilitated sensitivity analysis of the models. The results of the tests in Figures 4-11, 4-12, 4-13 and 4-14 clearly demonstrate the superiority of the LP model over THE. For all but the 45% cell information case, the LP model produces a perfect solution, with zero error statistics for both trip table closeness and link volume replication. THE error rates are generally significant in most cases.

Figure 4-11: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Correct 45%

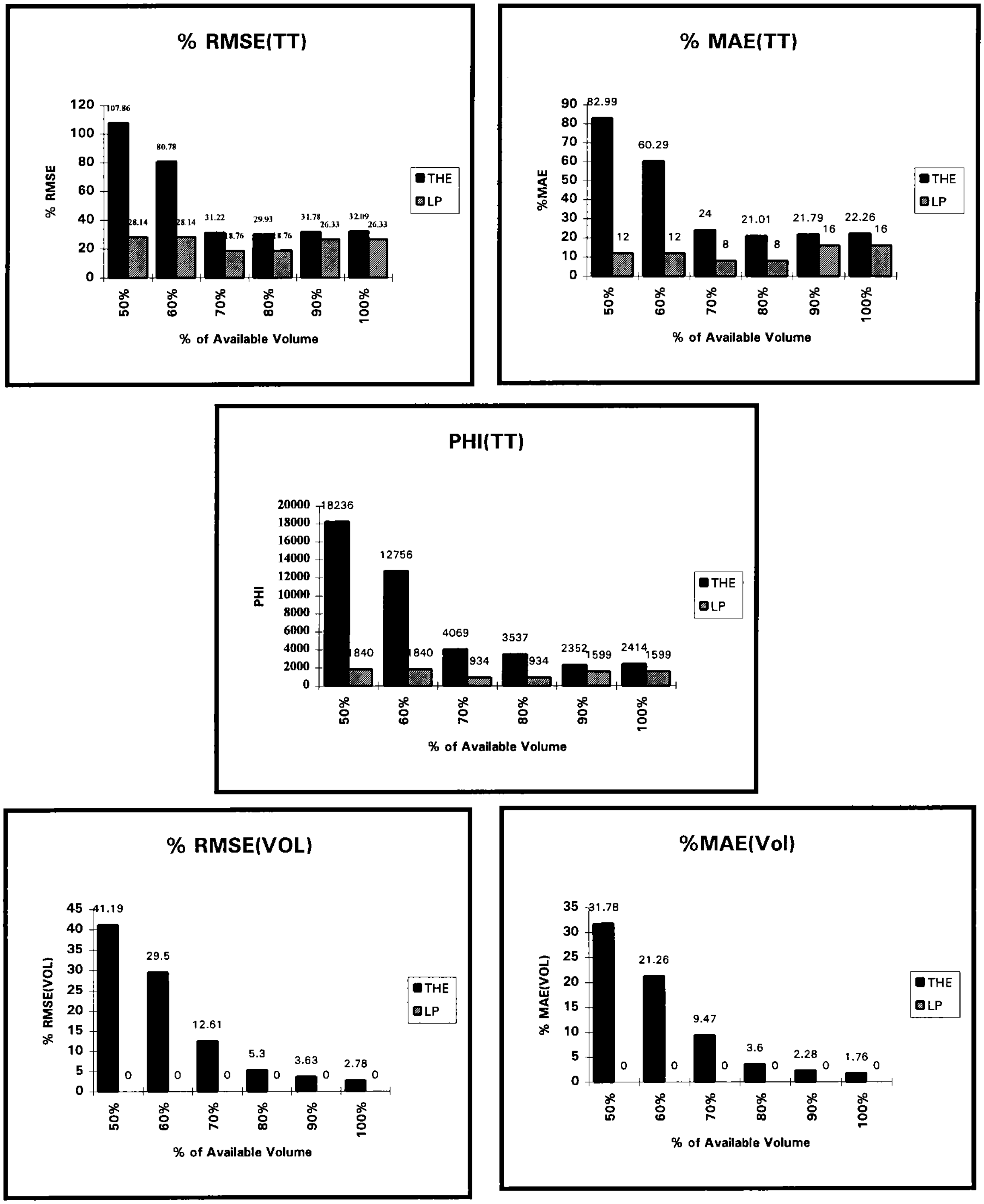


Figure 4-12: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Correct 64%

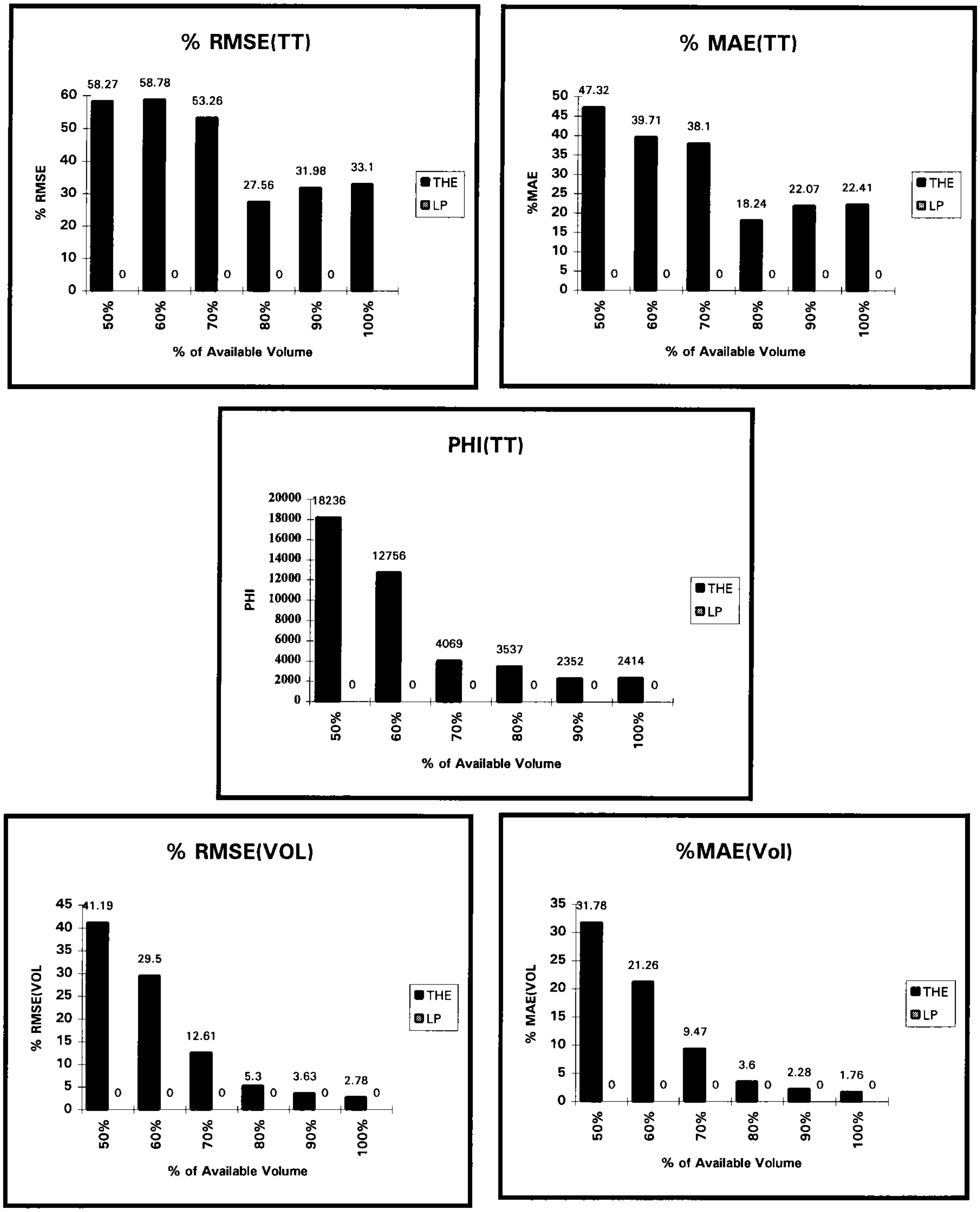


Figure 4-13: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Correct 82%

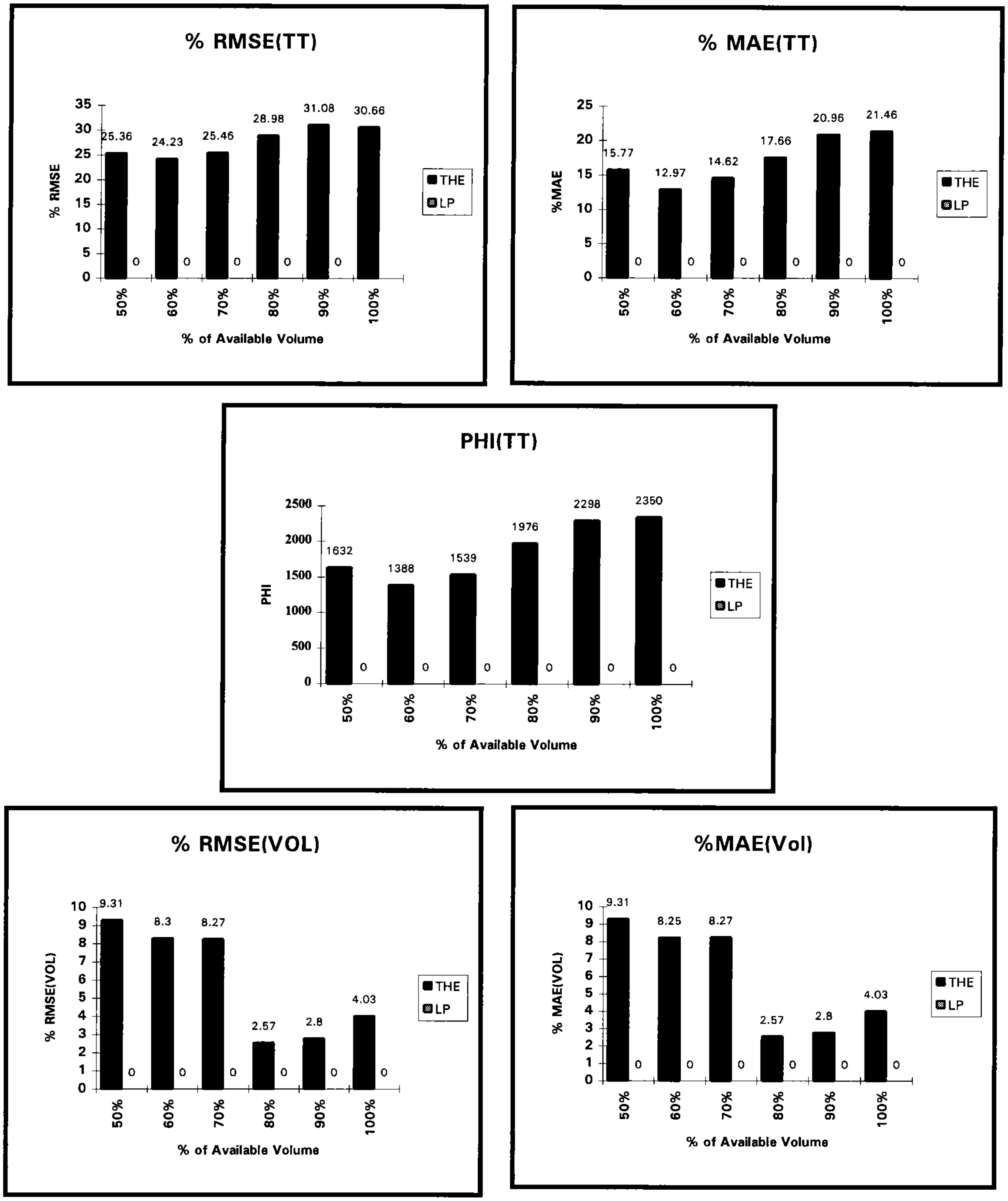
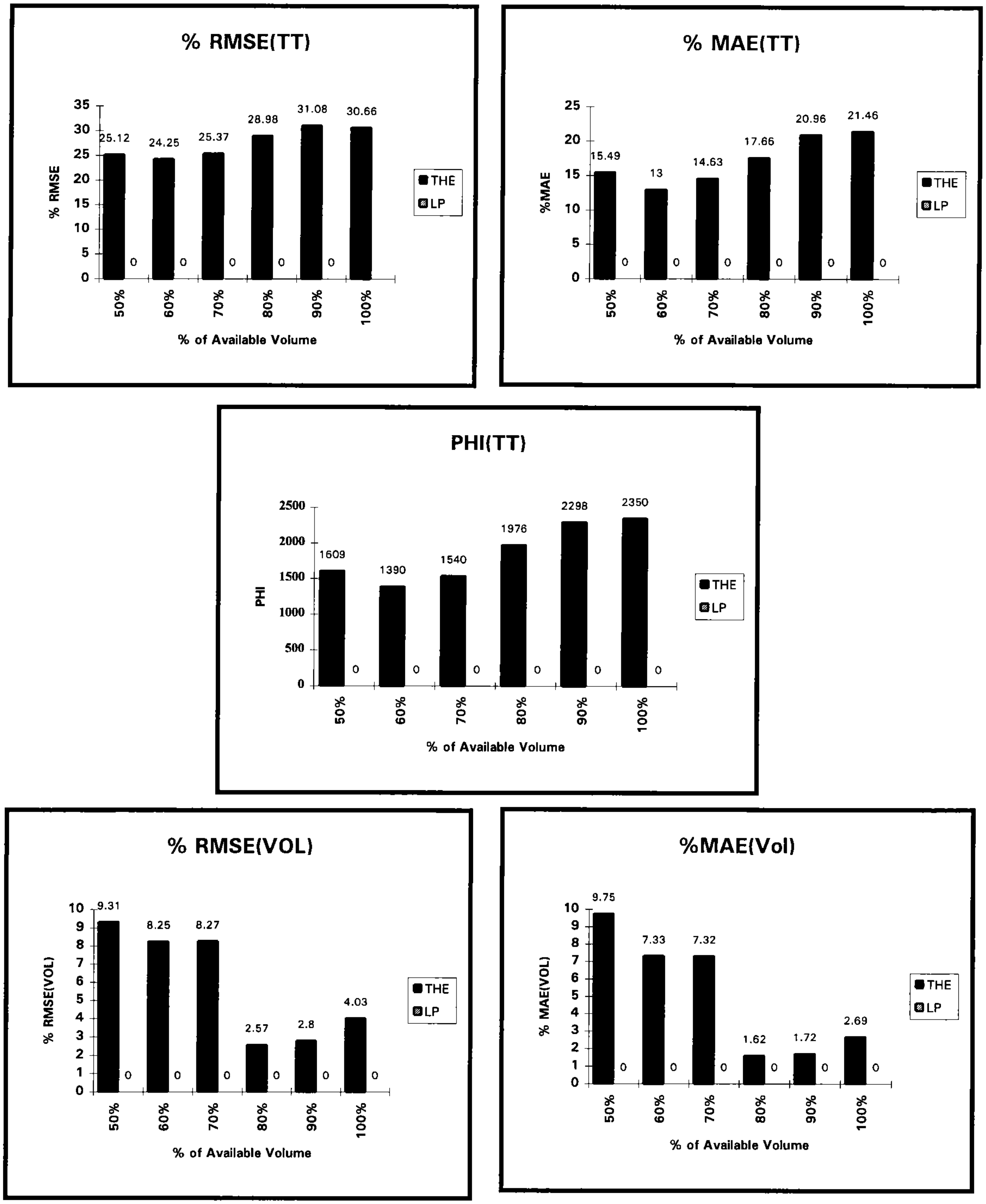


Figure 4-14: Trip Table (Modeled vs. Correct) & Volume (Modeled vs. Observed) Comparisons

Network: Sample **Target** Correct 100%



4.5 Conclusions

The test results for the sample network discussed in this chapter are graphically depicted in Figures 4-15, 4-16, 4-17, 4-18 and 4-19. Each figure shows the variation of one of the error statistics (represented in the z axis) with respect to the different available link volume and prior information cases (represented in the xy plane), for both the models. The motive for presenting these figures is to get a feel for the general trend in error statistics variations for different percentages of target table and link volume information.

Examining the variation of φ statistic shown in Figure 4-17, it can be concluded that for the LP model, this statistic generally decreases (with few exceptions) with the improvement in target table information, and with the increase in percentage available volumes. This is a logical conclusion one would expect. THE results also seem to show the above trend for many cases; however, there are some violations of this trend, as seen the figure. The figure also highlights the poorer performance of THE for cases where the percentages of target table and link volume information are low. However, a noteworthy point about THE is its superiority over the LP model (for most cases) in terms of the output tables for the structural target case.

Observing the variation of link volume replication errors measured through %MAE for both the models as shown in Figure 4-19, the LP model results are clearly superior to those of THE. For all the test cases, LP is able to replicate observed volumes exactly. For THE, in general, %MAE(Vol) is seen to improve with increase in percentage available volumes for each of the cases observed individually. Again, as with trip table error, link volume replication seems to be poor for cases when the percentages of target table and link volume information are low.

In summary, the figures illustrate the general superiority of the LP model over THE for the sample network, with the exception of the structural target case. The results and the conclusions regarding the test network reflect a hypothetical case, and not real data, but these tests were useful for understanding the performance of the models.

Figure 4-15: Trip Table Comparisons (Modeled vs. Correct)

Network: Sample **Measure:** %RMSE(TT)

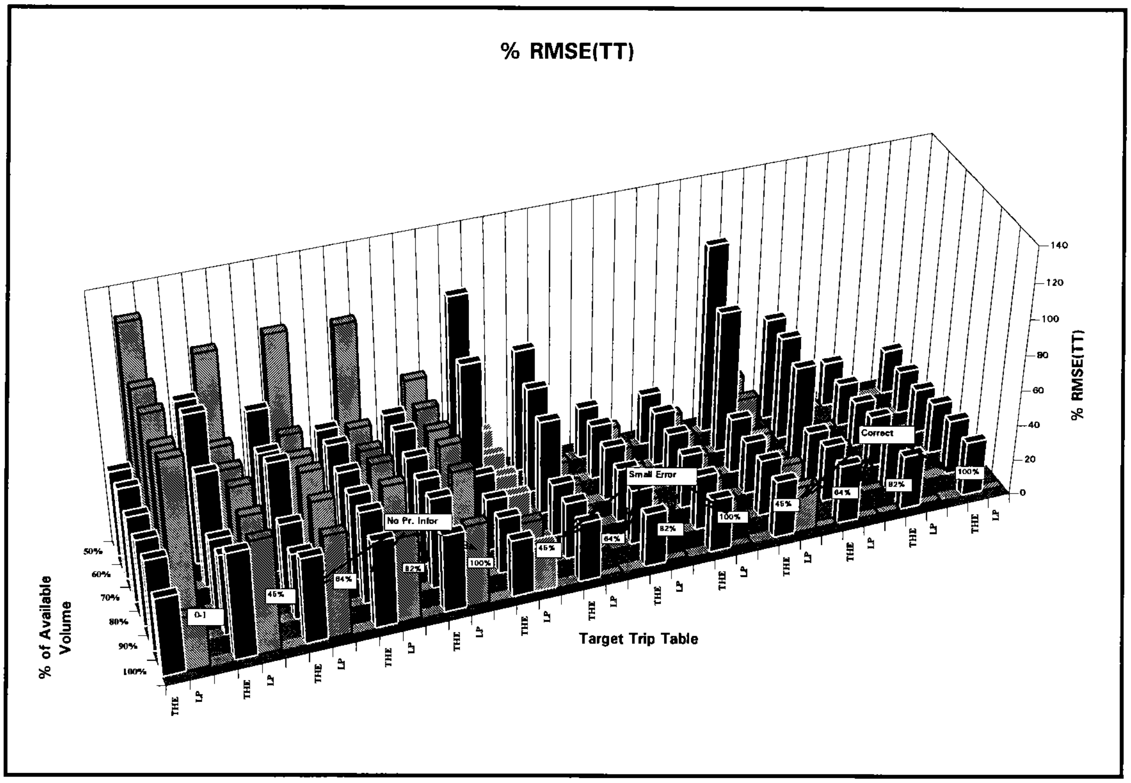


Figure 4-16: Trip Table Comparisons (Modeled vs. Correct)

Network: Sample **Measure:** %MAE(TT)

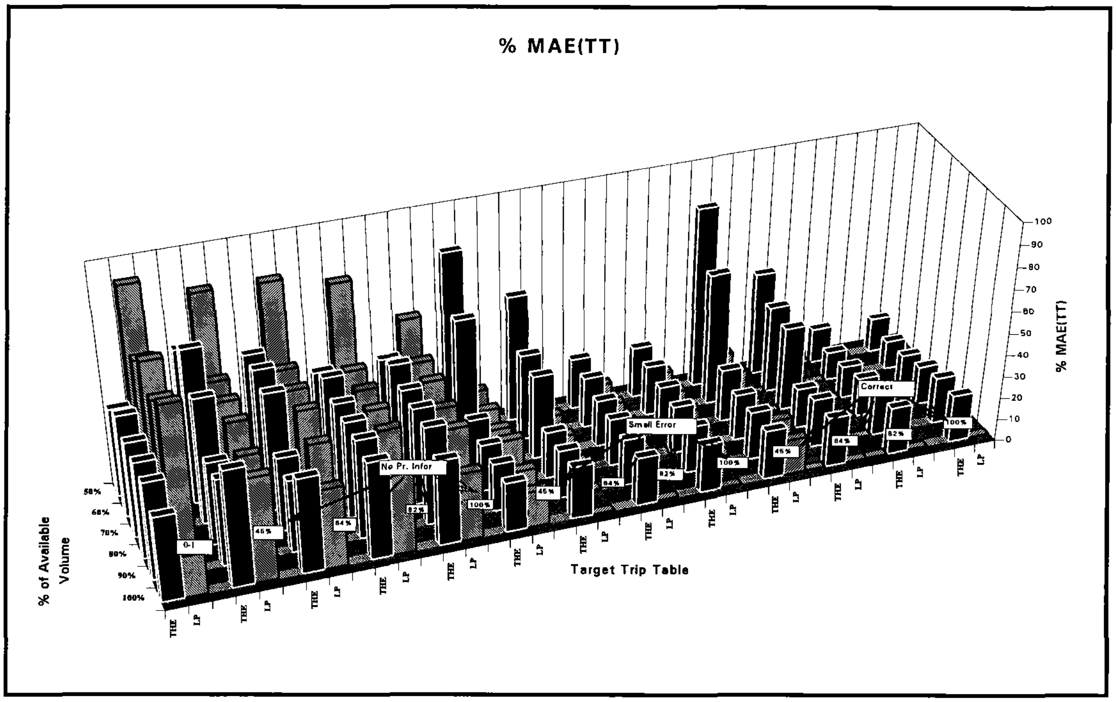


Figure 4-17: Trip Table Comparisons (Modeled vs. Correct)

Network: Sample **Measure:** PHI(TT)

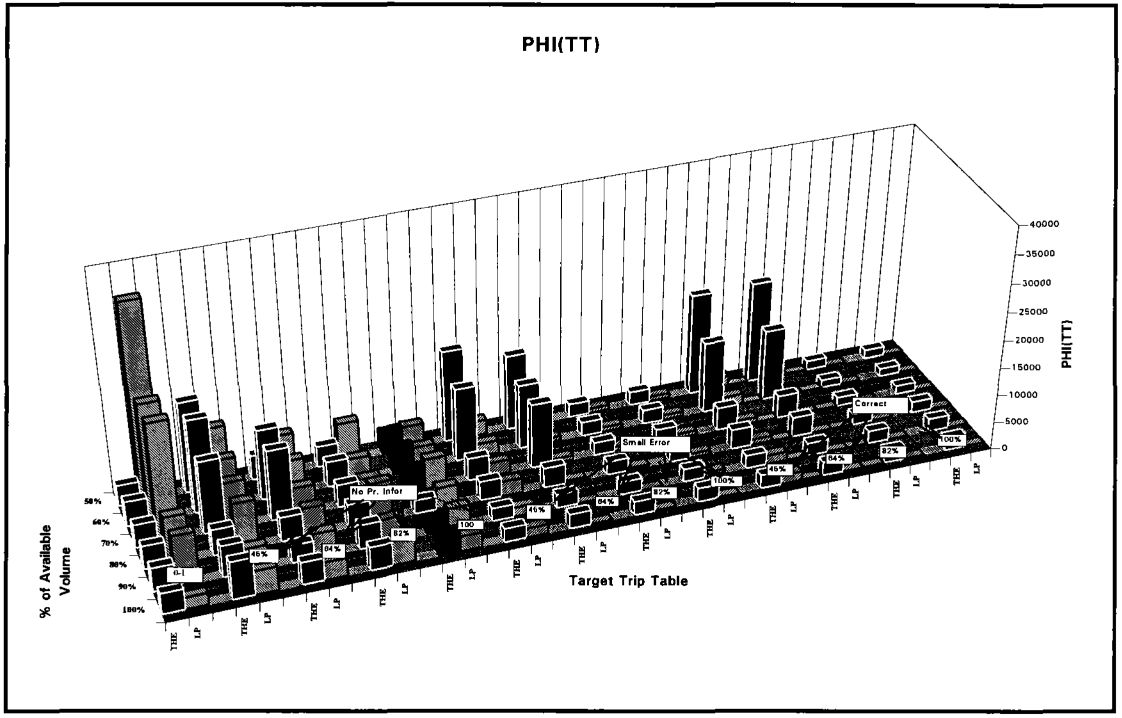


Figure 4-18: Volume Comparisons (Modeled vs. Observed)

Network: Sample **Measure:** % RMSE(VOL)

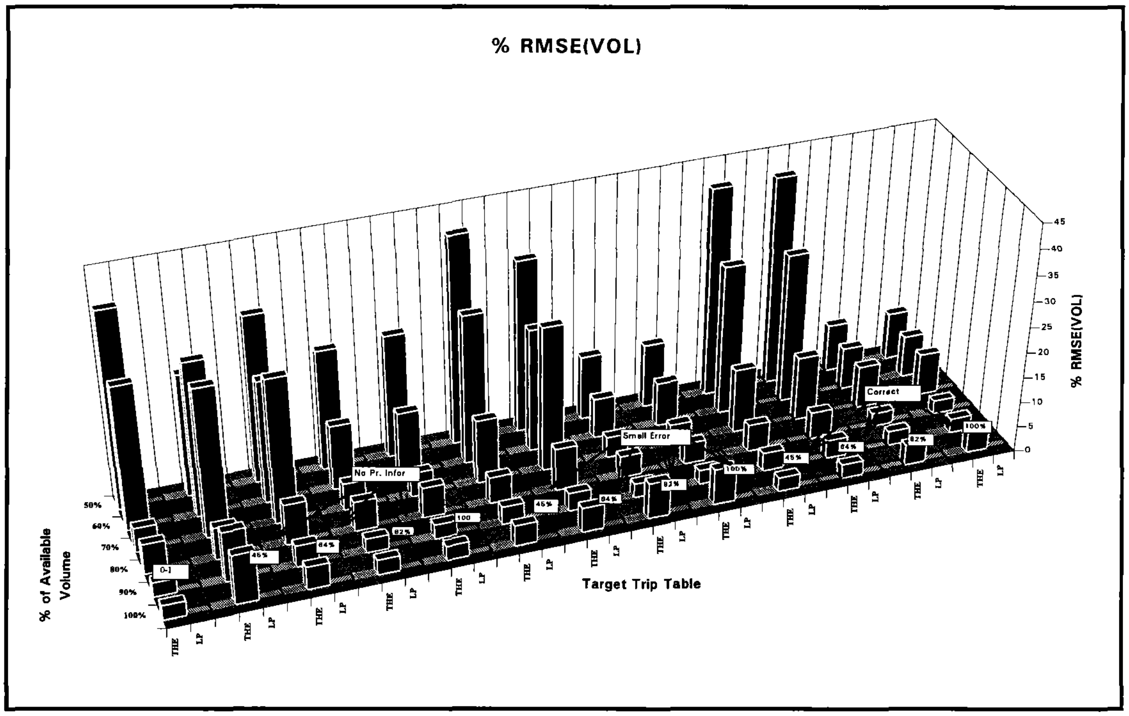
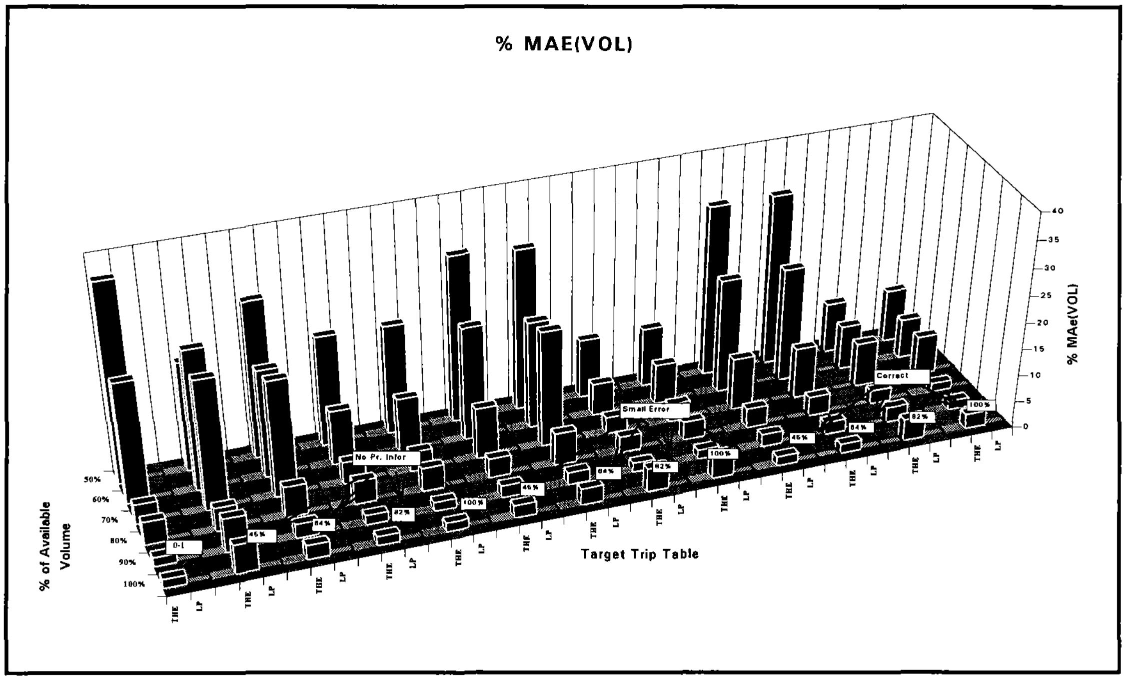


Figure 4-19: Volume Comparisons (Modeled vs. Observed)

Network: Sample **Measure:** % MAE(VOL)



Chapter 5.0

Evaluation of Models Using Purdue Network Data

5.1 Introduction

This chapter deals with the tests on the network of Purdue University, West Lafayette, Indiana. The details about the network and available data, applications of the models, analyses and discussion of results, and inferences are presented here (Narayanan, 1995).

5.2 Purdue University Network

The network chosen was the village network of Purdue University, West Lafayette, Indiana. The relevant data for this network was provided by Dr. J. D. Fricker of Purdue University. The network as applied to this case study had 16 zones, 43 intersection nodes and 130 links. The network covered an area of one square mile, and the size of the network lent itself well for the purpose of evaluating O-D estimation approaches. The network characteristics, including link volumes, required to test the models were available for every link of the network. A trip table that was obtained by synthesizing tables from five different approaches, including a license plate survey, and believed to be "reasonably good" by researchers at Purdue University (Barbour & Fricker, 1993), was also available. This table was assumed as the "correct / true" table for this study, and will be referred from now on as "surveyed" table. The modeled results were compared to this table.

One of the characteristics of this network was that the volume to capacity ratios were quite low for almost all links, thus making the updated travel cost on the links almost equal to their free flow costs. To obtain a partial set of link volumes, some of these link volumes were assumed to be unknown. While estimating the solution trip table using the LP model, the additional information that the actual travel costs are almost the same as the free flow cost was exploited to increase the computational efficiency of the solution procedure.

5.3 Test Cases

The target trip tables used in the tests conducted on this network are primarily of four types. Each of these four types contain cell values for all possible trip interchanges. Using these, 10 different target trip tables were derived and used for the tests. These included partial trip tables that were obtained by removing some cell information from the three of the four basic types of tables. The extent to which information was removed varied from 0%-40% of the total number of feasible interchanges. The logic behind the choice of this percentage range was the assumption that, in the event an old prior trip table was available for a study area, then at least 60% of the cells in that table may contain information relevant to that study. The variation in the percentages (0% -- 40%) for the missing information cells is used to test the sensitivity of the model to varying levels of prior information. Likewise, the percentages of links with missing volume information were based on the assumption that it will be impossible to obtain 100% volume information. The study of sensitivities of the models to volume information was also a motivation. The cells and links with missing information were identified based on a random selection.

The structural trip table represents one which has 1/0 values for its cells to indicate merely if that trip interchange is feasible or not, respectively. The no-prior-information trip table had a uniform value for all feasible interchanges. This value was equal to 27, which represents the average surveyed trip interchange based on total number of trips factored by a value of 0.8. The factor of 0.8 was arbitrarily chosen based on an assumption that the total number of trips for a past period will be in the range of, say, 70%-90% of current total trips. Thus, this value was used in order for the target trip table to emulate past conditions, with the likely possibility that the total trips in the network then was lesser. For this test case in this study, however, the no-prior-information target was derived from the surveyed table. The term "no-prior-information" has been used here to be consistent with the sample network case. The third and fourth types of trip tables used as target/seed, were relatively close to the surveyed trip table. They were generated by introducing errors into the surveyed trip table using the below mechanism:

$$P_{ij} = C_{ij}(\psi + \beta_{ij}); \qquad -\beta_{\max} < \beta < \beta_{\max}$$

where P_{ij} is the target table's ij^{th} cell, C_{ij} is the corresponding element in the surveyed table, ψ is the mean ratio of target table cell value to surveyed table cell value, β_{ij} is a normally distributed cell value error and $\beta_{\max}$ is the bound on this error. ψ was set to be the same for all cell values in a given table. For the third type of target tables, we used $\psi = 0.8$ and $\beta_{\max} = 0.2$. For the fourth type of target tables, we used $\psi = 0.9$ and $\beta_{\max} = 0.2$. This case was generated to create a variation in the small error target table.

In summary, 40 cases were tested for each of the models. These cases, arising out of a combination of different percentages of target trip table and link volume information availability, are shown in the following table. An IBM compatible personal computer was used for the test runs.

Table 5-1: Summary of Test Cases for Purdue Network

Target Table	% Available Target Info	% of Available Link Volumes				Total Cases
		50%	70%	90%	100%	
Struct. (0/1)	100% cells	●	●	●	●	4
No Prior Info	60% cells	●	●	●	●	4
	80% cells	●	●	●	●	4
	100% cells	●	●	●	●	4
Small Errors ψ=0.8	60% cells	●	●	●	●	4
	80% cells	●	●	●	●	4
	100% cells	●	●	●	●	4
Small Errors ψ=0.9	60% cells	●	●	●	●	4
	80% cells	●	●	●	●	4
	100% cells	●	●	●	●	4
Total Cases		10	10	10	10	40

5.4 Discussion of Model Results

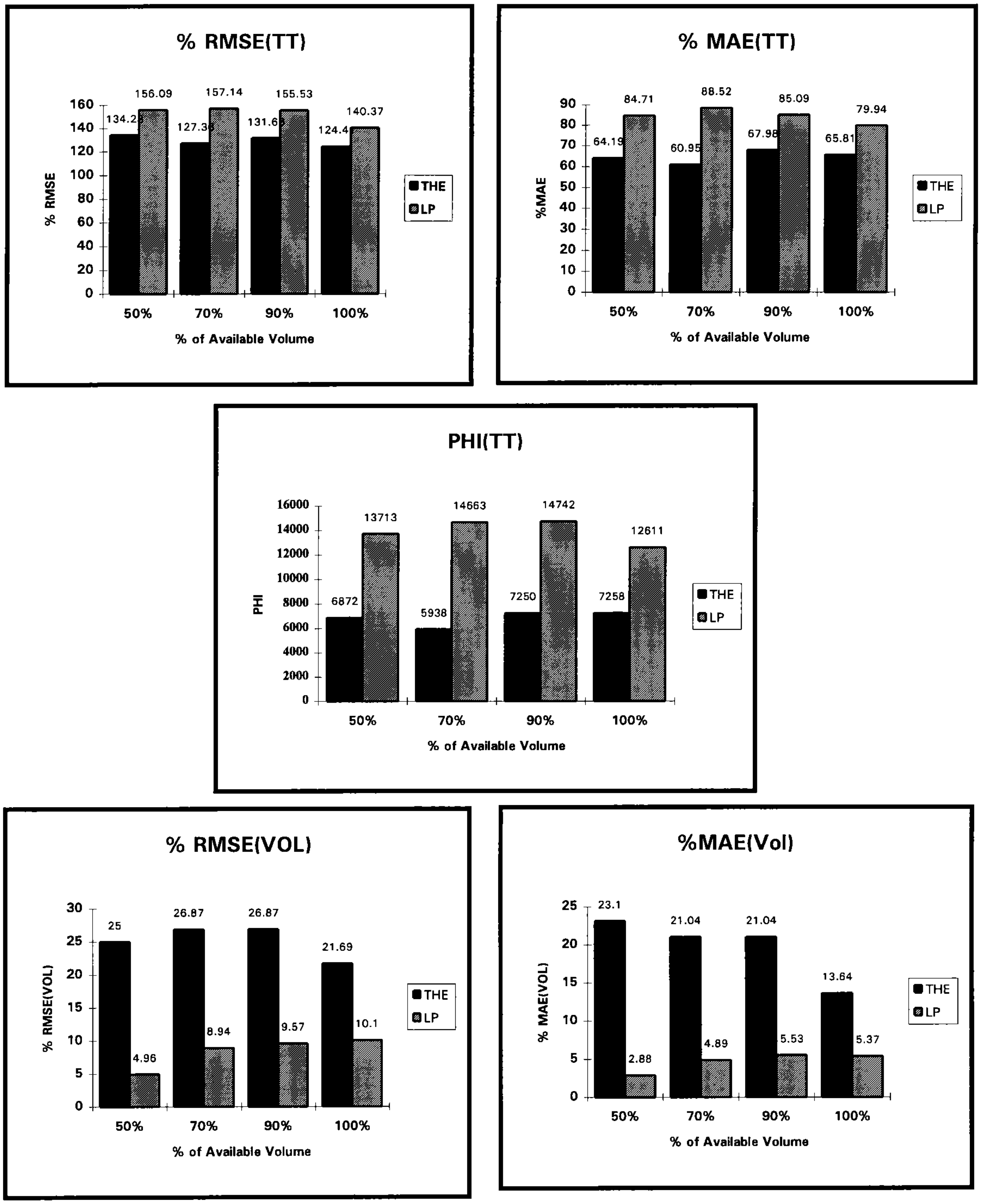
The discussions that follow are structured around the four cases of target table, and highlight the performance of the LP and THE models. Again, a model is judged based on its ability to match the "surveyed" table as closely as possible, and at the same time its capability to replicate the observed volumes. A model will be judged good if it can achieve both the above objectives

(a) Structural Table as Target/Seed: As mentioned before, the structural target/seed trip table is used when no prior trip table information is available. In practice, when a trip table is being established for an urban area for the first time, and therefore no previous table is available for use as target, this kind of seed table may be the only option. Both THE and LP were run with this target for the four cases (50%, 70%, 90% and 100%) of available link volumes. The resulting trip tables were then compared with the "surveyed" trip table, which was the synthesized table. Also, the modeled volumes were compared with observed volumes to test how well the models replicated the volumes.

Examining the results of the above comparisons for both models, as shown in Figure 5-1, it is seen that The Highway Emulator yielded trip tables that were closer to the "surveyed" trip table, as compared to the LP model tables. This is highlighted by %RMSE (TT), %MAE(TT), and PHI (TT) statistics. Looking at the PHI(TT) statistics, the value for THE ranges from 5,938 to 7,258 for different cases of available link volumes. The corresponding values for LP range from 12,611 to 14,742. On the other hand, observing the statistics on the replication of link volumes, the LP model outcomes are much superior to THE's, as indicated both by % RMSE(Vol) and % MAE(Vol). A point to be noted in this test is that both the models in general do not show a clear improvement in trip table errors (PHI(TT)) with increase in percentage of available volumes.

Figure 5-1: Trip Table (Modeled vs. Surveyed) & Volume (Modelled vs. Observed) Comparisons

Network: Purdue **Target** Structual



(b) "No-Prior-Information" Table as Target/Seed: As described before, the no-prior-information-based target trip table used here carried an equal number of trips (27) for all feasible interchanges. In addition to the four different percentages of availability for the observed volumes, three cases of percentage available cell information (60%, 80% and 100%) were considered for test runs.

The charts depicting the statistics for the comparison of modeled versus surveyed trip table and modeled versus observed volumes for the 60%, 80% and 100% cell information are shown in Figures 5-2, 5-3 and 5-4, respectively. Examining the PHI(TT) statistics, the LP model yielded better results compared to THE for all cases except the 100% cell information case. With regard to replicating link volume information, the LP model has proven superior for all the cases. It can also be concluded in general, that the quality of output tables, with respect to their closeness to the surveyed table, improves for both models with increase in percentage target cell information.

Figure 5-2: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** No-Prior-Infor 60%

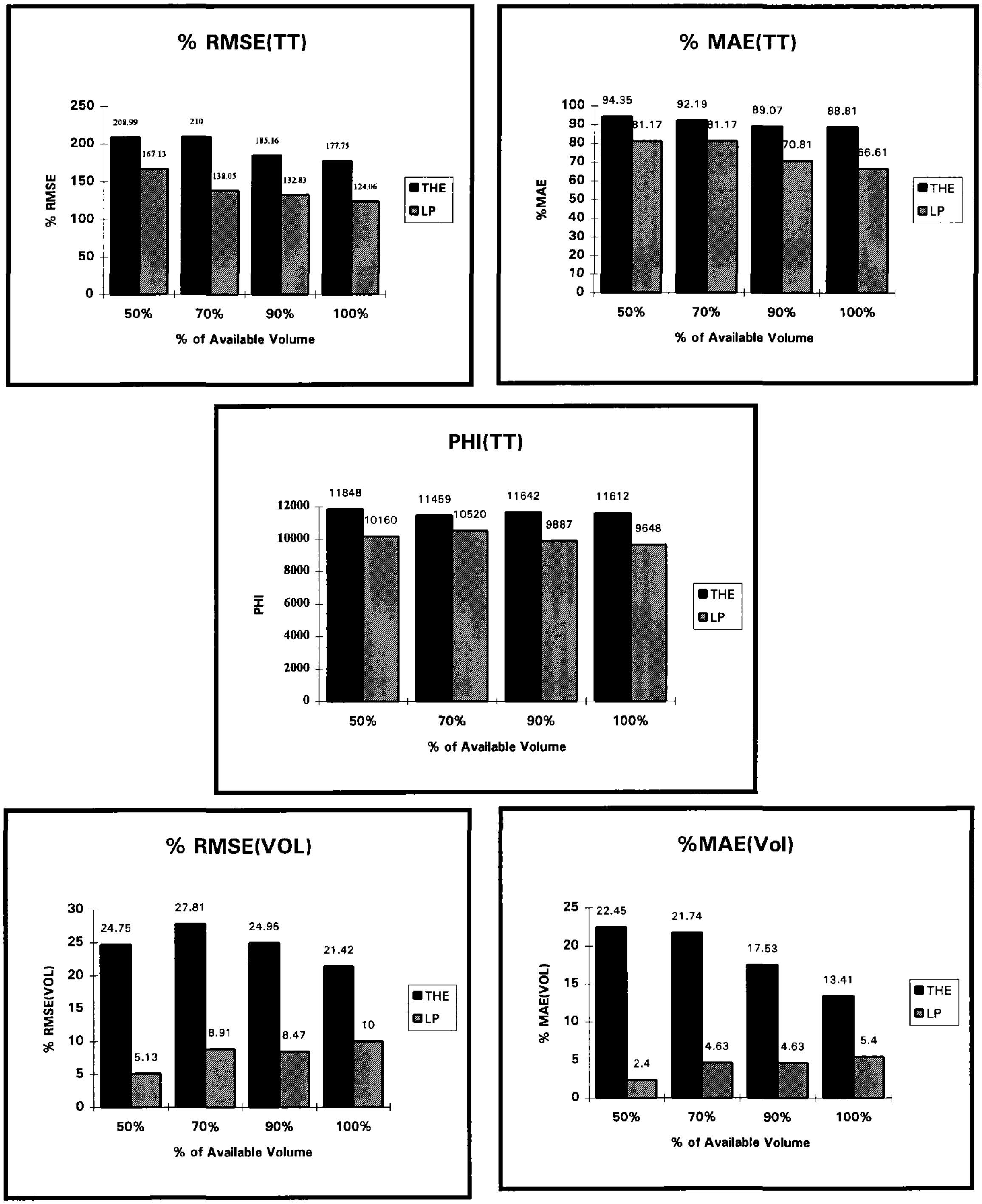


Figure 5-3: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** No-Prior-Infor 80%

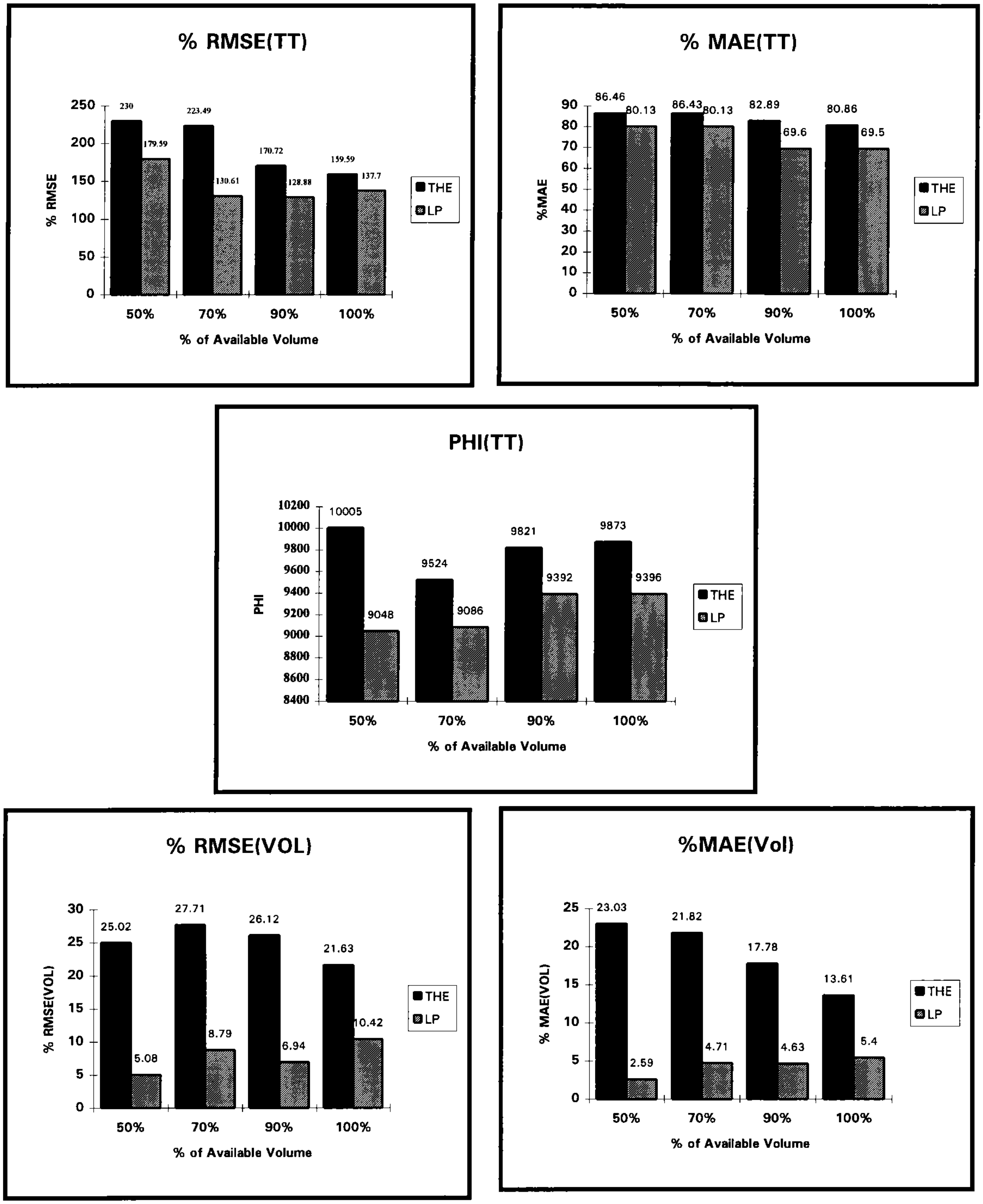
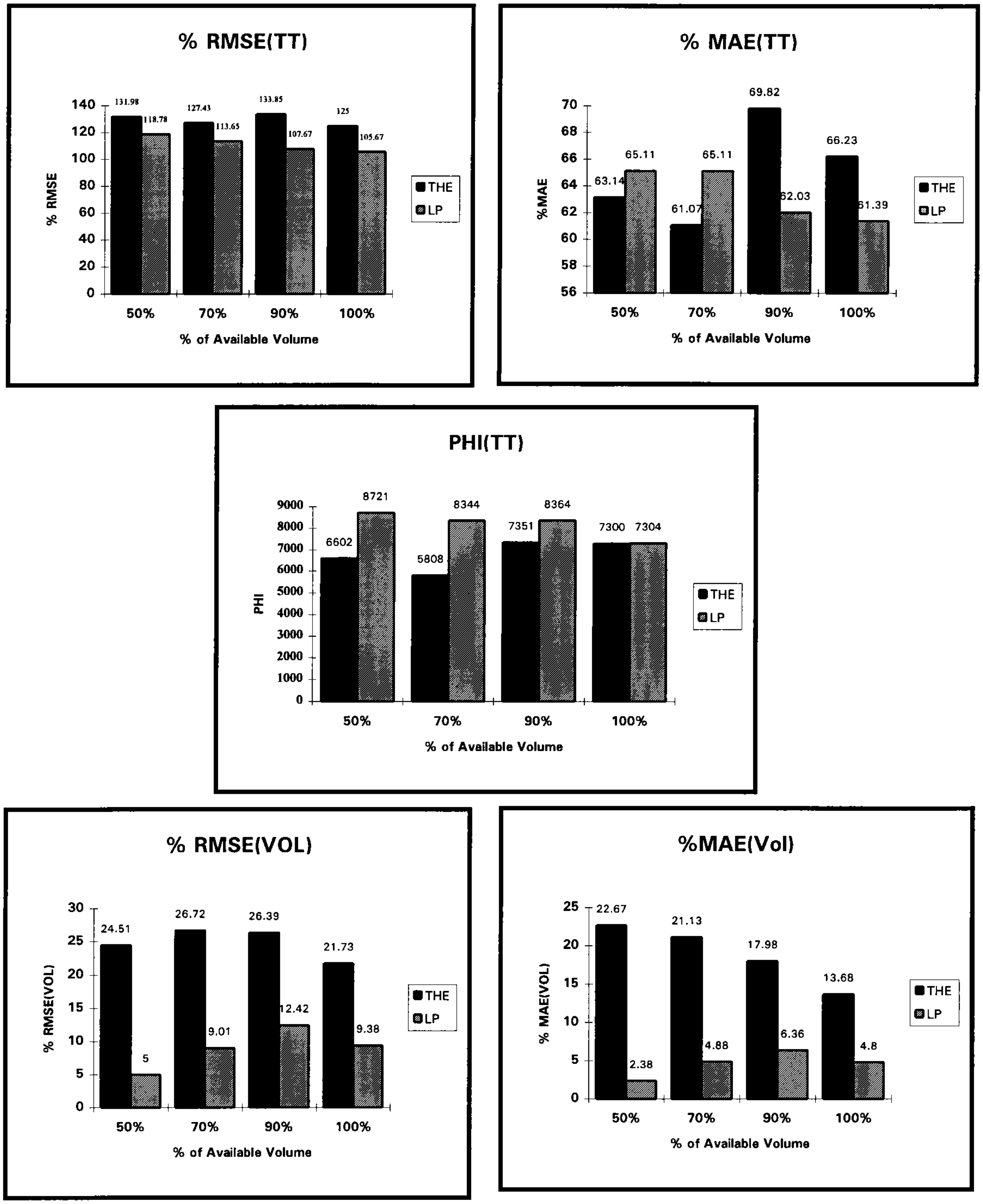


Figure 5-4: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** No-Prior-Infor 100%



(c) "Small Error" Trip Table as Target (ψ=0.8): As described in section 5.3, the small error target tables were generated by introducing errors into the surveyed table. These errors were controlled so as to obtain tables that can be assumed to be representative of the small error table. In other words, these tables will contain relatively small errors when compared to the surveyed table, which in this case is assumed to be "true/correct".

Presented below are the test results for the small error target case, when a value of $\psi = 0.8$ (see sec. 5.3) was employed. The charts depicting the statistics for comparison of modeled versus surveyed trip tables and modeled versus observed volumes for the 60%, 80% and 100% cell information are shown in Figures 5-5, 5-6 and 5-7, respectively. The LP model has once again proven superior to THE. This applies to all cases, and in terms of all the statistics. The LP model yielded better results, both in terms of the quality of the output table, and in terms of replicating volumes.

Figure 5-5: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** Small Error Psi=0.8, 60%

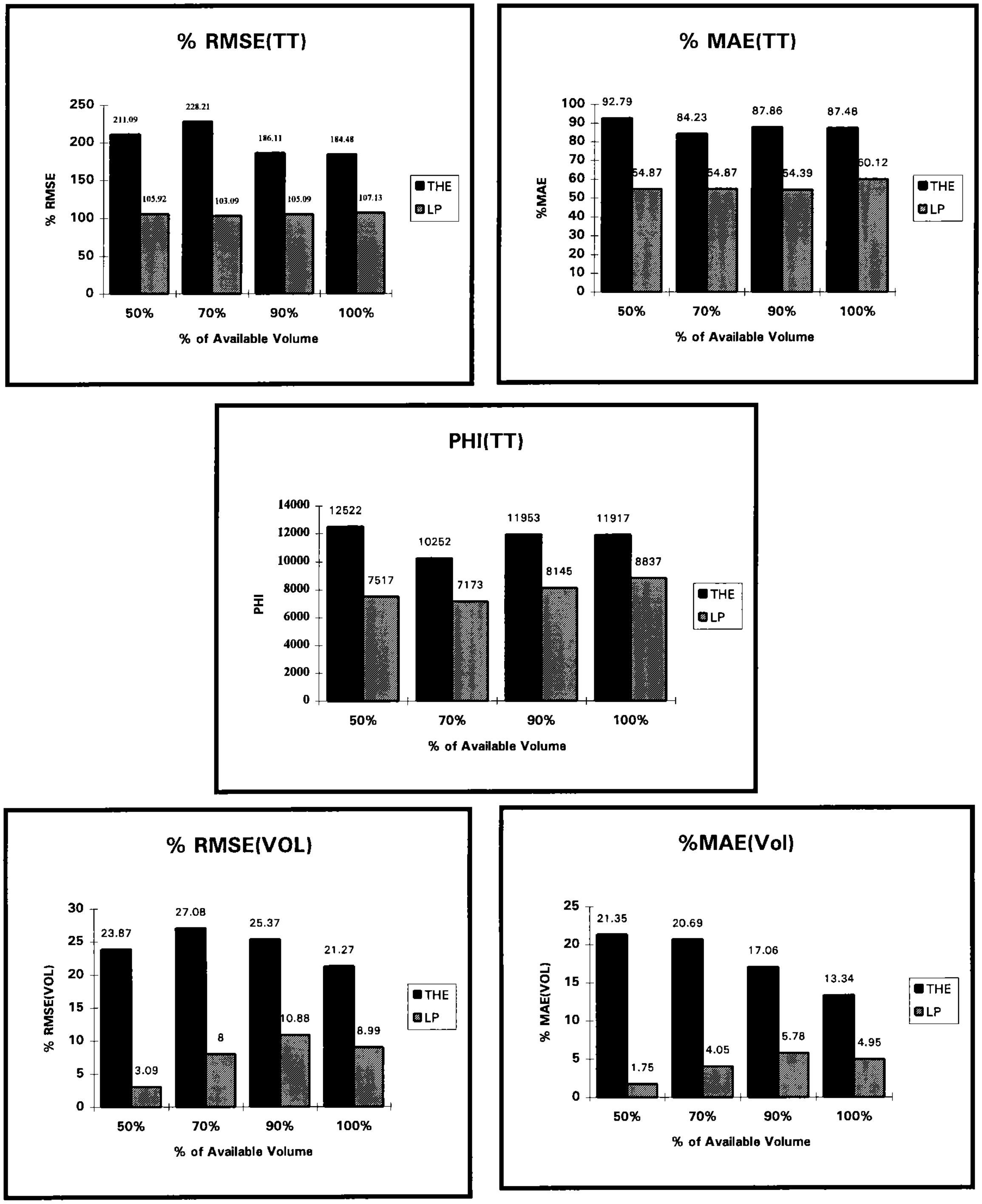


Figure 5-6: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** Small Error Psi = 0.8, 80%

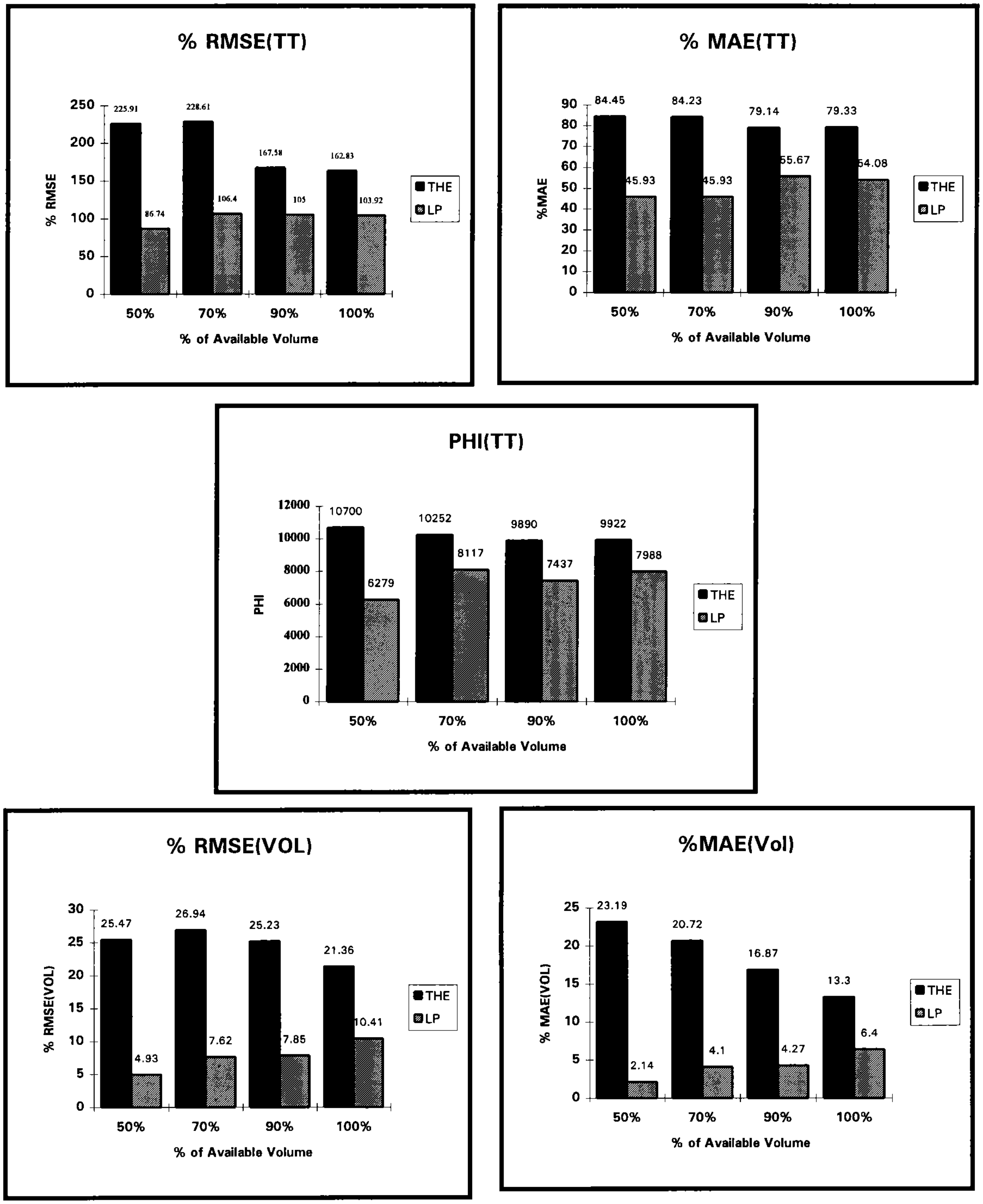
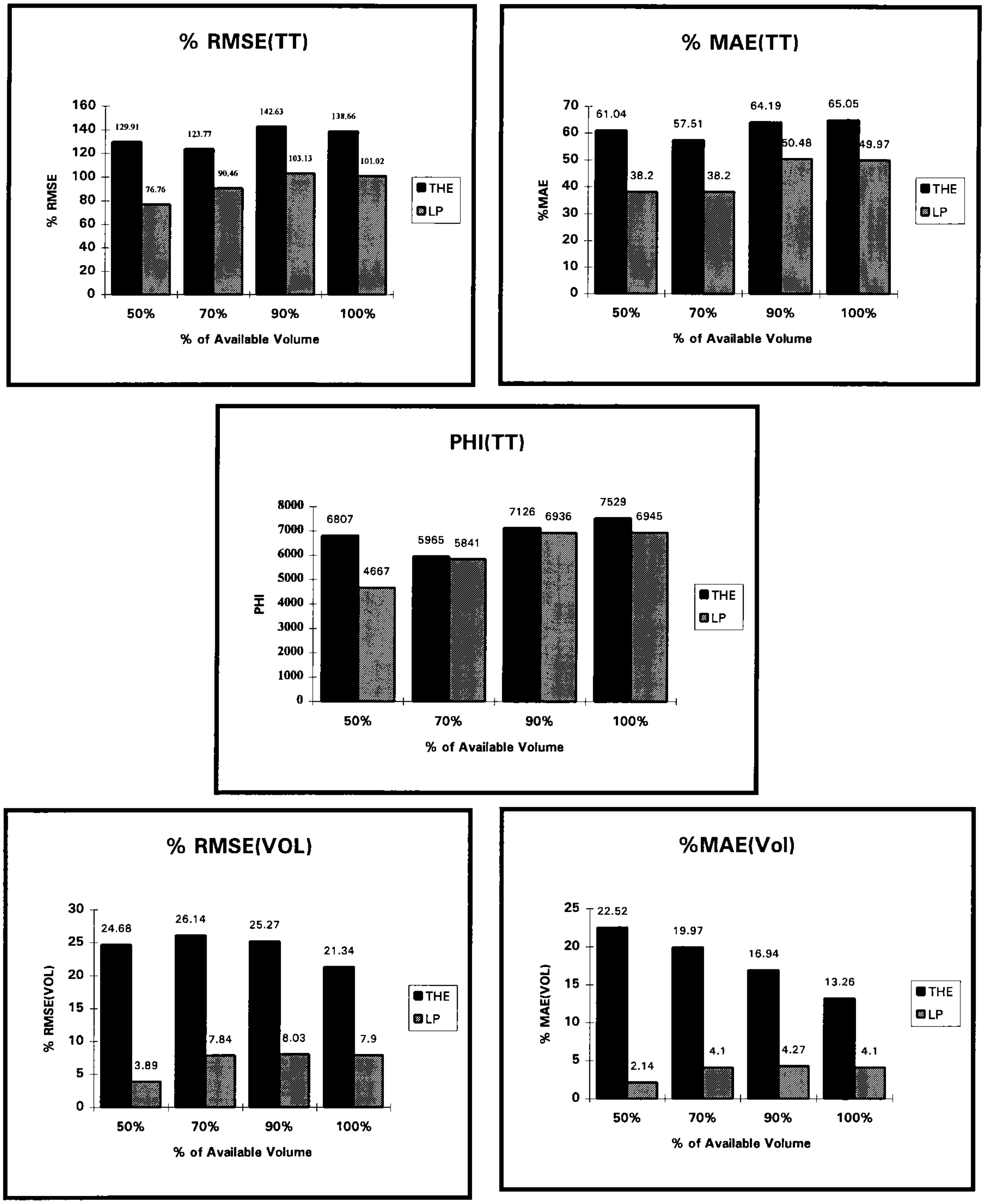


Figure 5-7: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

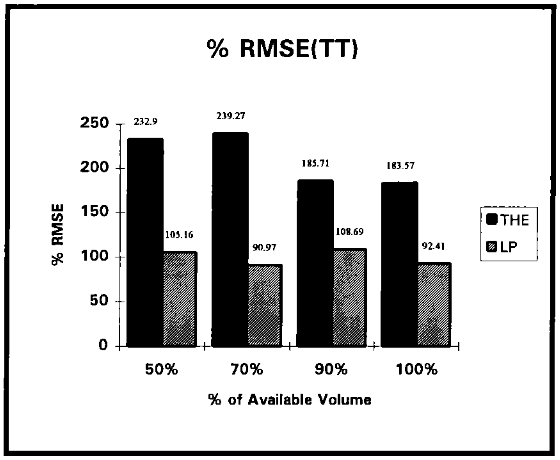
Network: Purdue **Target** Small Error Psi=0.8, 100%

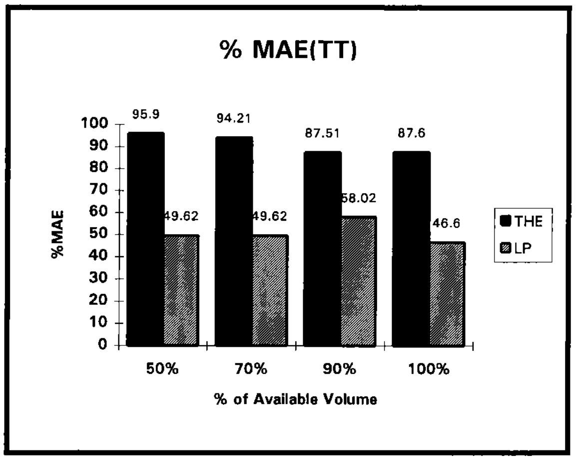


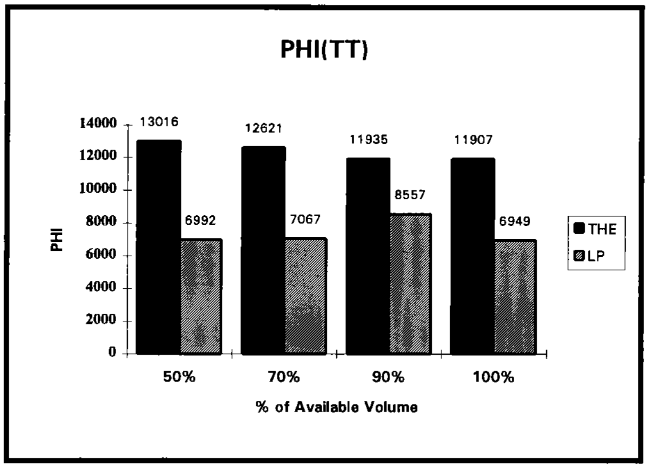
(d) "Small Error" Trip Table as Target (ψ=0.9): This section presents the test results for the small error target case, when a ψ value of 0.9 (see Sec. 5.3) was employed. The charts representing the statistics for comparison of modeled versus surveyed trip tables and modeled versus observed volumes for the 60%, 80% and 100% cell information are shown in Figures 5-8, 5-9 and 5-10, respectively. These figures again indicate the clear superiority of the LP model over THE. For each of the test cases, every error statistic, both for trip table closeness and link volume replication, is lower for the LP model.

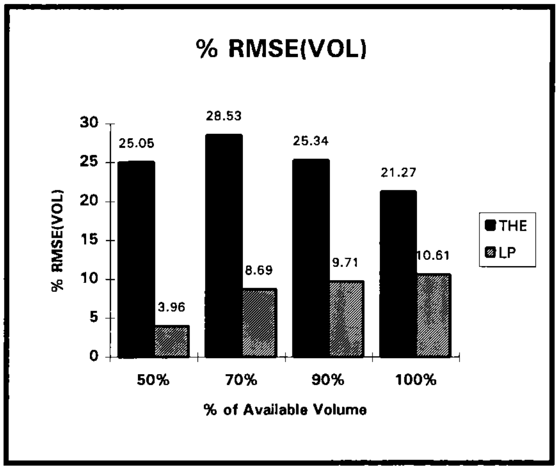
Figure 5-8: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** Small Error Psi=0.9, 60%









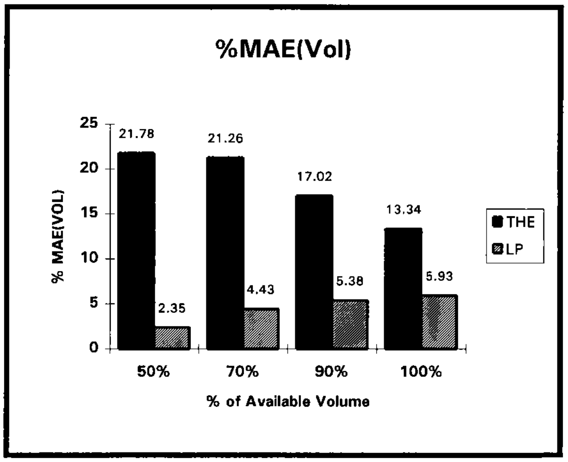


Figure 5-9: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** Small Error Psi=0.9, 80%

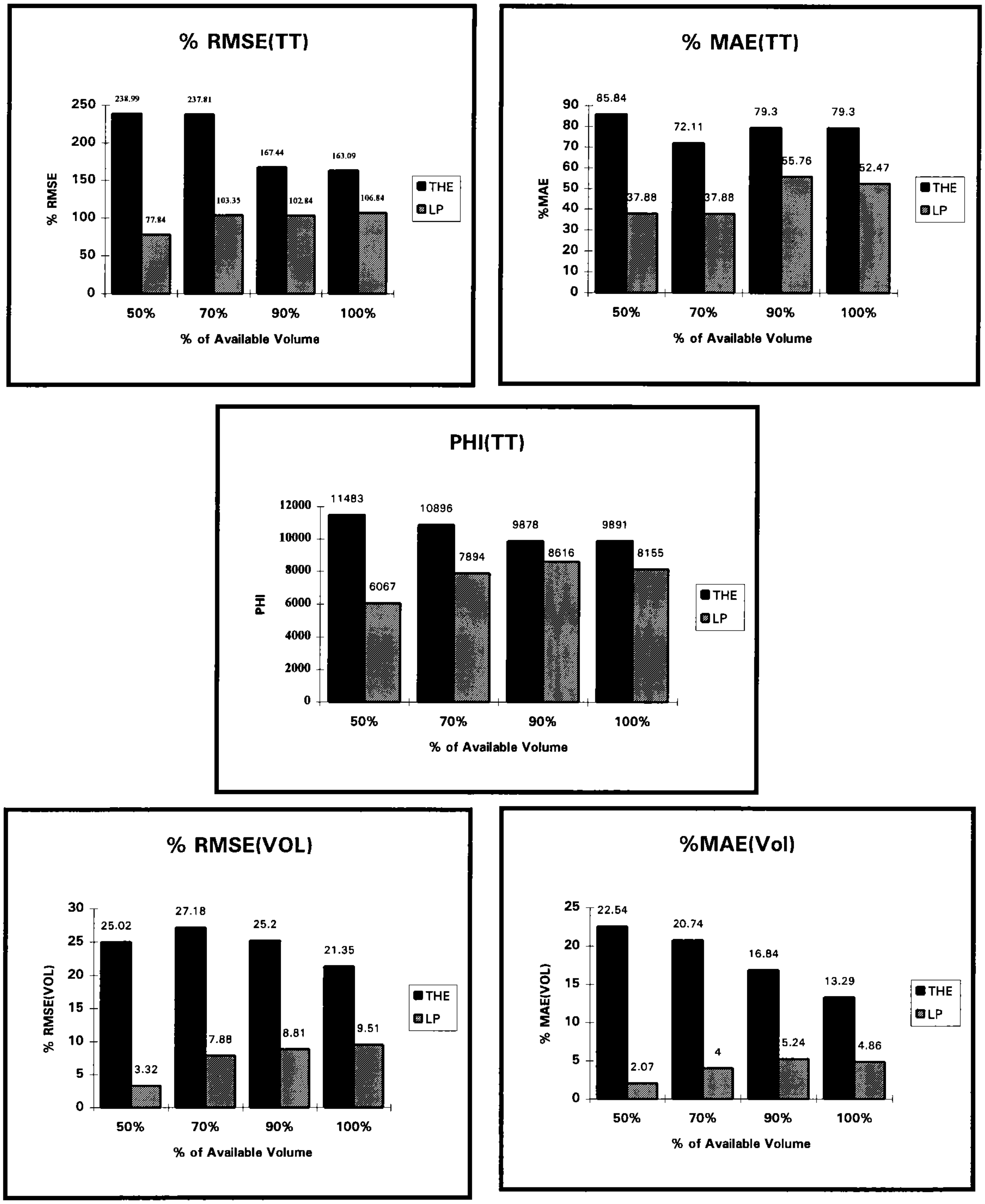
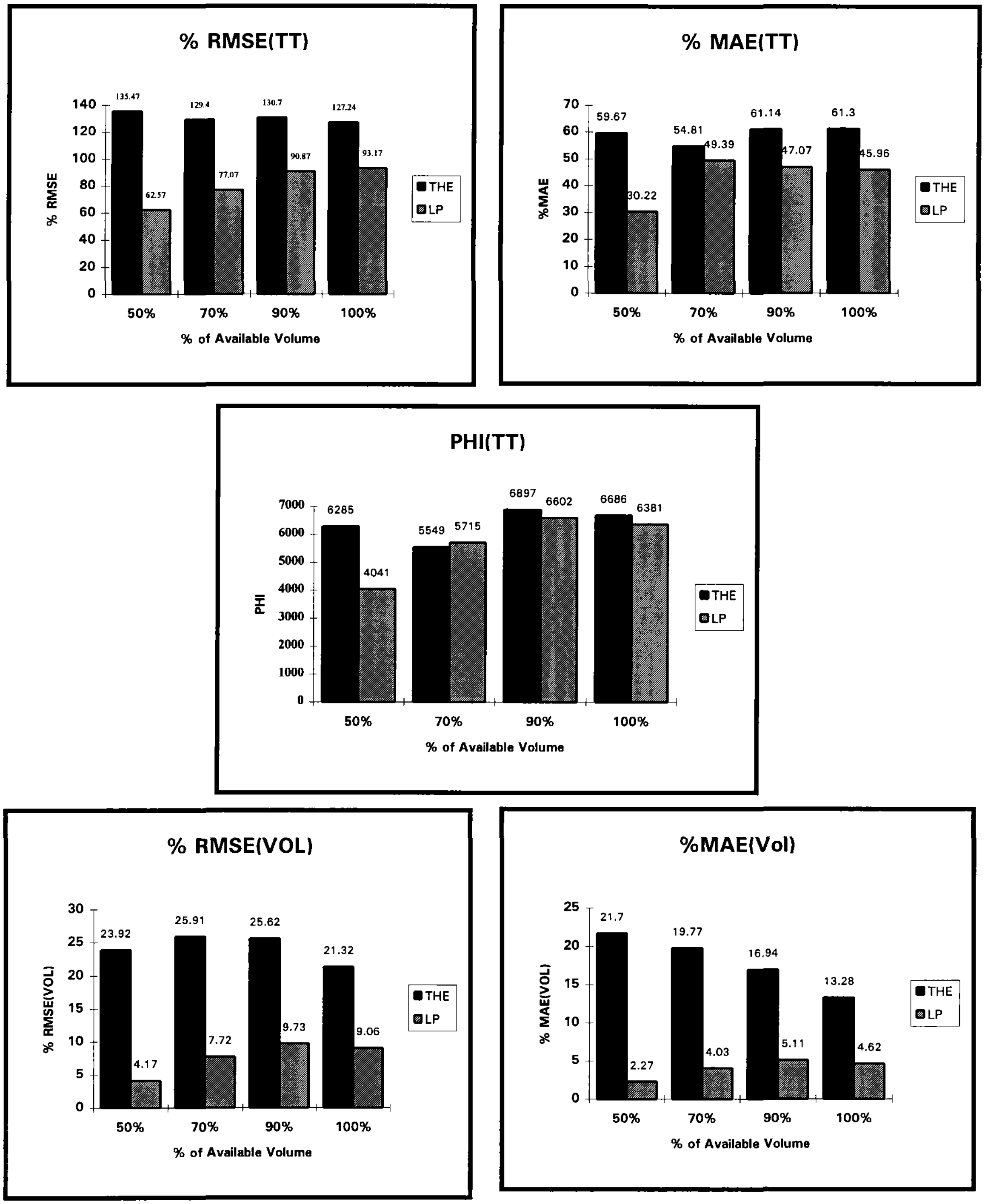


Figure 5-10: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Purdue **Target** Small Error Psi=0.9, 100%



5.5 Conclusions

The test results for the Purdue network discussed in this chapter have been synthesized, and are shown graphically in Figures 5-11 through 5-15.

Examining the variation of ϕ statistic shown in Figure 5-13, for the LP model, this statistic is seen to generally decrease (with few exceptions) with the improvement in target table information, which is as expected. For THE, this trend is generally seen among the cases within each basic target case (except structural target), and not between the different target cases. With regard to the variation of ϕ with percentage variation in volumes, mixed trends are noticed for both models. While for some cases, this statistic decreases with increase in percentage available volumes, for some others it increases. This may be attributable to two reasons: first, the link volumes may not be consistent with the surveyed O-D tables, and second, there may have been inconsistencies/errors in observed volume data. In general, the LP model has lower values of ϕ (except for structural target case), as compared to THE model. The figure also highlights the relatively poorer performance of THE model for cases when the percentages of target table and link volume information are low. However, a noteworthy point about THE is its superiority over the LP model in terms of the quality of the output table for the structural target case.

The variation of the link volume replication errors for the LP and THE models, as measured by the %RMSE(Vol) and %MAE(Vol) statistics, is depicted in Figures 5-14 and 5-15, respectively. As seen in the figures, the LP model has significantly lower values for these error statistics for every test case.

Figure 5-11: Trip Table Comparison (Modeled vs. Surveyed)

Network: Purdue **Measure:** %RMSE(TT)

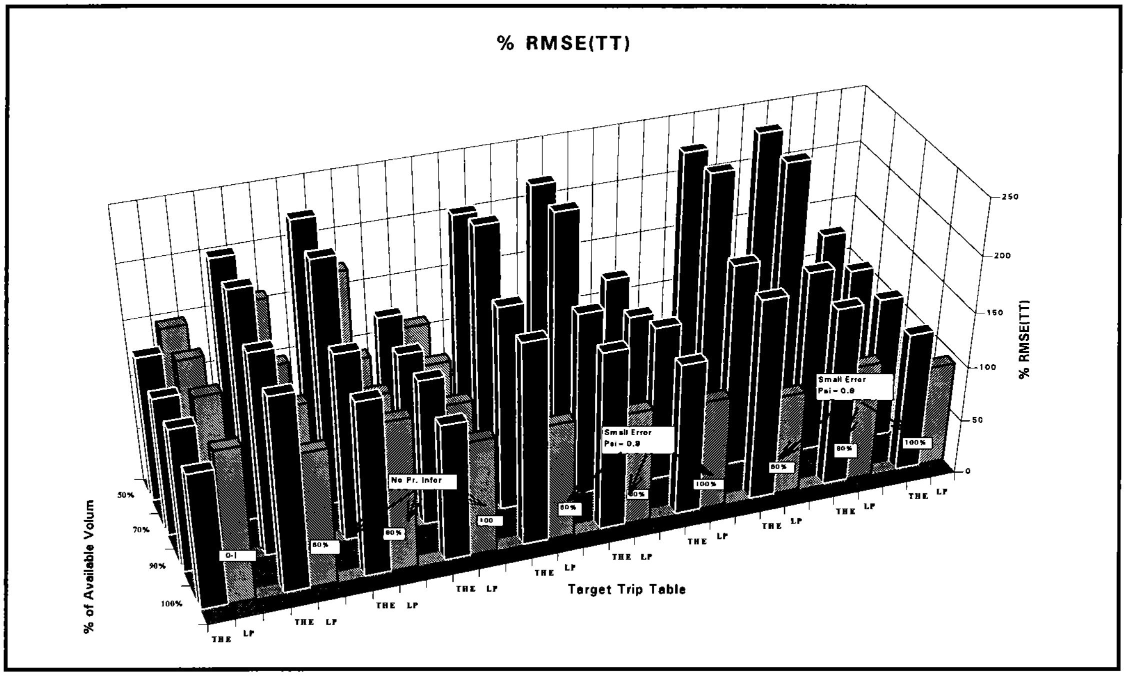


Figure 5-12: Trip Table Comparison (Modeled vs. Surveyed)

Network: Purdue **Measure:** %MAE(TT)

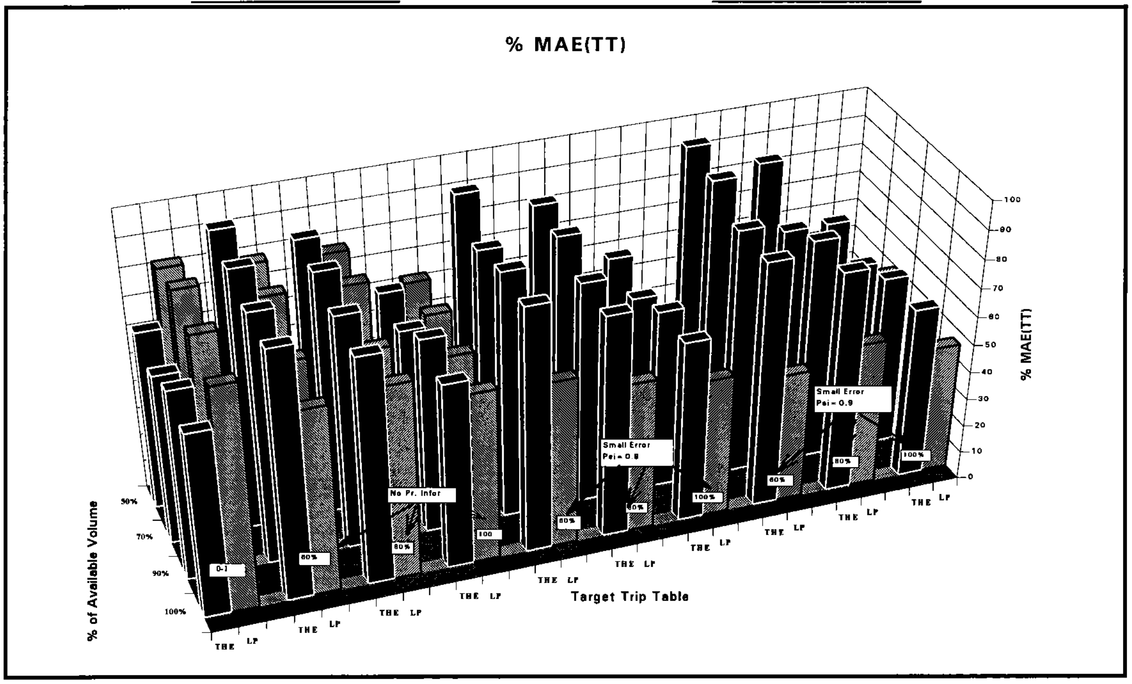


Figure 5-13: Trip Table Comparison (Modeled vs. Surveyed)

Network: Purdue **Measure:** PHI(TT)

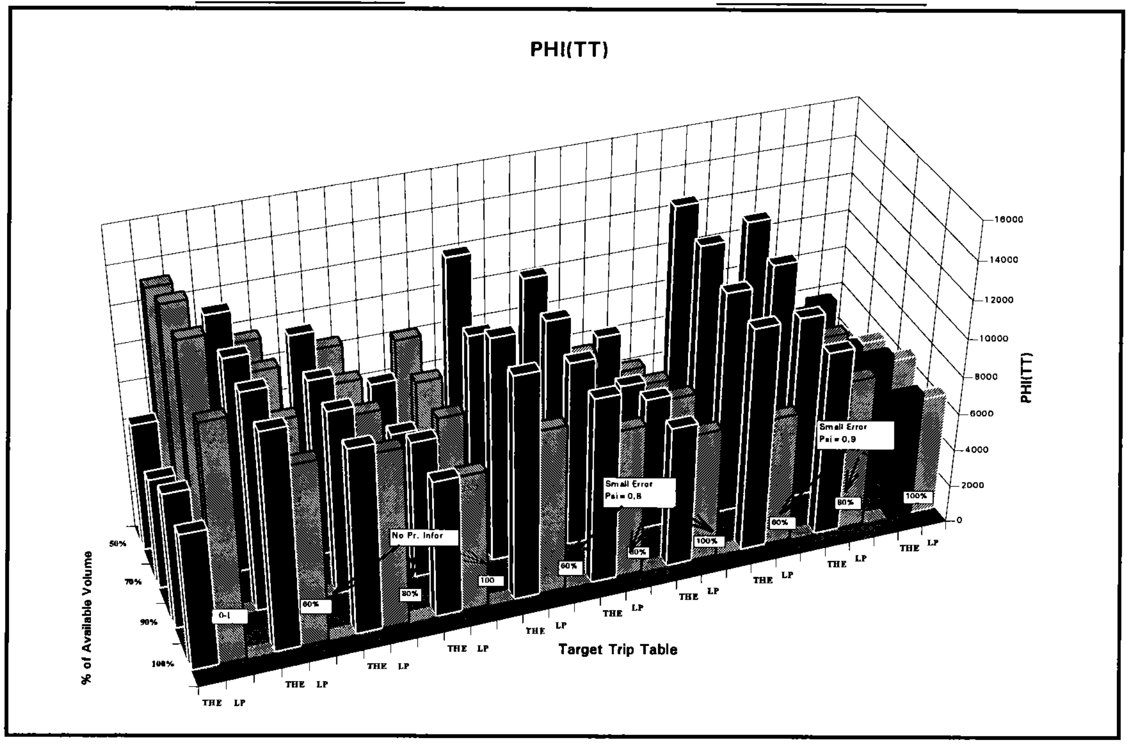


Figure 5-14: Volume Comparison (Modeled vs. Observed)

Network: Purdue **Measure:** %RMSE(VOL)

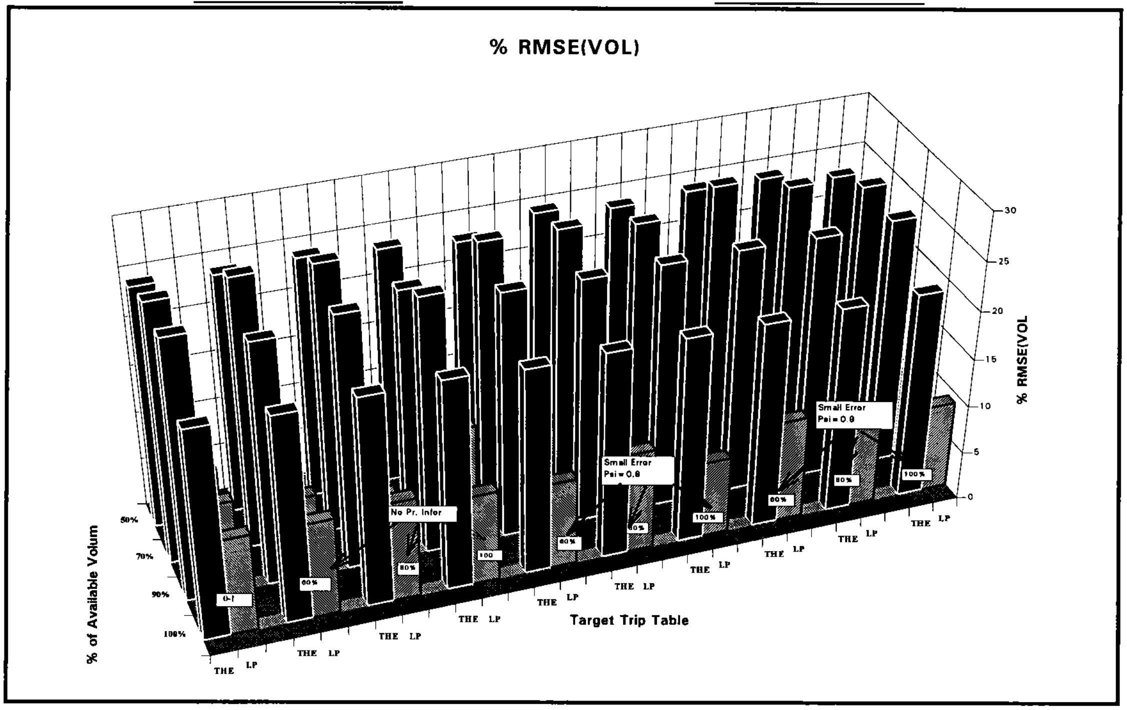
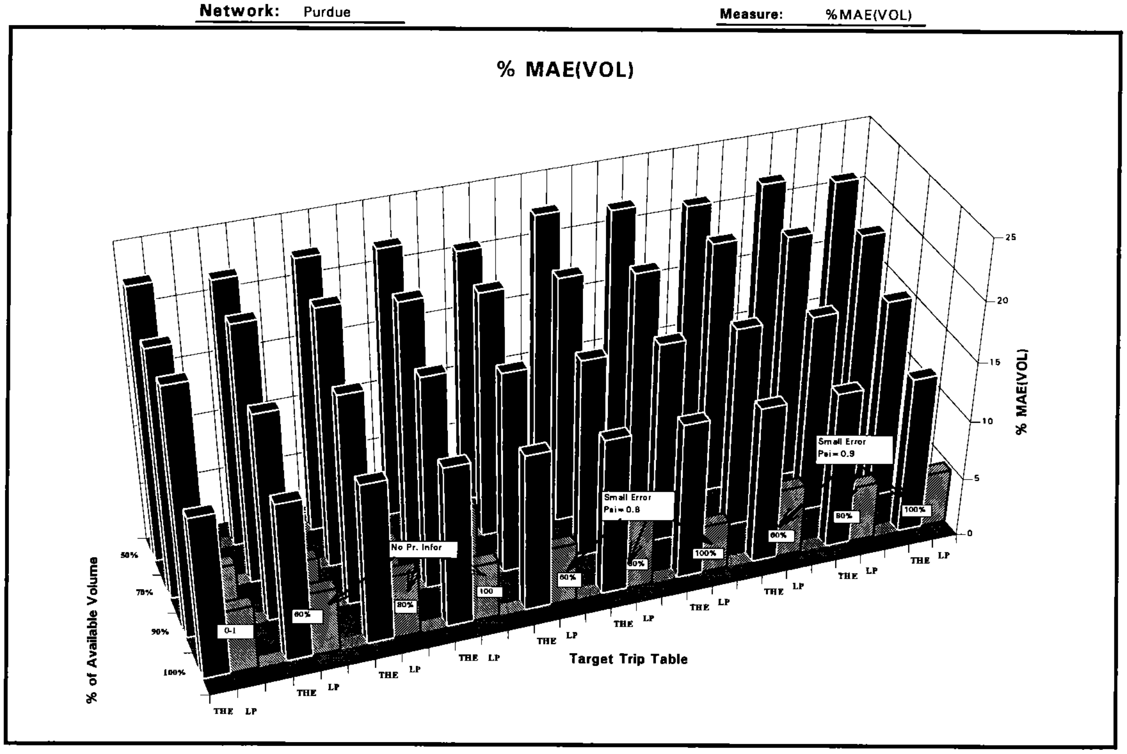


Figure 5-15: Volume Comparison (Modeled vs. Observed)

Network: Purdue **Measure:** %MAE(VOL)



Thus, the results lead to the conclusion that the LP model is, in general, superior to THE (except for the structural target case). However, these conclusions are based on the assumption that the trip table against which the results are compared are in fact “true/correct”.

Chapter 6.0

Evaluation of Models Using Pulaski Network Data

6.1 Introduction

This chapter deals with the applications of both THE and LP models on the real network of Pulaski, Virginia. The Pulaski application facilitated a more realistic validation due to the fact that a surveyed trip table was available through Virginia Department of Transportation (VDOT) for comparison purposes. The details about the network and available data, applications of the models, analyses and discussion of results, and inferences are presented here.

6.2 Pulaski Network

Located in the central area of Pulaski County, Southwestern Virginia, Pulaski had a population of around 10,000 in 1990. The network, as defined by VDOT, consists of 21 internal zones and 11 external stations. These internal zones have been divided according to the density of population and the activity centers in and around the area. The original network was provided by VDOT. This network was reduced by Center for Transportation Research by eliminating redundancies and other information not necessary for test purposes. The test network as used in this study had 32 zones, 57 intersection nodes and 230 links (Figure 6-1). The actual Pulaski map is attached as Appendix 1. Data on network characteristics, such as link lengths, free flow speeds and capacities were also provided by VDOT.

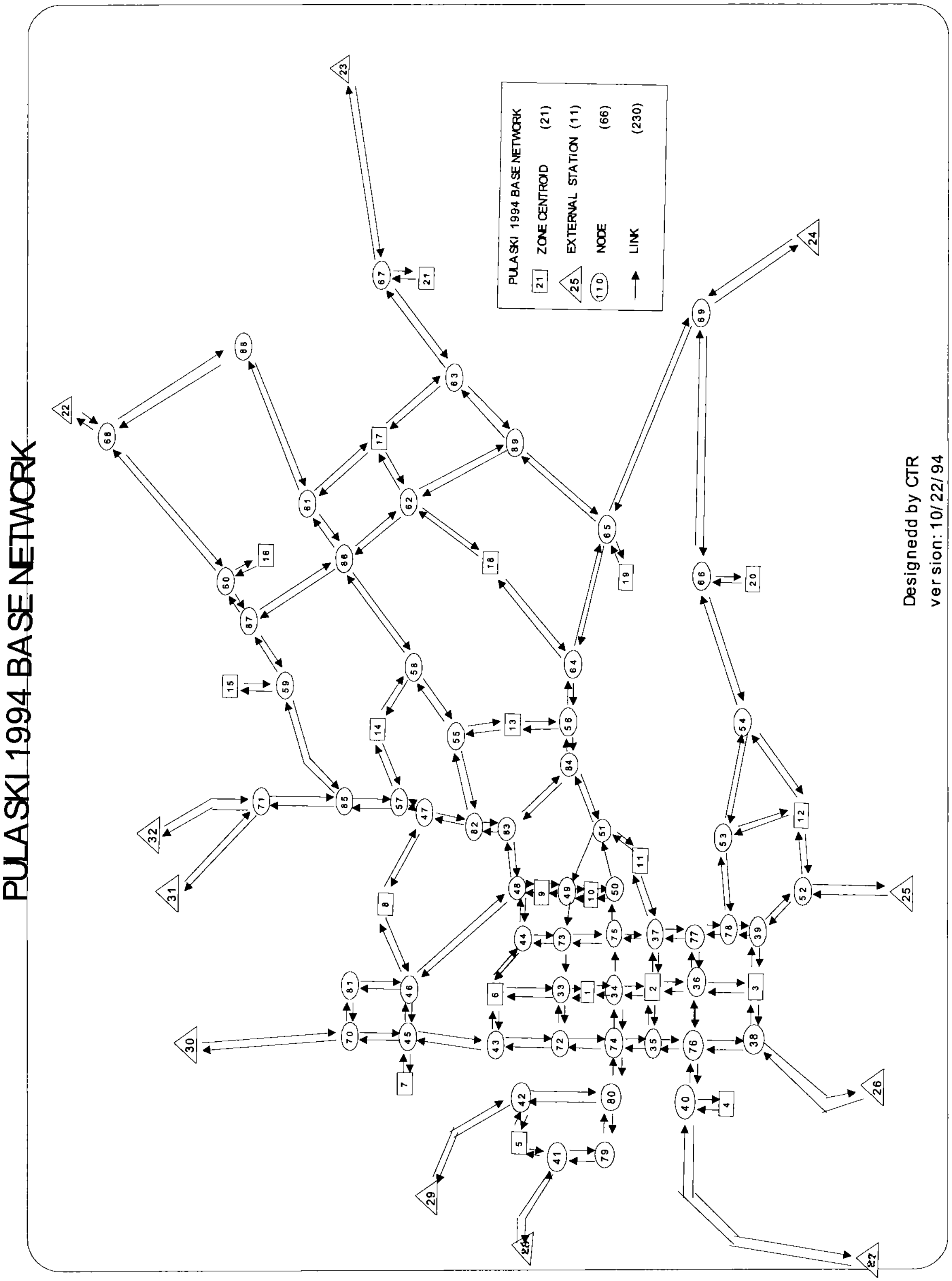


Figure 6-1: Pulaski Base Network (Source: VDOT)

In order to validate the O-D models with real data, VDOT, with the help of Virginia Tech's Center for Survey Research (CSR), conducted an O-D survey, and established a trip table. The details of this survey are also included in this chapter.

6.2.1 Network Volume Data Collection

In order to facilitate volume input for the O-D models, in 1994 VDOT surveyed 24 hour traffic volumes on 175 out of the 230 links of the Pulaski network (defined for this study) using counters. These volumes were collected for 15 minute intervals, which also helped in determining peak-hour volumes. Since VDOT was interested in estimating both the daily (24 hr) and the peak hour trip tables, the corresponding volume data were used in the models. Since there were some variations/inconsistencies in volume measurements for some of the stations, some cleaning-up of the data was needed. The period between 9:00 AM on June 14, '95 and 9:00 AM on June 15 was chosen as the 24 hour data for consideration. Since complete data for the above period were not available for some stations, data collected during the second measurement were used for the missing time periods. Since not all the links of the network had the peak flow during the same hour, the peak hour was chosen as 3:30 - 4:30 PM, based on the occurrence of peak flow on majority of the links.

It must be noted that volume data was not available for 55 links. These links were mostly centroid connectors. Since these connectors are an abstraction of several minor streets on the field, single volume measurements cannot be performed for these. Hence, in several modeling applications, centroid connector volumes are generally unknown. In addition, there were some links where construction activities hampered data collection. Thus, observed volumes were available for only 75% (appx.) of the links. This may be considered reasonable and realistic, since similar situations could be expected for such real-life applications. Also, this created an opportunity to evaluate the performance of the models in the case of 25% missing volumes.

6.2.2 Trip Table Data

Trip table data was required for two purposes:

(1) To validate the model results against a "true" or "correct" trip table.

(2) To provide target/seed information to the models for guiding their solutions.

The first purpose was of primary importance in this research work, since the major objective here was to validate the models, which meant that their results needed to be compared with the "true," "correct," or "real" trip tables. Since Pulaski town did not have such a table readily available, an Origin-Destination (O-D) survey was conducted. VDOT, assisted by the Center for Survey Research at Virginia Tech, conducted the O-D survey by mail. For this research work, these "surveyed" tables were assumed to be "true/correct" and were used for comparison purposes. The second purpose was accomplished by distorting the surveyed tables to act as seed/target information.

6.2.2.1 Town of Pulaski Origin-Destination (O-D) Mail Survey

The contents of this section have been extracted from the O-D mail survey report (Center for Survey Research, 1994).

A two-part research methodology designed by VDOT included a mail survey of Pulaski residents and roadside surveys of drivers on the roads entering and leaving Pulaski. The Virginia Tech Center for Survey Research (CSR) was contracted by VDOT to administer the mail survey and perform data entry of the roadside surveys. The procedures for CSR's administration of the Town of

Pulaski Origin-Destination Mail Survey has been documented in the O-D survey report (Center for Survey Research, 1994).

The survey was administered in two waves. Prior to the mailing, VDOT prepared a press release for distribution to the print media serving the Pulaski area which explained the purpose of the study and encouraged citizen cooperation. The first wave of 3,900 surveys was mailed on June 3, 1994 with the trip diary date designated as June 8. A postcard was mailed June 6 as a reminder of the survey date and to encourage residents to complete their surveys. In cases where the survey package was returned by the Post Office for any reason, such as forwarding address expired, resident deceased, etc., a second wave survey package was mailed to the same residence addressed to “Current Resident”.

The second wave of surveys was mailed to 3,200 non-respondents on July 15, 1994 with a trip diary date of July 20. Because 56 surveys mailed in the first wave were received during the time of the second wave mailing, those residents received a survey package even though they had already completed it. The survey package in both waves of administration contained a cover letter from Thomas Combiths (Town Manager of Pulaski), the household characteristics survey, instructions for completing the trip diaries, and a postage paid return envelope. The texts of the postcard and instructions for completing the trip diaries are provided in the O-D survey report (Center for Survey Research, 1994).

A total of 874 completed household characteristics surveys were returned with trip diaries from the first and second waves. After excluding 336 addresses which were undeliverable or otherwise ineligible from the initial sample of 3,900, the total population of Pulaski households surveyed was 3,564. Thus, a rate of 24.5 percent was achieved. Assuming the 874 completed forms are representative of all Pulaski households, the margin of error is ±3.8 percent at the 95 percent confidence interval. That is, assuming there are no substantial differences between completed and uncompleted household characteristics surveys, results reported are within ±3.8 percentage points of the actual values in the population. This assumption may not hold true, however, since the response rate was low. Entries of survey data were performed by Center for Survey Research.

In addition to the above mail survey, VDOT conducted roadside surveys of motorists to capture the travel patterns of external-external and external-internal trips. These data were entered by the Center for Survey Research. From these data, the final O-D tables, both 24 hour and peak hour, projected for the population of Pulaski town were established by VDOT (attached as Appendices 2 & 3). As per VDOT information, there were some data collection errors during the surveys. Hence, these tables cannot be taken as fully "true" or "correct." In addition, basing the survey on samples may also contribute to some errors. However, conducting an O-D survey exclusively for the purpose of validating the models has been a great advantage in this research.

6.3 Test Cases

LP and THE were tested separately for several cases of availability of link volumes and prior trip table information. The model results were judged by measuring how close they were to the surveyed or observed values. For these measures of closeness, %MAE, %RMSE and PHI statistics were used for the trip table comparisons, and %MAE and %RMSE were used for the volume comparisons.

The prior/target/seed trip tables used in the tests conducted on the Pulaski network are primarily of three types - structural, no-prior-information, and small error tables. Using these three types, five different target tables were derived for each of the cases of daily and peak hour trip tables. These included partial trip tables that were obtained by removing some cell information from two of the three basic types of tables. The extent to which information was removed varied from 0%-40% of the total number of feasible interchanges. The logic behind the choice of this percentage range was the assumption that, in the event an old prior trip table was available for a study area, then at least 60% of the cells in that table may contain information relevant to that study. The variation in the percentages (0% -- 40%) for the missing information cells was used to test the sensitiveness of the models to varying levels of prior information. Likewise, the percentages of links with missing volume information were based on the assumption that it will be impossible to obtain 100% volume information. The study of the sensitivity of the models to volume information was also a motivation. Since the maximum percentage of available volumes was approximately 75, only three cases (50%, 60% and 75%) of available link volumes were tested. The cells and links with missing information were identified based on a random selection.

The structural trip table has 1/0 values for its cells to indicate merely if that trip interchange is feasible or not. The no-prior-information trip table had a uniform value for all feasible interchanges. This value was equal to 33 for a 24 hour case, which represents the average surveyed trip interchange based on total number of trips factored by a value of 0.75. The factor of 0.75 was arbitrarily chosen based on an assumption that the total number of trips for a past period will be in the range of, say, 70%-90% of current total trips. Thus, this value was used in order for the target trip table to emulate past conditions. Similarly, a value of 3 was used for the cells of the no-prior-information target table for the peak hour case. This value was obtained using a factor of 0.8. For this test case in this study, however, the no-prior-information target was derived from the surveyed table. The term "no-prior-information" has been used here to be consistent with the sample network case. The third type of trip table used as target/seed was relatively close to the surveyed trip table. It was generated by introducing errors into the surveyed trip table using the below mechanism:

$$P_{ij} = C_{ij}(\psi + \beta_{ij}); \qquad -\beta_{\max} < \beta < \beta_{\max}$$

where P_{ij} is the target table's ij^{th} cell, C_{ij} is the corresponding element in the surveyed table, ψ is the mean ratio of target table cell value to surveyed table cell value, β_{ij} is a normally distributed cell value error and $\beta_{\max}$ is the bound on this error. ψ was set to be the same for all cell values in a given table. We used $\psi = 0.8$ and $\beta_{\max} = 0.2$ for this case.

In summary, 15 cases were tested for each 24 hour and peak hour scenario (a total of 30 cases), for each of the models. These cases, arising out of a combination of different percentages of target trip table and link volume information availability, are shown below (Table 6-1). Because of the higher computational demands of the LP model for this network, a higher power SUN/SPARC server 1000 machine was used for LP runs. THE runs could, however, be made on an IBM compatible PC. The total number of cases for this network is less than that for Purdue. This is due to the fact that the number of percentage variations for available link volumes was limited to three, since the maximum possible percentage was only 75%. Also, LP model runs were very time consuming, thus limiting the number of cases that could be tested.

Table 6-1: Summary of Test Cases for Pulaski Network

Target Table	% Available Target Info.	% of Available Link Volumes			Total Cases
		50%	60%	75%	
Struct. (0/1)	100%	●	●	●	3
No-Prior-Info (0/33 and 0/3)	100%	●	●	●	3
Small Error	60% Cells	●	●	●	3
	80% Cells	●	●	●	3
	100% Cells	●	●	●	3
Total Cases		5	5	5	15

(Note: 15 cases were tested for each of the daily and peak hour table scenarios)

6. 4 Discussion of Model Results

Extensive model runs for different combinations of available information in the form of link volumes and prior trip tables have enabled us to analyze and verify the performance of the models and their sensitivity to different levels of data. This exercise has turned out to be very worthwhile for real-life applications of these models. A detailed discussion of model results for various cases is presented below. The results are organized around the two cases of trip tables: (a) 24 hour or daily, and (b) peak hour. Both the cases have significance in the context of practical applications for transportation planning/operations.

6. 4. 1 Case (a): Daily/24 hour Trip Table:

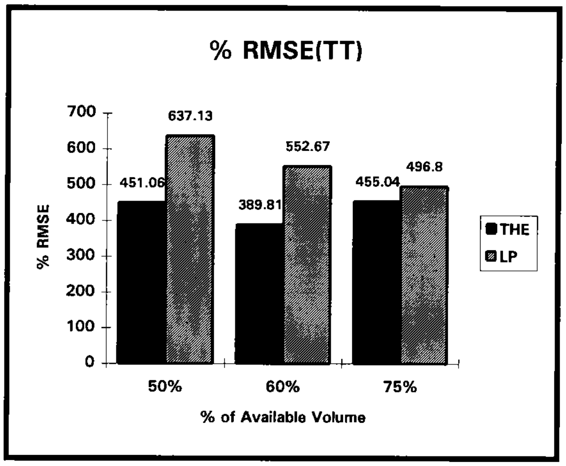
A daily or 24 hour trip table is one that shows the origin-destination travel patterns for a typical weekday (24 hour period). This table is of interest for several planning and traffic operations purposes. In order to establish such a table using observed network link volumes, corresponding period (24 hours) volumes were used. Likewise, a daily trip table had to be used as target/prior table. As noted earlier, three cases of target: (a) structural table, (b) no-prior-information table, and (c) small-error table, were used for test purposes. The discussions that follow are structured around these three cases, and highlight the performance of the LP and THE models. The models were judged based on their ability to match the prior table as closely as possible, and at the same time their capability to replicate the observed volumes. The discussion of results presented below centers around these two criteria.

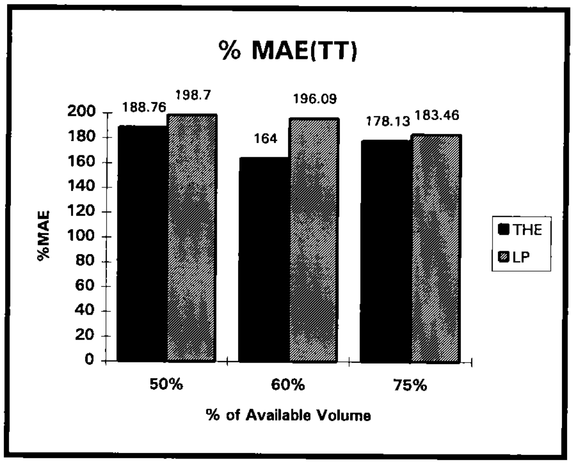
(a) Structural Table as Target/Seed: This case is one where the least amount of information is provided in the form of target. All that is input to the model is a structural table with 0/1 cell values, 1 signifying that the O-D interchange represented by that cell is a feasible interchange, and 0 indicating an infeasible interchange. When no prior trip table information is available, this target is the only option. This case has a practical significance in the context when a trip table is being established for an urban area for the first time, in which case no previous table will be available for use as target. Both THE and LP were run with this target for the three cases (50%, 60%, and 75%) of available link volumes. The resulting trip tables were then compared with the VDOT surveyed trip table. Also, the modeled volumes were compared with observed volumes to test how well the models are able to replicate the volumes.

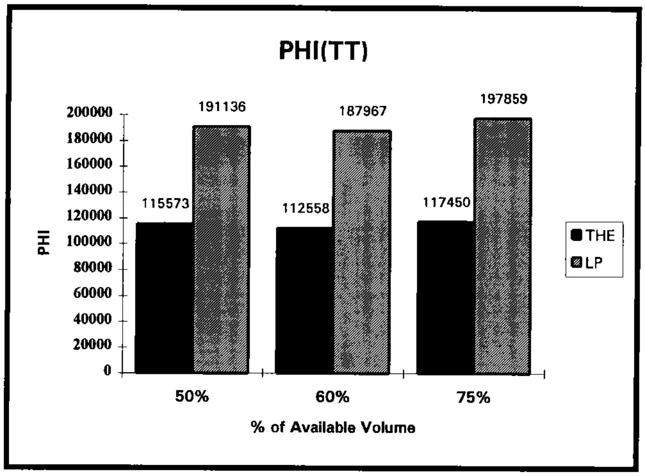
Examining the results of above comparisons for both the models, as shown in Figure 6-2, it is seen that in general The Highway Emulator yielded trip tables that were closer to the surveyed trip table, as compared to the LP model tables. This is highlighted by %RMSE (TT), %MAE(TT), and PHI (TT) statistics. Mixed trends are noted for both the models in terms of PHI variation with % available volumes. This may be due to some inconsistencies of the surveyed trip table with the observed volumes and/or due to inconsistencies/errors in observed volumes. Examining the statistics on the replication of link volumes, the LP model outcomes are superior (except for the 50% volume case) to THE's, as evidenced by %RMSE (Vol) and %MAE (Vol) charts. If higher weightage is given to the criteria on the closeness of the trip table to the surveyed table, it can be concluded that the performance of THE is generally superior to that of LP for this case, even though the PHI closeness statistic is poor for both the models. The output tables for both the models for this case are attached in the appendix.

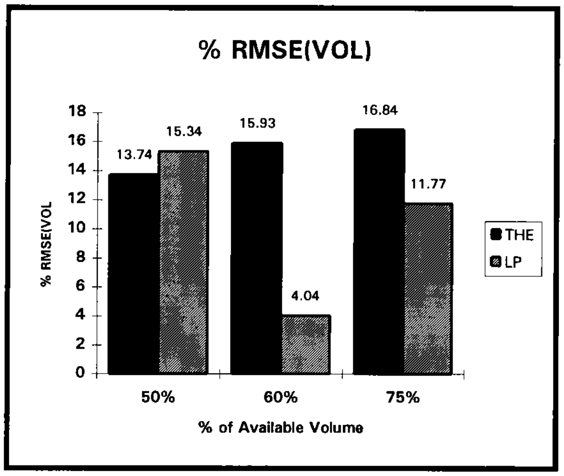
Figure 6-2: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

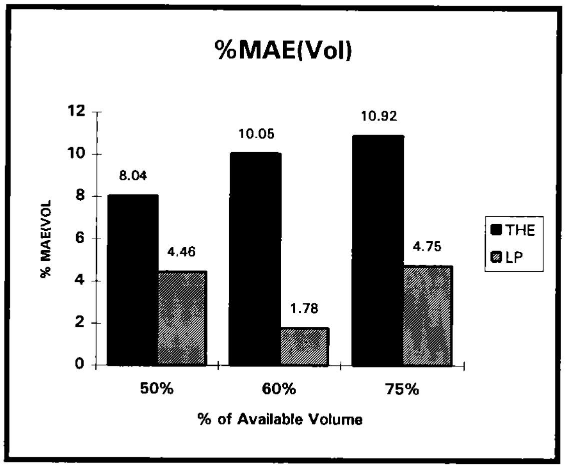
Network: Pulaski **Case:** 24 Hour **Target:** Structural









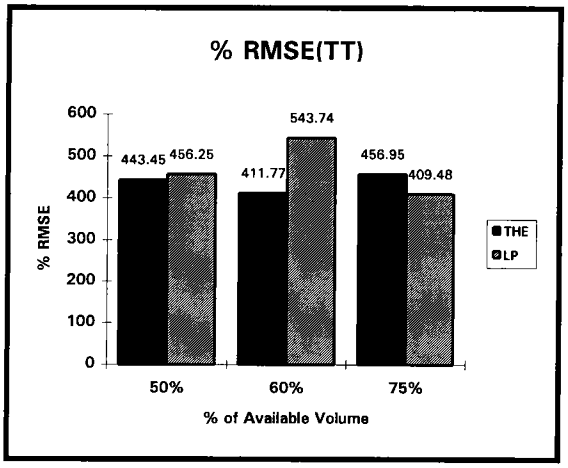


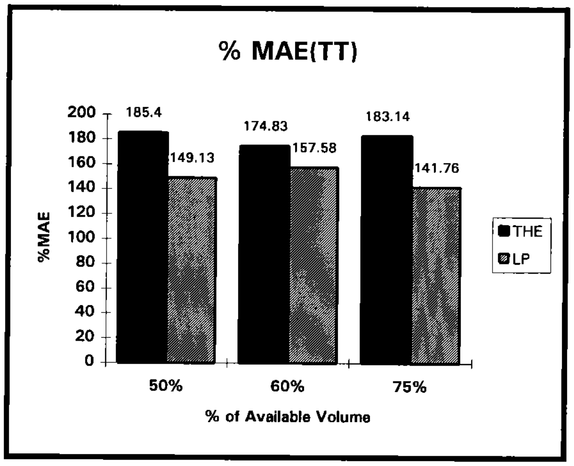
(b) **"No-Prior-Information" Table as Target/Seed:** For this study, the "no-prior-information" target table was the one with uniform cell values, representing an average value of a prior trip table. Both THE and LP were run with this target for the three cases (50%, 60%, and 75%) of available link volumes. The resulting trip tables were then compared with the VDOT-surveyed trip table. Also, the modeled volumes were compared with observed volumes to test how well the models are able to replicate the volumes.

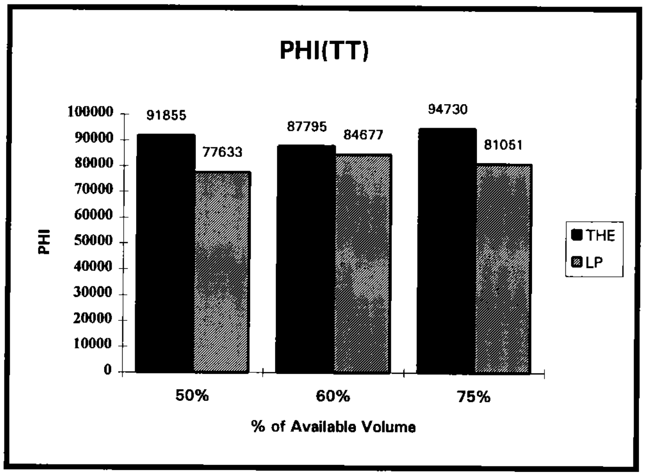
Examining the results of above comparisons for both the models, as shown in Figure 6-3, now it is seen that, in general, the LP model yielded trip tables that were closer to the surveyed trip table based on PHI statistic, as compared to THE model tables. Again, as in the previous case, the PHI value does not always decrease as the percentage available link volumes increases. This may be because of inconsistencies of the surveyed trip table with the observed volumes or inconsistencies/errors in the observed volumes. Observing the statistics on the replication of link volumes, again the LP model outcomes are superior (except for the 50% volume case) to THE's, as evidenced by %RMSE (Vol) and %MAE (Vol) charts. Thus, in this case, the performance of LP is generally superior to that of THE.

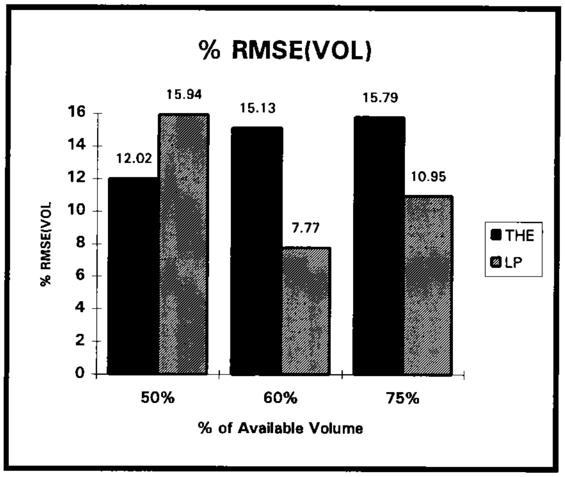
Figure 6-3: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

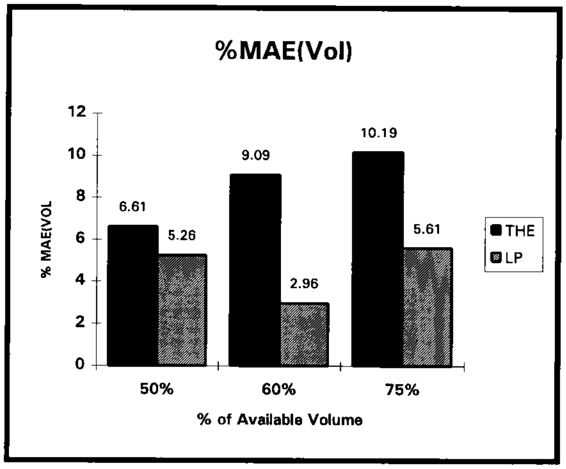
Network: Pulaski **Case:** 24 Hour **Target:** No-Prior-Info











(c) "Small Error" Trip Table as Target: This case represents a situation where an old and not-so-outdated table for the region is available as a target. For this study, however, since an old table was not available, as mentioned in Section 6.3, the VDOT surveyed table was distorted by inducing random errors, and the resulting table was considered as the "small error" target.

The charts depicting the statistics for comparison of modeled versus surveyed trip tables and modeled versus observed volumes for the 60%, 80% and 100% cell information are shown in Figures 6-4, 6-5 and 6-6, respectively. Observing the charts for 60% cell information (Figure 6-4), the LP model has lower statistics, as seen from PHI(TT) and %MAE(Vol). When the percentage cell information is increased to 80% (Figure 6-5), there is a significant improvement in terms of PHI(TT) values for the LP model, whereas THE shows only a marginal improvement. In fact, there is a slight deterioration in PHI value for the 50% volume case. The replication of link volumes shows a mixed trend for both the models. However, in general the %MAE(Vol) values are only in the low range. For the 100% cell information (when the complete target table is specified) (Figure 6-6), the LP model shows further improvement (except for 75% volume) in terms of PHI(TT). It must be noted here that THE's results for this case are the same as for the 80% volume case. This is because the target table in this case had to be derived from the surveyed table, as noted earlier, and contained many cells with zero values. When a partial table had to be specified as target, cells with zero values were first treated as missing cells. Then, if necessary, additional cells were picked randomly for assumption as missing cells. In the case of THE, the value of zero is to be given even if the cell value is unknown. Thus, the 80% and 100% cells targets were both the same, and yielded the same output.

Figure 6-4: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** 24 Hour **Target:** Small Error(60% Cells)

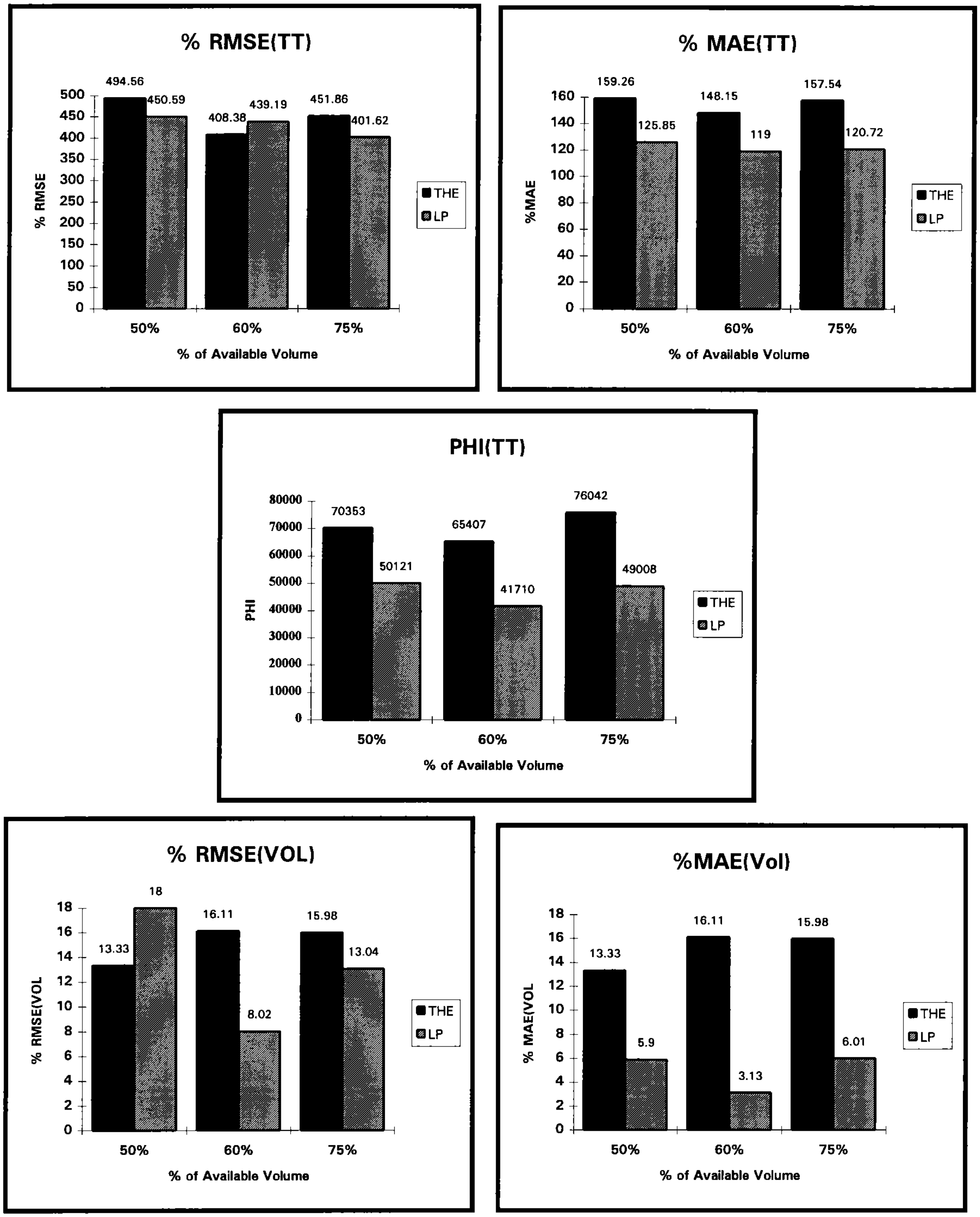


Figure 6.5: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** 24 Hour **Target:** Small Error(80% Cells)

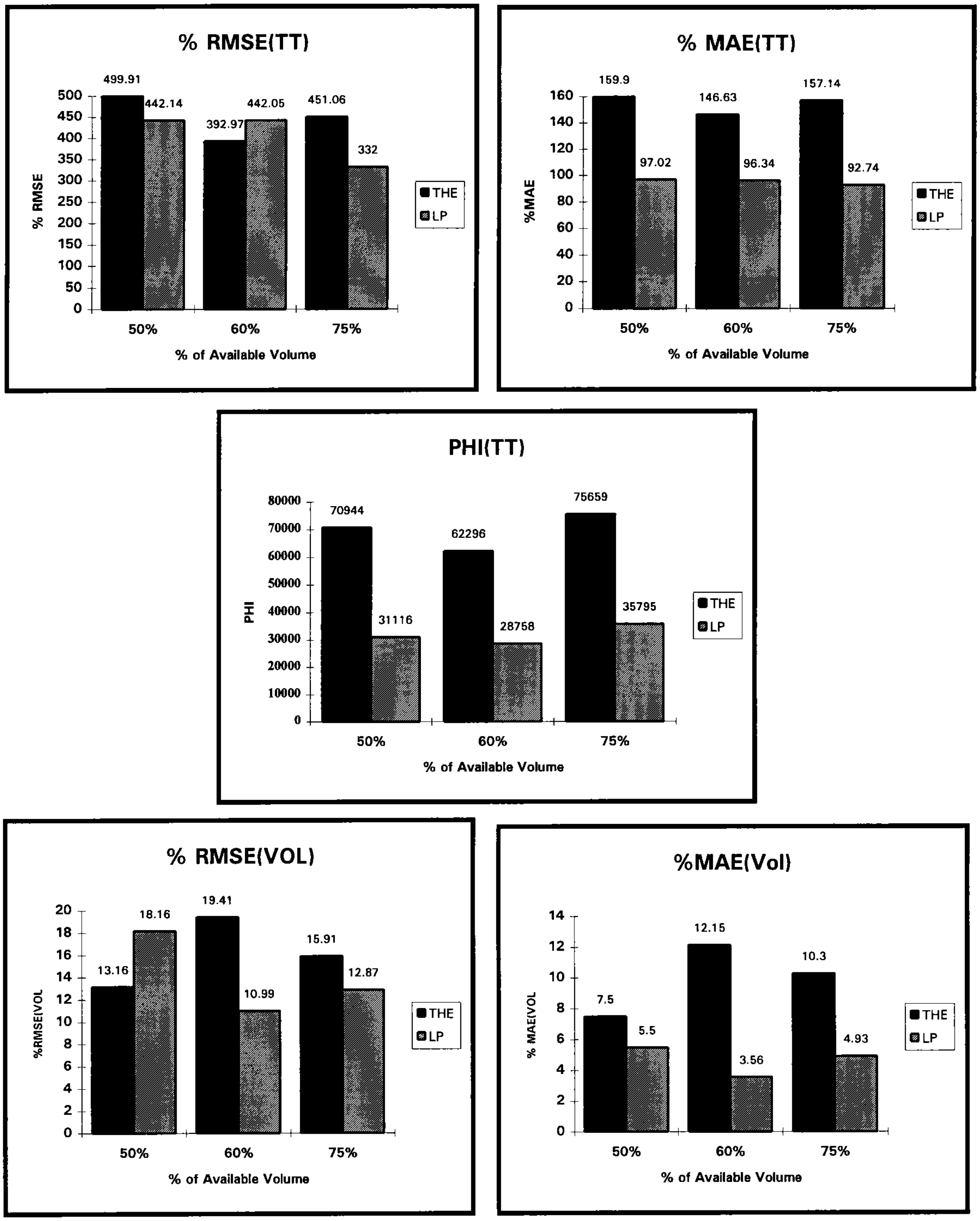
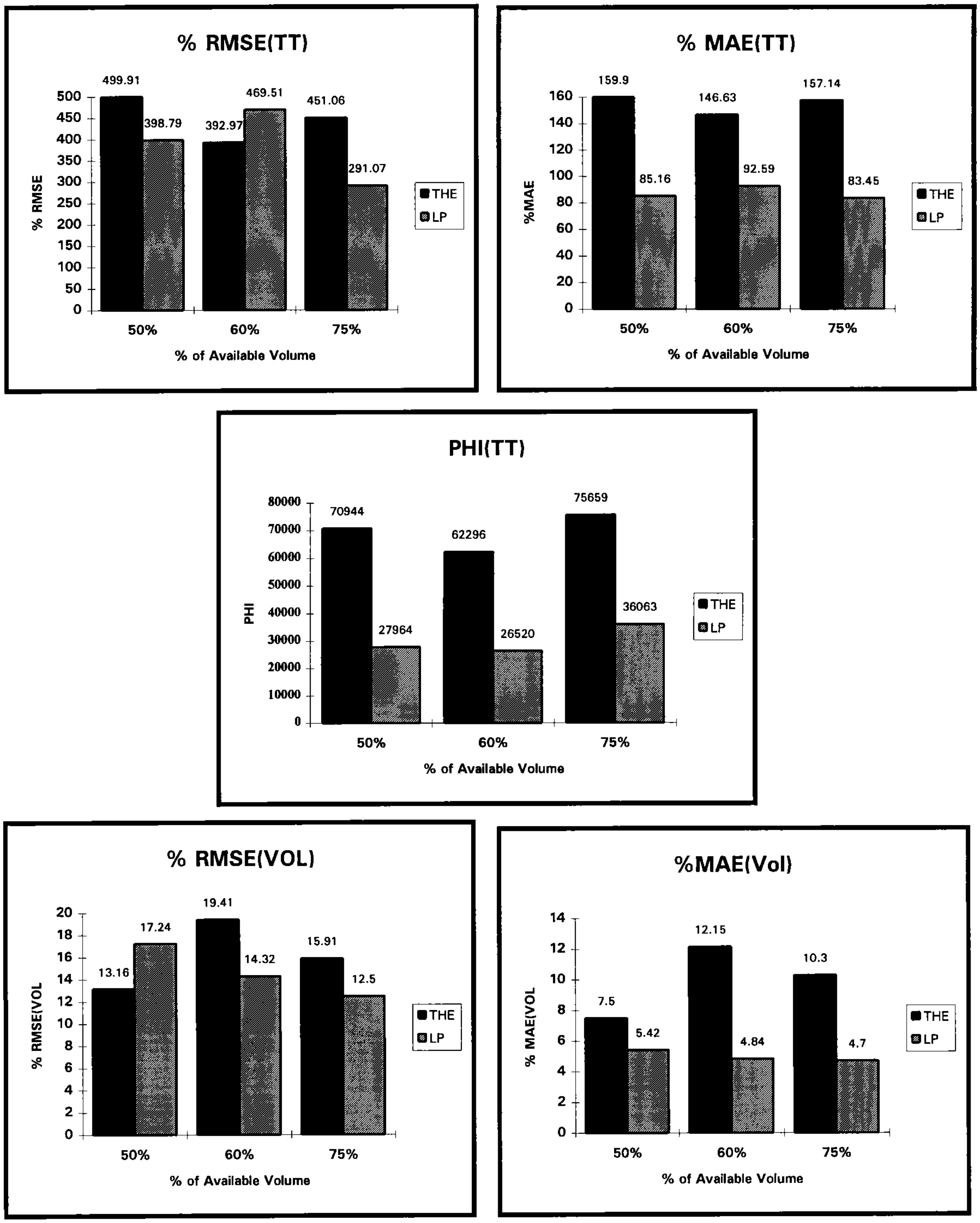


Figure 6-6: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** 24 Hour **Target:** Small Error(100% Cells)



In summary, the LP model performance turned out to be superior in all the cases of small-error target, both in terms of closeness of the output tables to the surveyed one, and in terms of replication of observed volumes. The output tables of both the models for this case (100% cells) are attached in the appendix.

6. 4. 2. Case (b): Peak Hour Trip Table

A peak hour trip table is one that shows the origin-destination travel patterns during the peak hour. In order to establish such a table using observed volumes, corresponding peak hour link volumes were used. Also, a peak hour trip table had to be used as target/prior table. Similar to the 24 hour case, three different targets: (a) structural, (b) no-prior-information, and (c) small error tables were used for test purposes.

The comparison charts for this case are shown in Figures 6-7 through 6-11. Many of the trends in results are, in general, similar to the 24 hour trip table case (with some exceptions), and this is evident from the figures. The LP model again proved superior to THE (except for the structural target case). The output tables for both the models for the structural target and small-error target (100% cells) are attached as appendix.

Figure 6-7: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** Peak Hour **Target:** Structural(0-1)

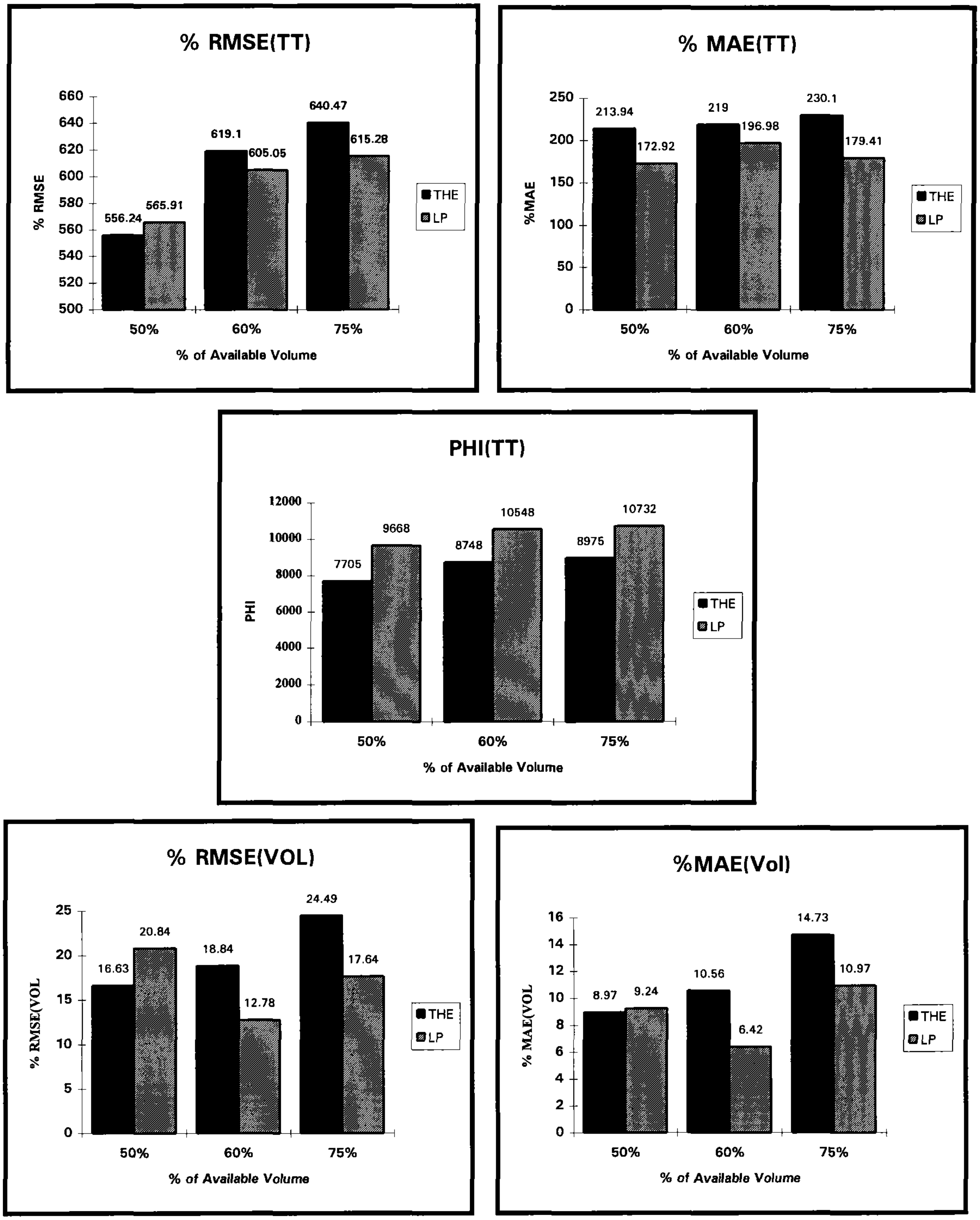


Figure 6-8: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** Peak Hour **Target:** No-Prior-Info

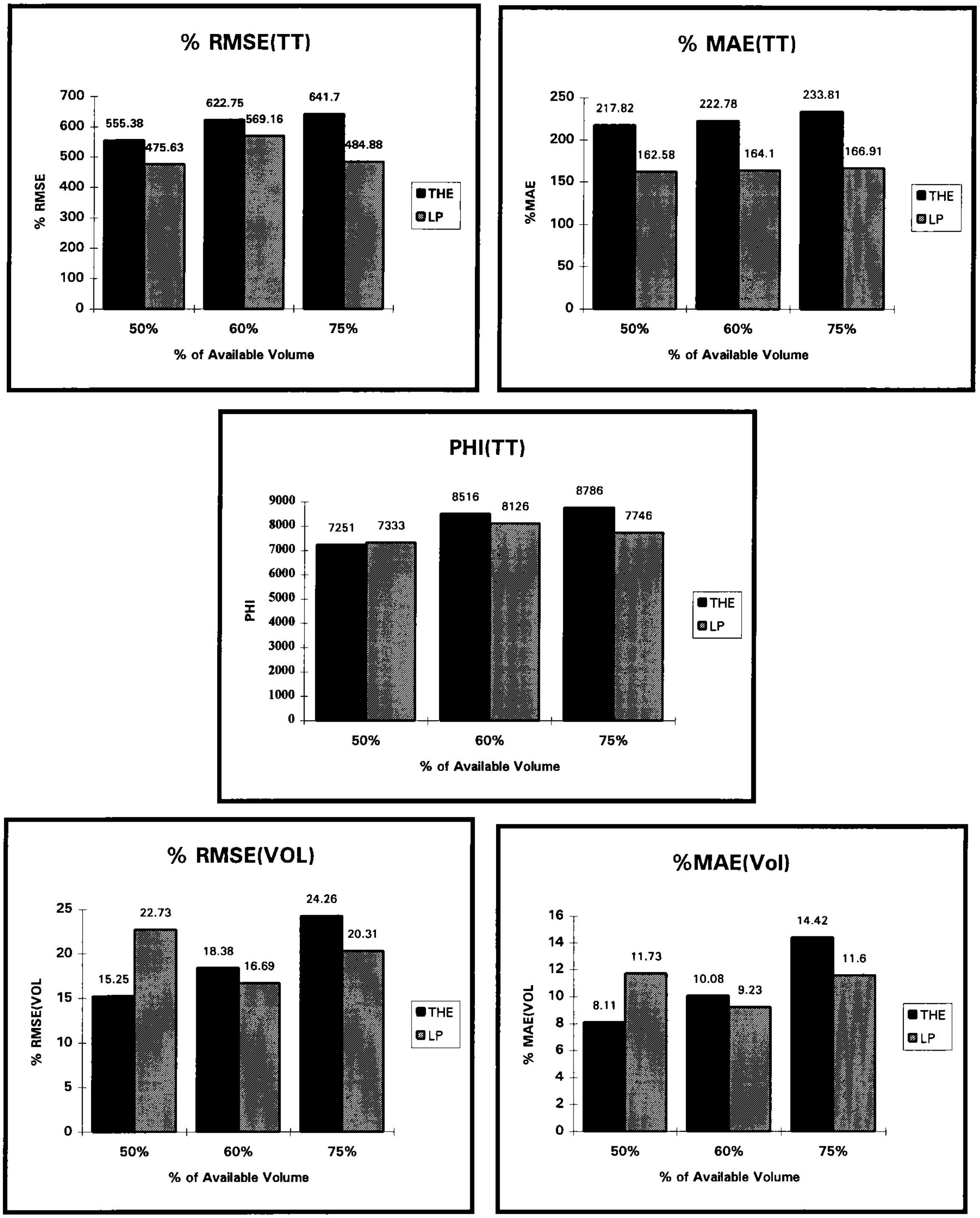


Figure 6-9: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** Peak Hour **Target:** Small Error(60% Cell)

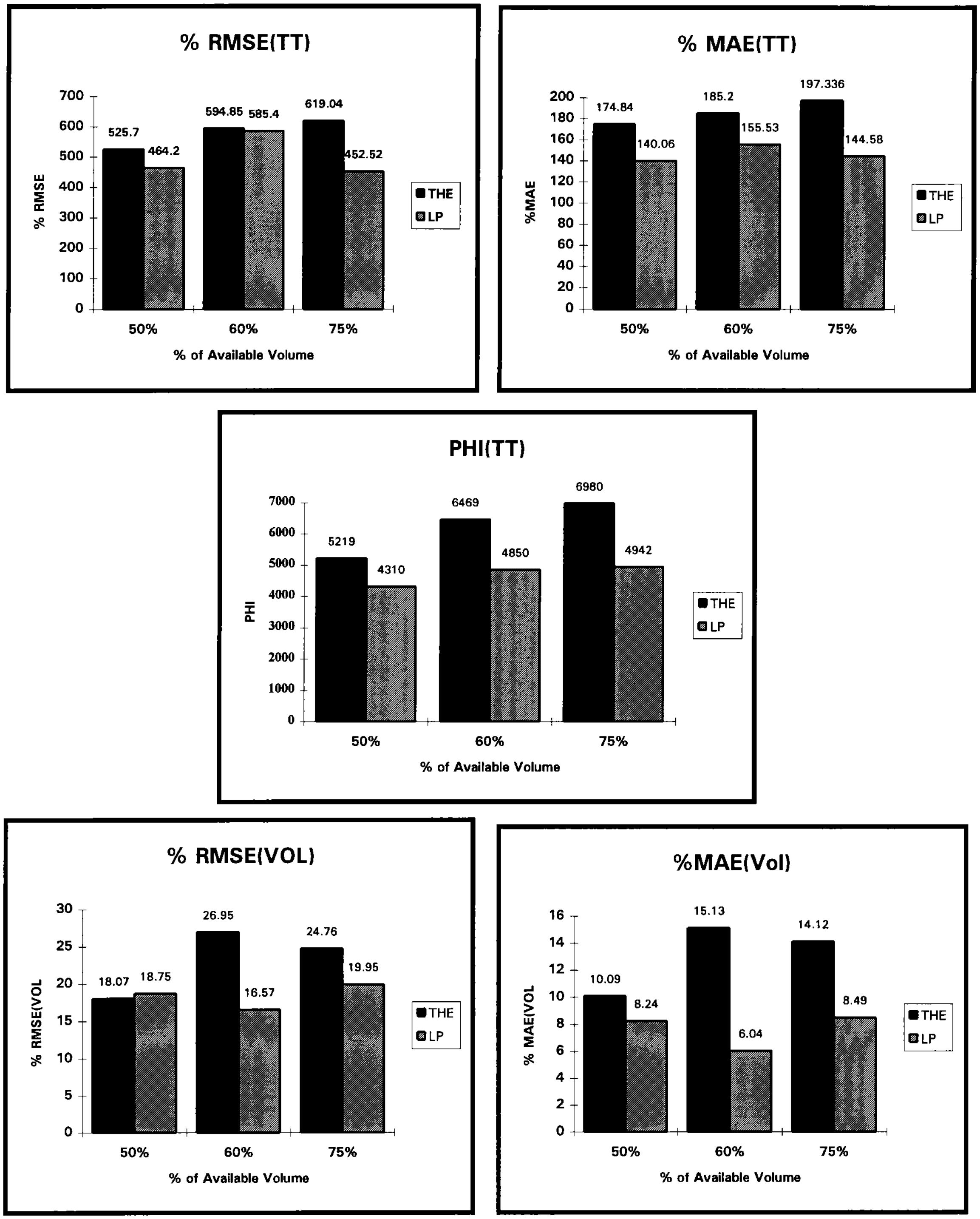
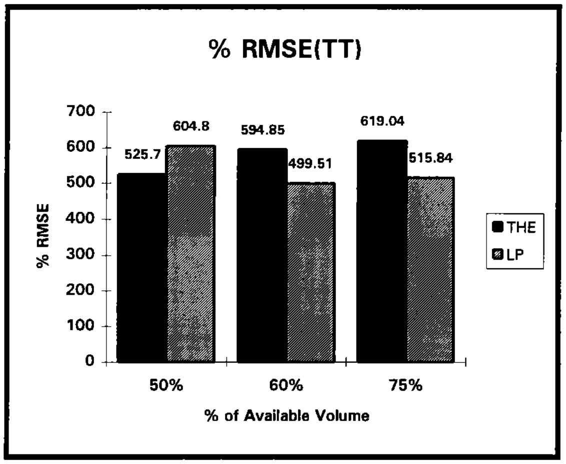
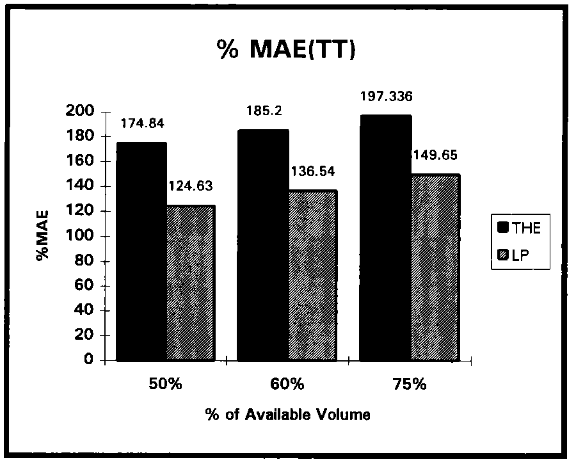
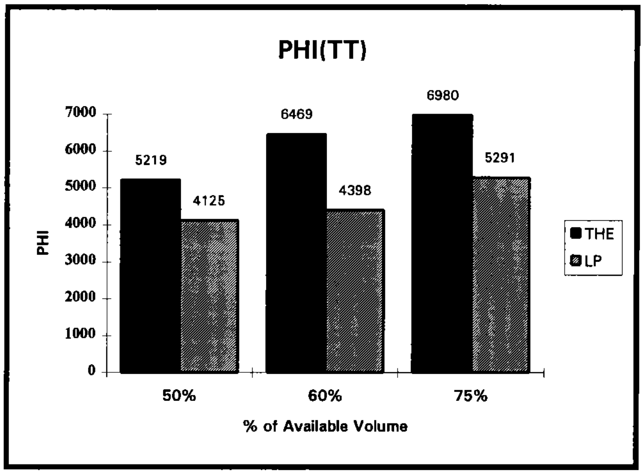


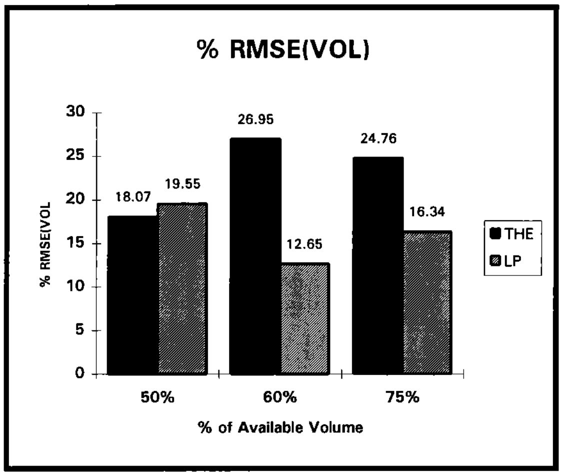
Figure 6-10: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

Network: Pulaski **Case:** Peak Hour **Target:** Small Error(80% Cell)









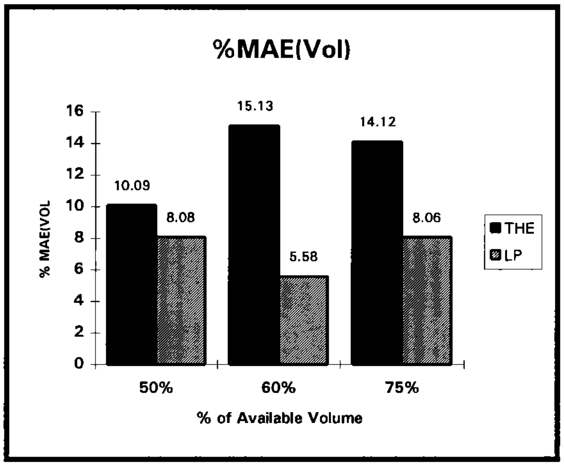
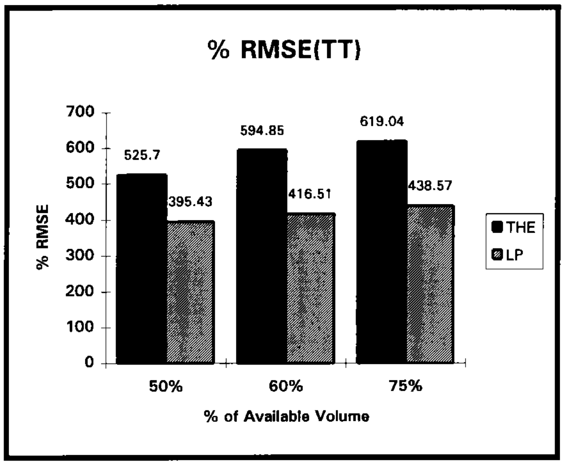
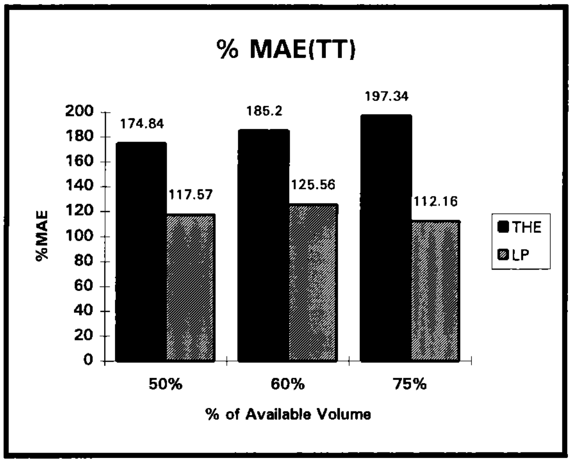
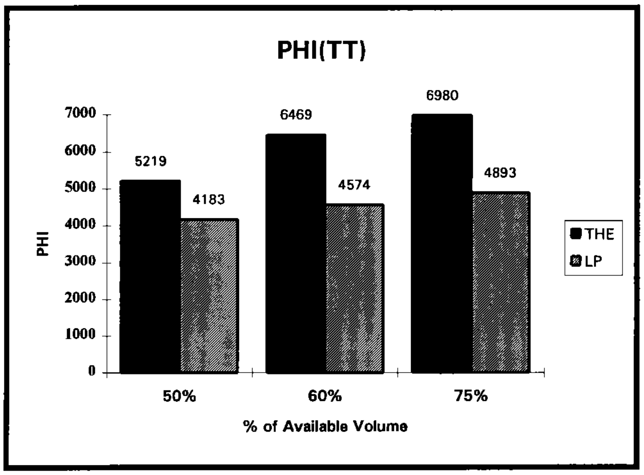


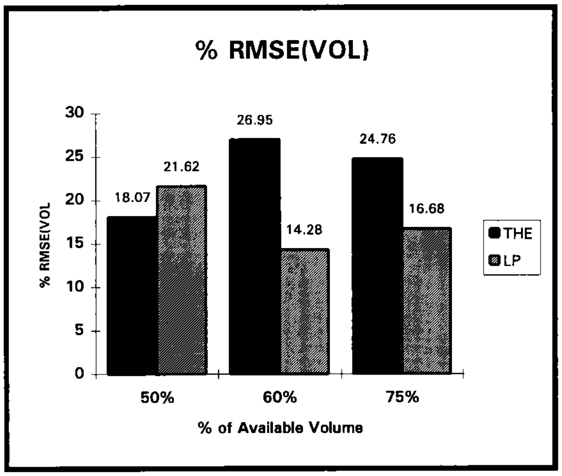
Figure 6-11: Trip Table (Modeled vs. Surveyed) & Volume (Modeled vs. Observed) Comparisons

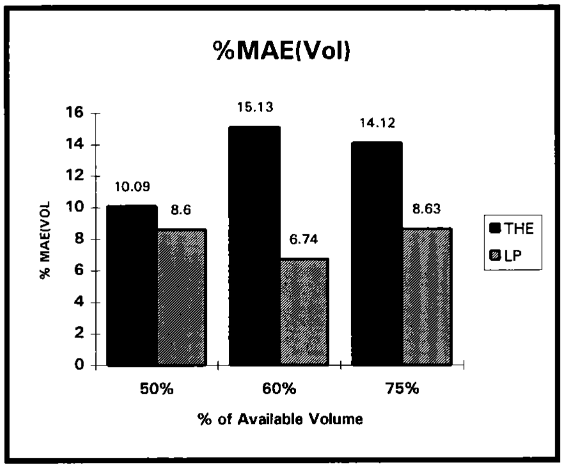
Network: Pulaski **Case:** Peak Hour **Target:** Small Error(100% Cell)











6.5 Conclusions

The synthesized test results for different cases for the Pulaski network are graphically shown in Figures 6-12 through 6-16 for the 24 hour case, and in Figures 6-17 through 6-21 for the peak hour case.

The Pulaski case study is believed to be more credible than the sample and Purdue network case studies, since the data collection here was specifically designed for this purpose, and a trip table was established through a conventional O-D survey for comparing the model results. This surveyed table was assumed as "true/correct". For this network, both daily (24 hour) and peak hour tables were studied.

As expected, for both the models, the trip table error statistics are seen to have high values for the structural target table case. For this case, THE came out superior to LP, in terms of closeness of modeled tables to the surveyed table. When different versions of the small error table are provided as target, both the models are seen to produce tables that are closer to the surveyed table. Again, as in the case of the Purdue network, both the models show mixed trends in performance with increasing available link volume percentages. This may be attributed to the fact that the link volumes may not be consistent with OD flows, or to possible inconsistencies/errors in observed link volume data. In general, the linear programming model has lower values for the PHI(TT) statistic, except for the structural target case, compared to THE.

The variation of the link volume replication error for the LP and THE models, as measured by the %MAE(Vol) statistic, is depicted in Figure 6-16. The LP model has lower values of this statistic, as compared to those of THE, for every test case.

Many of the above trends (with some exceptions) in comparison statistics are observed for the peak hour case (Figures 6-17 through 6-21).

Thus, once again the results favor the LP model (except for the structural target case, for which THE yields superior results). This conclusion assumes that the VDOT surveyed table represents the "correct" or "true" trip table for the region. It must also be noted that the surveyed table itself was established through sampling, and inconsistencies or errors in these tables and the link volume data cannot be ruled out completely. This was further confirmed by indications from VDOT, and through some preliminary checks conducted by the study team.

Figure 6-12: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** 24 Hour **Measure:** %RMSE(TT)

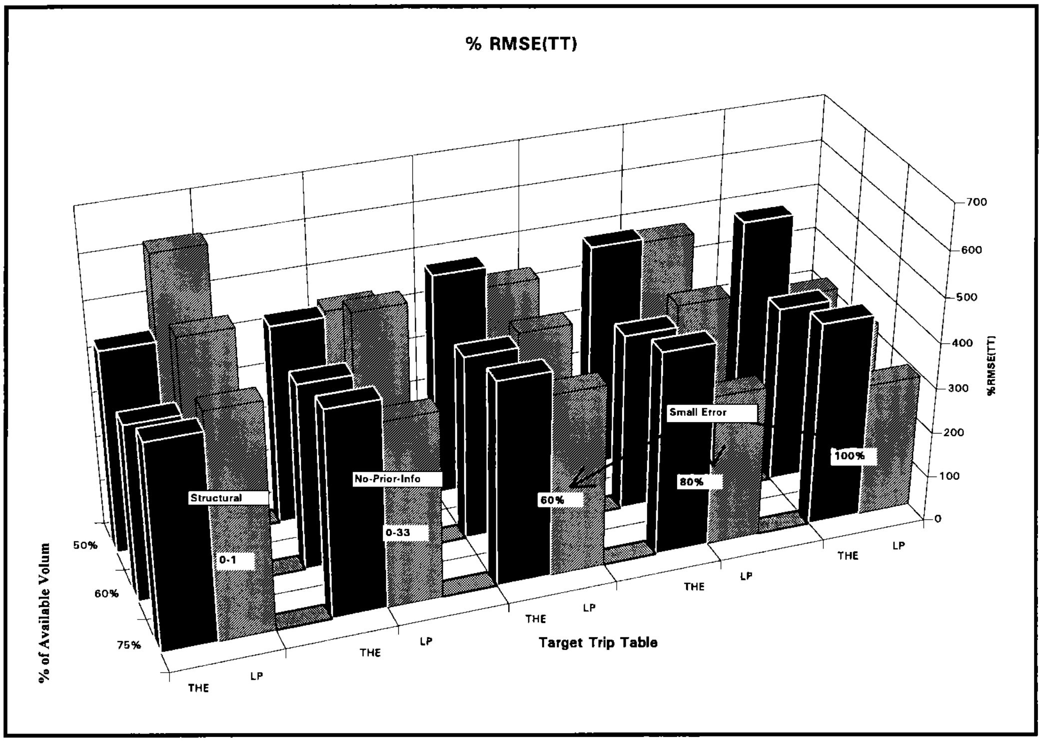


Figure 6-13: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** 24 Hour **Measure:** % MAE(TT)

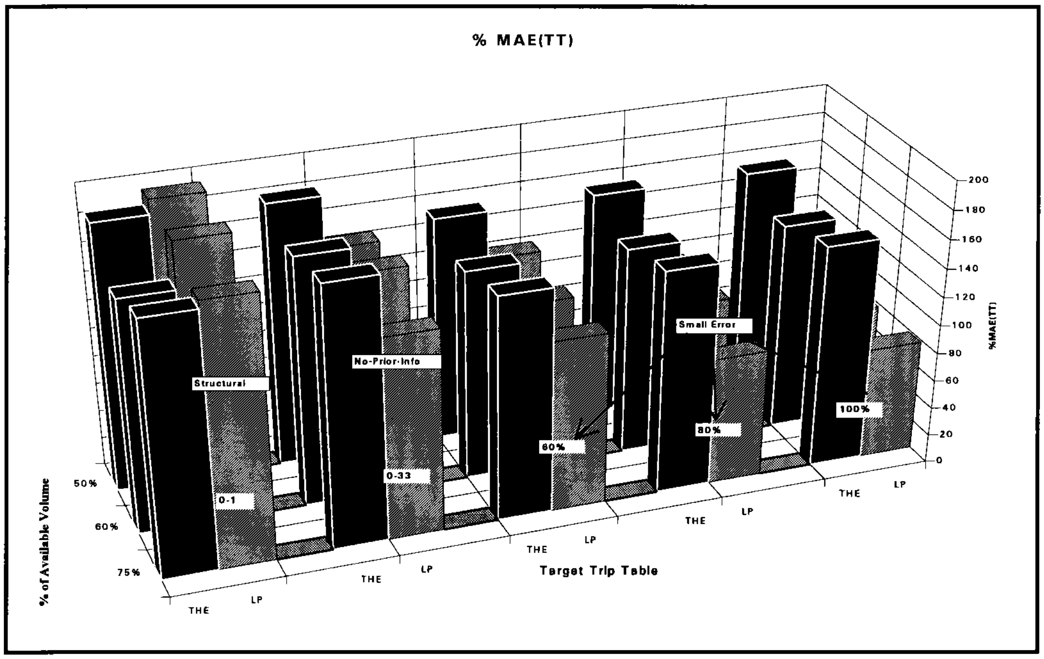


Figure 6-14: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** 24 Hour **Measure:** PHI(TT)

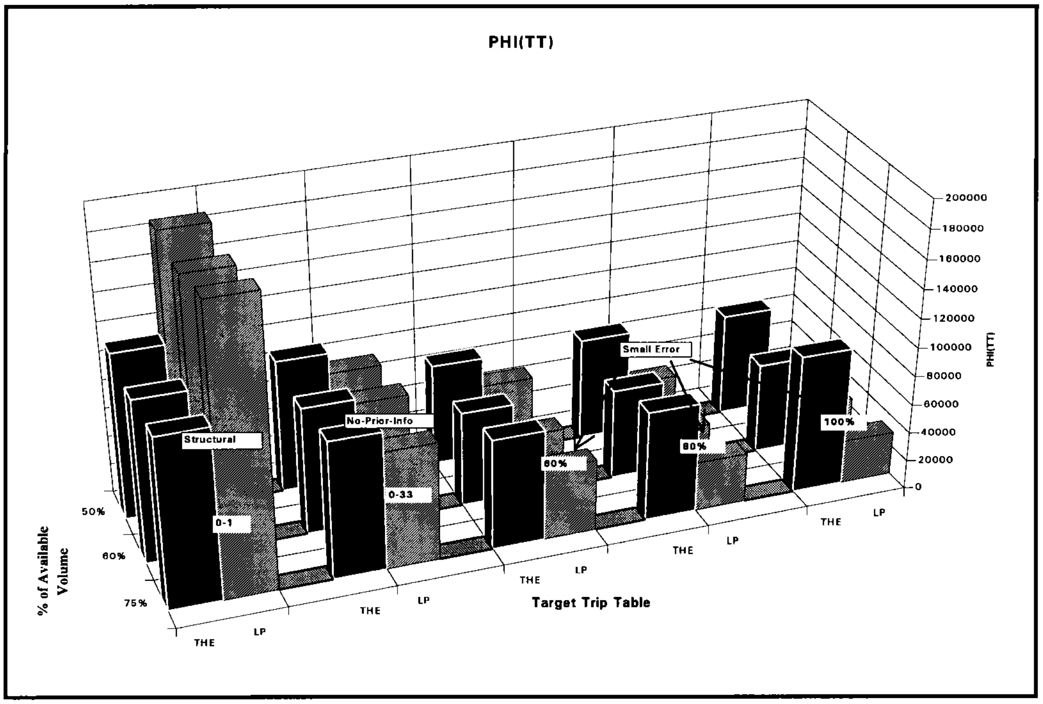


Figure 6-15: Volume Comparison (Modeled vs. Observed)

Network: Pulaski **Case:** 24 Hour **Measure:** %RMSE(VOL)

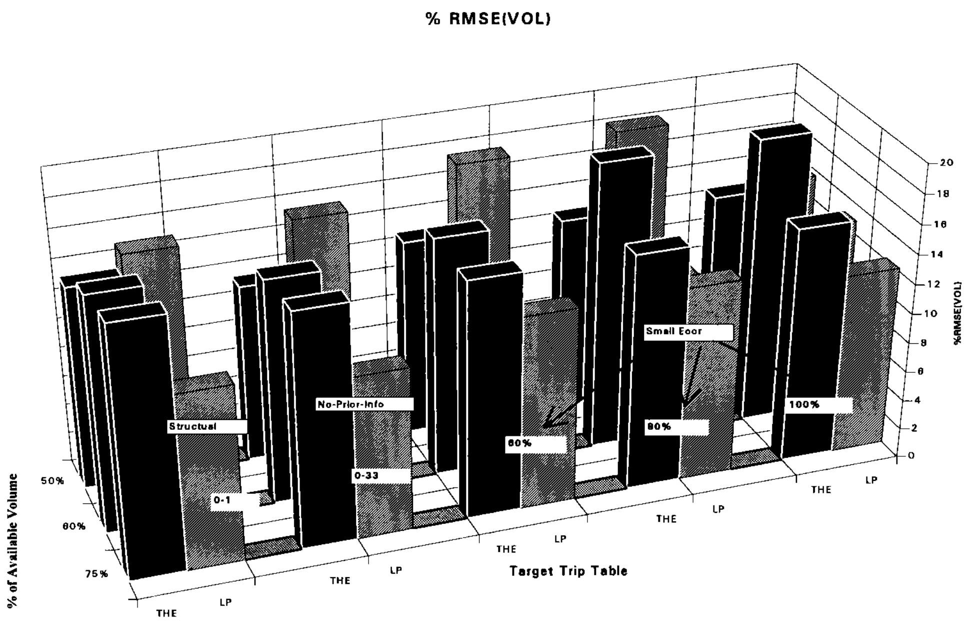


Figure 6-16: Volume Comparison (Modeled vs. Observed)

Network: Pulaski **Case:** 24 Hour **Measure:** % MAE(Vol)

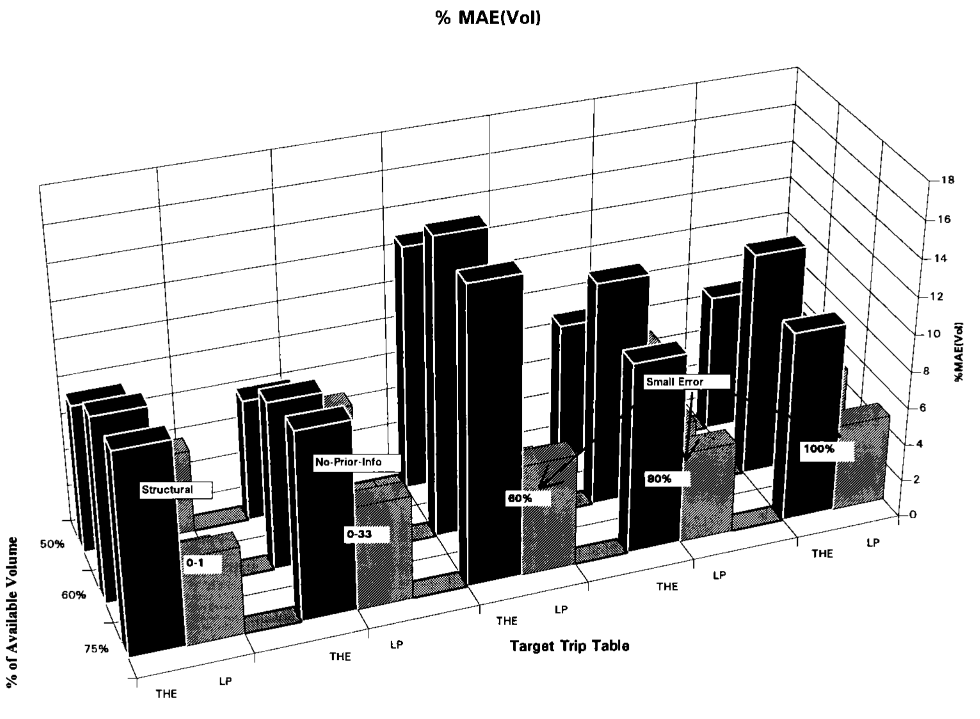


Figure 6-17: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** Peak Hour **Measure:** %RMSE(TT)

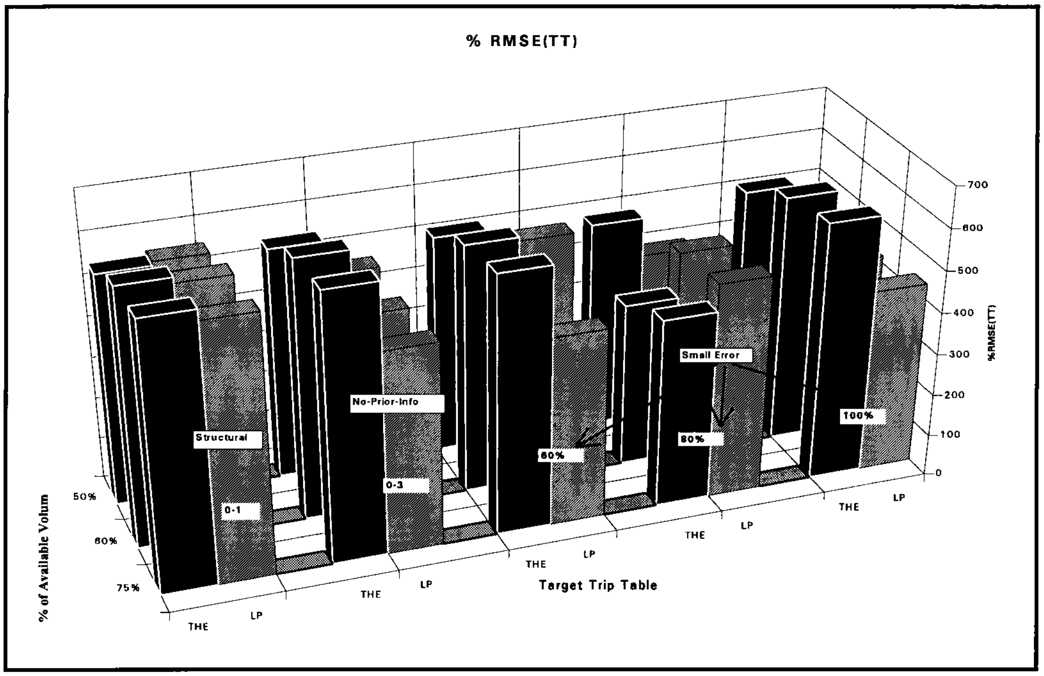


Figure 6.18: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** Peak Hour **Measure:** % MAE(TT)

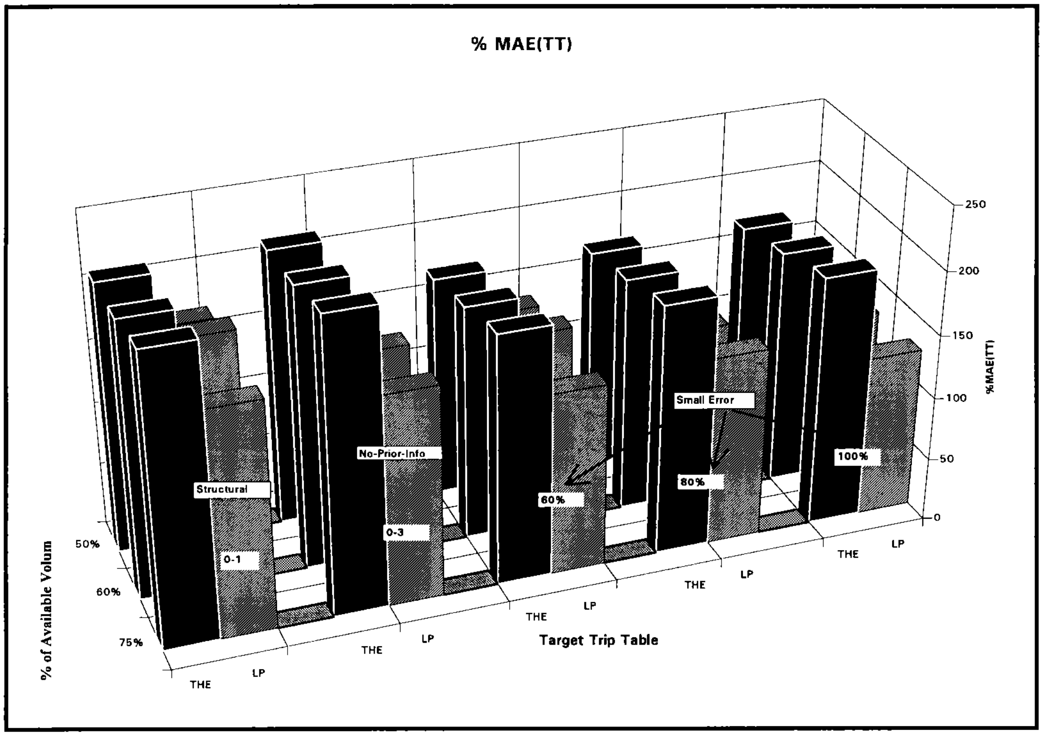


Figure 6-19: Trip Table Comparison (Modeled vs. VDOT Surveyed)

Network: Pulaski **Case:** Peak Hour **Measure:** PHI(TT)

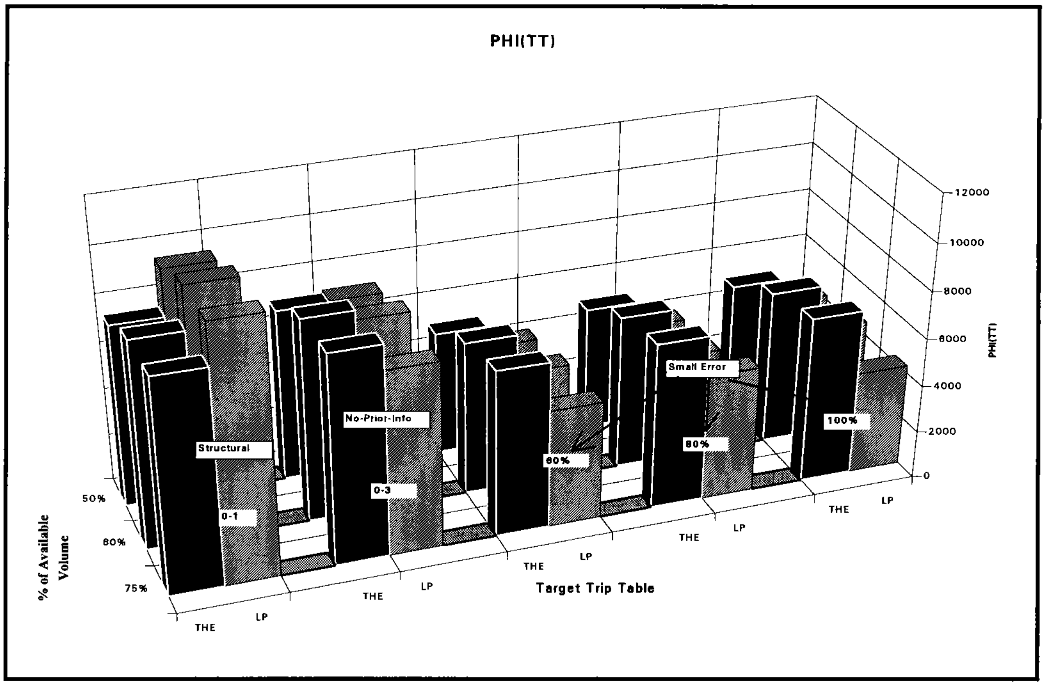


Figure 6-20: Volume Comparison (Modeled vs. Observed)

Network: Pulaski **Case:** Peak Hour **Measure:** %RMSE(VOL)

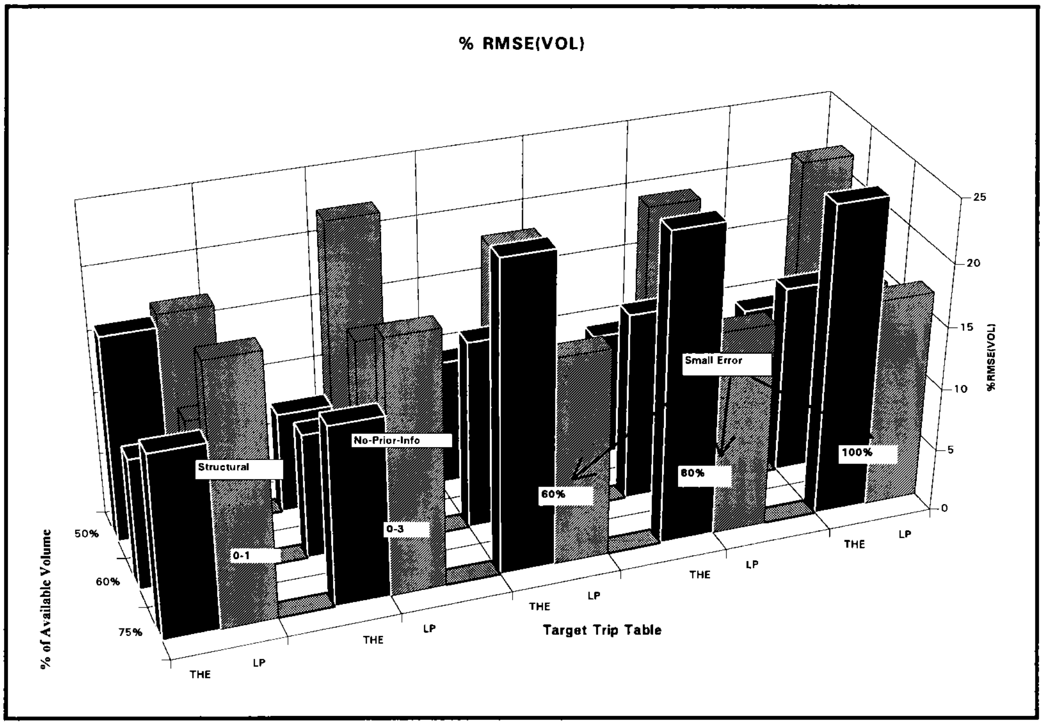
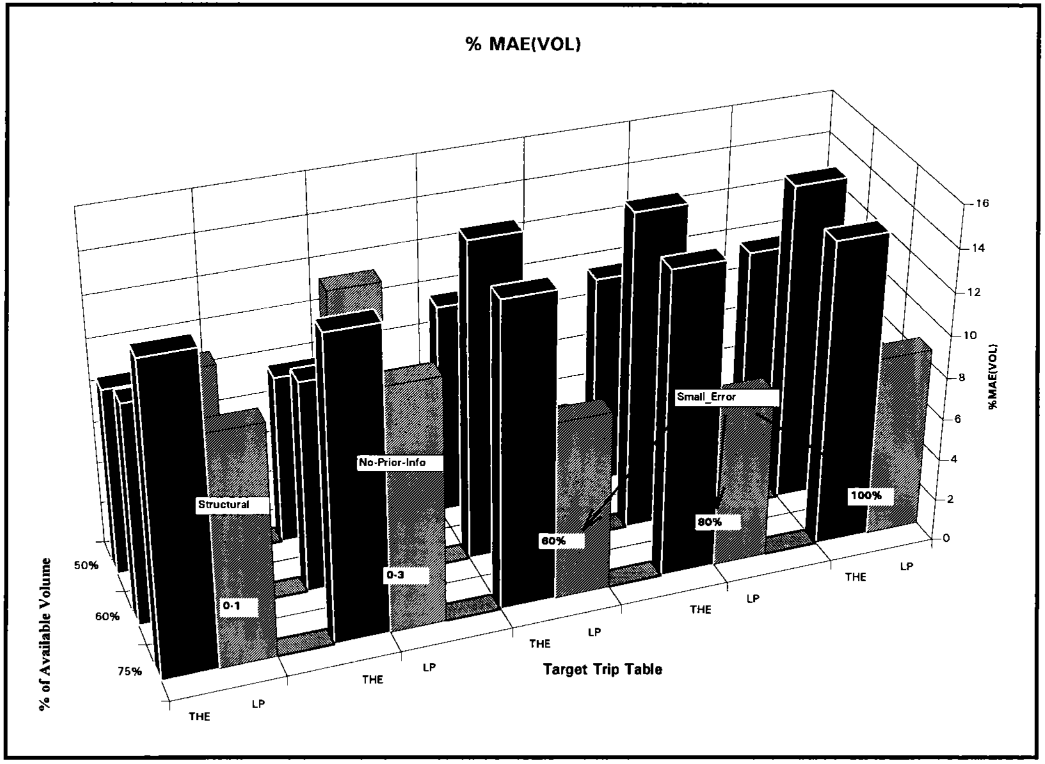


Figure 6-21: Volume Comparison (Modeled vs. Observed)

Network: Pulaski **Case:** Peak Hour **Measure:** %MAE(VOL)



CHAPTER 7.0

SUMMARY FINDINGS AND CONCLUSIONS

7.1 Introduction

This research effort was motivated by the desire of planning agencies such as the Transportation Planning Division (TPD) of the Virginia Department of Transportation (VDOT) to seek alternative methods of deriving a current or base year Origin-Destination (O-D) trip table. In these times of budget constraints and fiscal austerity, planning agencies are compelled to look for quicker and cheaper ways to establish trip tables than conventional O-D surveys, which are expensive, time consuming and labor intensive. This can be achieved by utilizing theoretical models that derive trip tables using information contained in the network traffic volumes. Many of these models are available in the form of computer models. The purpose of this research was to evaluate such models for use in practical situations.

This research effort fulfilled the following major objectives set forth by Virginia Transportation Research Council (VTRC):
(1) To conduct a review of existing approaches and models that produce trip tables from ground counts, and to select a few models for testing and evaluation.
(2) To perform a detailed testing of selected models based on application to both hypothetical and real networks, and to conduct performance evaluations and sensitivity analyses of these models.

The selection of models and case studies, summary findings, and conclusions of the study are summarized below.

7.2 Selection of Models and Case Studies

Based on the theoretical evaluation of various O-D estimation models, the opinion of several transportation professionals, and the availability of computer programs and their extent of usage, the following models were chosen for comprehensive testing and evaluation:

(1) The Highway Emulator (THE)
(2) The Linear Programming (LP) Model.

The concept of maximum entropy has been incorporated in several computer programs, including THE. We learned through personal communications that THE model, chosen for evaluation in this study, is popular and has been or is being used for several applications. The linear programming (LP) model developed at Virginia Tech had shown superior results in initial tests, and the enhanced version was employed for further testing and evaluation in this study.

The above two models were applied to the following three case studies:

(1) Sample Network,
(2) Purdue University Network,
(3) Pulaski Town Network.

The sample network, though hypothetically constructed, had several characteristics desirable for evaluating the O-D estimation models. This network provided insights on the theoretical aspects of the models, and enabled us to judge the preliminary performance of these models and conduct sensitivity analyses. The Purdue University case study represents a more realistic situation, with the network and data being real. A trip table synthesized through several methods was available for comparing the test results. The Pulaski town network and data represented a further step in the testing process, where data was collected specifically for this research, and a trip table was established with surveys, mainly for comparing and evaluating the model results. The three case studies were a logical progression in the evaluation process.

7.3 Summary Findings

The three case studies offered an opportunity to perform an in-depth evaluation of the two selected models. These models were evaluated on the three networks for different cases of target table information and combinations of percentage available target cells and link volume information. These tests enabled a comprehensive evaluation of the performance and sensitivity analyses of the models. A total of 148 cases were tested for the three networks together. These cases are summarized in Table 7-1 below.

Table 7-1: Study Test Cases

Target Table	Network			Total Cases
	Sample	Purdue	Pulaski	
Structural	6	4	6	16
No-Prior-Information	24	12	6	42
Small Error	24	24	18	66
Correct	24	0	0	24
Total Cases	78	40	30	148

The results and analysis of these cases are summarized for each of the networks. The test results were judged by two criteria: (1) the closeness of the model output tables to the "correct" or "surveyed" tables, and (2) the replication of observed link volumes by the models. These two criteria were measured by percentage Mean Absolute Error (%MAE) and percentage Root Mean Square Error (%RMSE) (for both criteria) and 'PHI' (for criterion 2 only) statistics. Since these are measures of error rates or closeness, the lower the values, the better the results. These measures were defined in Chapter 3.0.

7.3.1 Case (a): Sample Network:

The test results in terms of trip table closeness (criterion 1) for both the models are shown in Figure 7-1. Though the 'PHI' statistic is a better measure of this criterion, %MAE(TT) statistics are shown here to get a better idea of percentage deviations from the "correct" table.

Examining the variation of %MAE(TT) statistic for the LP model, this statistic is seen to generally decrease (with few exceptions) with the improvement in target table information, and with increase in percentage available volumes. This is a logical trend one would expect. THE results also seem to show the above trend for many cases; however, there are some violations of this trend, as seen in the figure. The figure also highlights the poorer performance of THE for cases where the percentages of target table and link volume information are low. However, a noteworthy point about THE is its superiority over the LP model (for most cases) in terms of the output tables for the structural target case.

Observing the variation of link volume replication errors measured through %MAE for both the models, as shown in Figure 7-2, the LP model results are clearly superior to those of THE. For all the test cases, LP is able to replicate observed volumes exactly. For THE, in general, %MAE(Vol) is seen to improve with increase in percentage available volumes for each of the cases observed individually. Again, similar to trip table error, link volume replication seems to be poor for cases when the percentages of target table and link volume information are low. In summary, the figures illustrate the general superiority of the LP model over THE for the sample network, with the exception of the structural target case. However, the results and the conclusions must be viewed in the light that the test network was a hypothetical case, and does not represent real data. Yet, these tests were useful in understanding the performance of the models.

Figure 7-1: Trip Table Comparisons for Sample Network

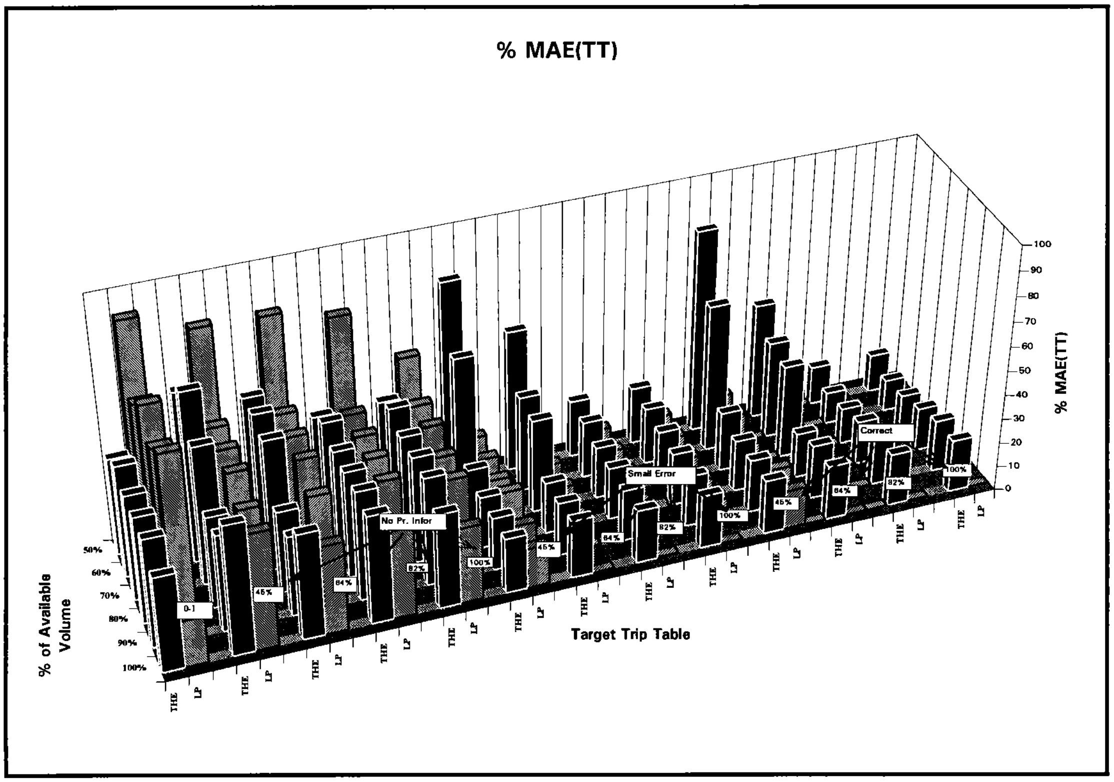
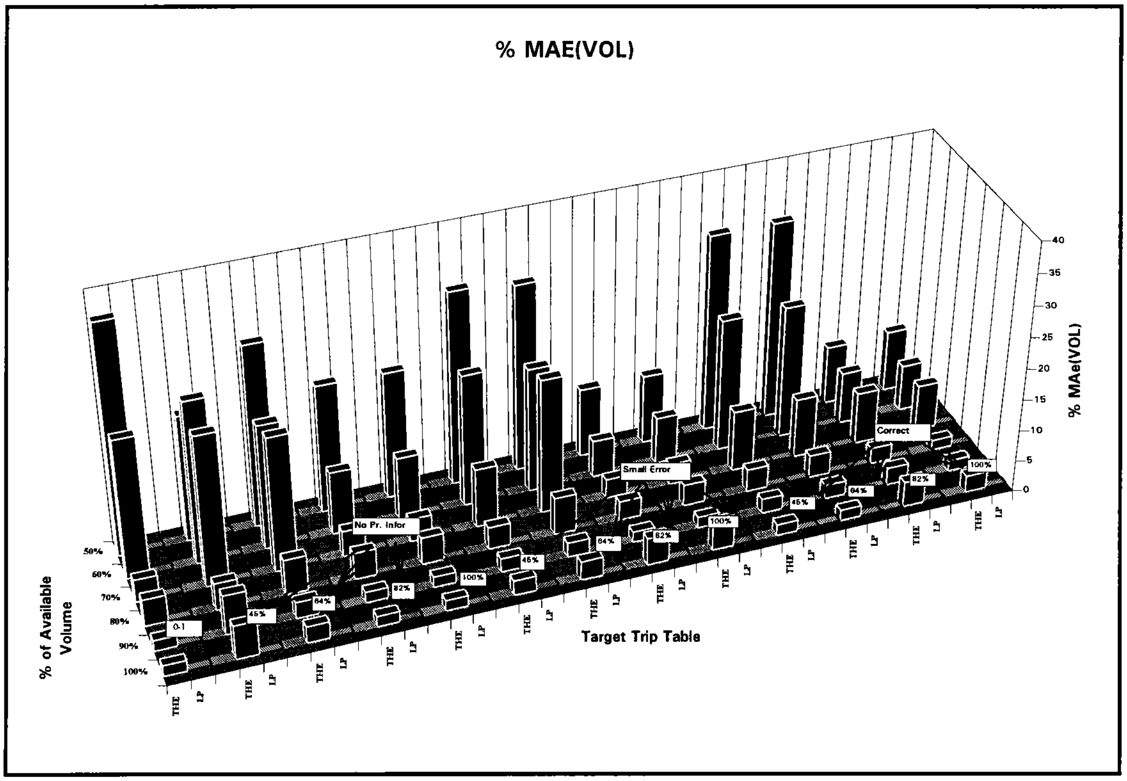


Figure 7.2: Volume Comparisons for Sample Network

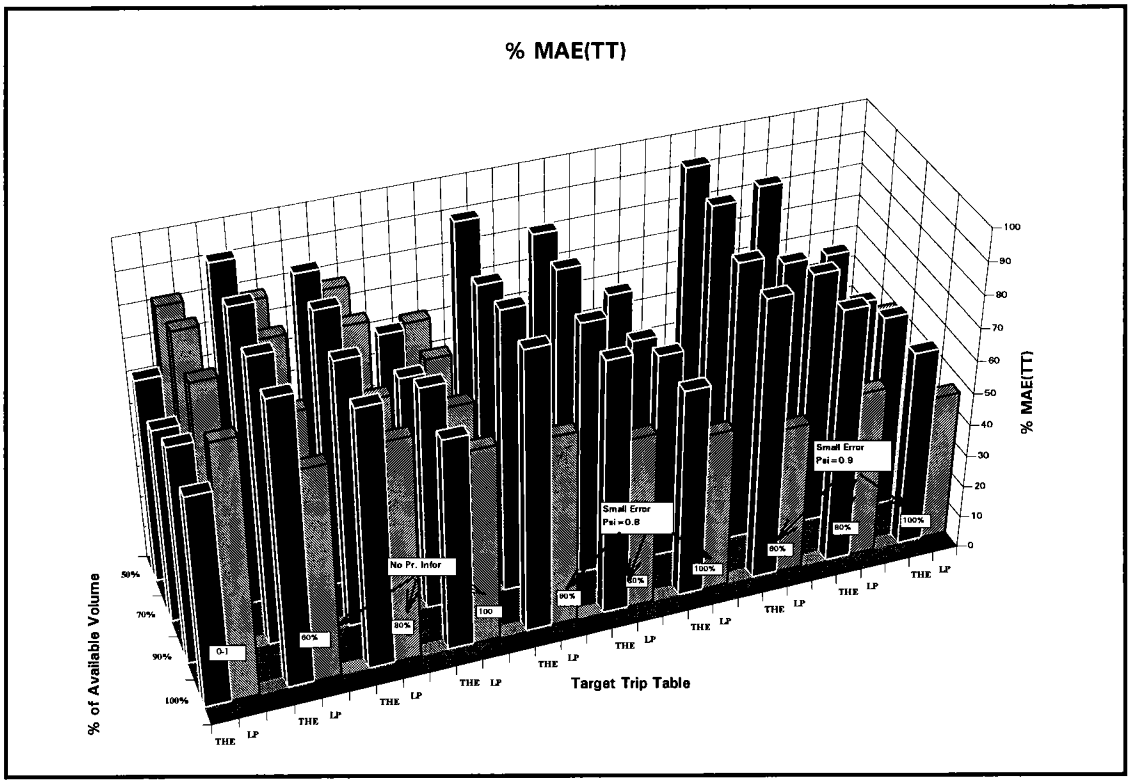


7.3.2 Case (b): Purdue Network

The test results for this network in terms of criterion 1 for both the models are shown in Figure 7-3.

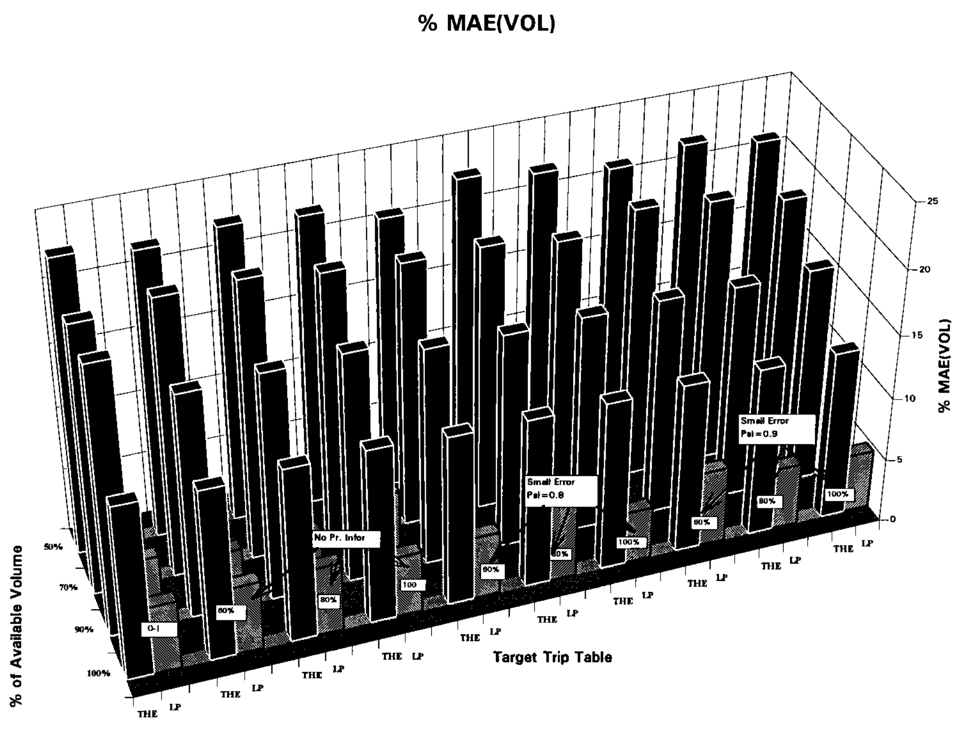
Examining the variation of %MAE(TT) statistic, for the LP model this statistic is seen to generally decrease (with few exceptions) with the improvement in target table information, which is expected. For THE this trend is generally seen among the cases within each basic target case (except structural target), and not between the different target cases. With regard to the variation of %MAE(TT) with percentage variation in volumes, mixed trends are noticed for both the models. While for some cases, this statistic decreases with increase in percentage available volumes, for some others it increases. This may be attributable to two reasons: first, the link volumes may not be consistent with the surveyed O-D table, and second, there may have been inconsistencies/errors in observed volume data. In general, the LP model has lower values of %MAE(TT) (except structural target case), as compared to THE. The figure also highlights the relatively poorer performance of THE for cases when the percentages of target table and link volume information are low. However, a noteworthy point about THE is its superiority over the LP model in terms of the quality of the output table for the structural target case.

Figure 7-3: Trip Table Comparisons for Purdue Network



The variation of the link volume replication errors for the LP and THE models, as measured by the %MAE(Vol) statistics is depicted in Figure 7-4. As seen in the figure, the LP model has significantly lower values for this error statistic for every test case.

Figure 7-4: Volume Comparisons for Purdue Network



The results lead to the conclusion that the LP model is, in general, superior to THE, except for the structural target case. However, these conclusions are based on the assumption that the trip tables against which the results are compared are in fact “true/correct”.

7.3.3 Case (c): Pulaski Network

The Pulaski case study is believed to be more credible than the sample and Purdue network case studies, since the data collection was specifically designed for this purpose, and a trip table was established through a conventional O-D survey for comparing the model results. This surveyed table was assumed as "true/correct". For this network, both daily (24 hour) and peak hour tables were studied. The test results in terms of criterion 1 (%MAE(TT)) for both models for the 24 hour table is shown in Figure 7-5.

As expected, for both models the %MAE statistics are seen to have high values for the structural target table case. For this case, THE has come out superior to LP, in terms of closeness of modeled tables to the surveyed table. When different versions of the small error table are provided as targets, both models produce tables that are closer to the surveyed table. Again, as in the case of the Purdue network, both models show mixed trends in %MAE(TT) values with increasing available link volume percentages. This may be attributed to the fact that the link volumes may not be consistent with OD flows, and/or due to possible inconsistencies or errors in observed link volume data. In general, the linear programming model has lower values for the %MAE(TT) statistic, except for the structural target case, as compared to THE.

The variation of the link volume replication error for the LP and THE models, as measured by the %MAE(Vol) statistic are depicted in Figure 7-6. The LP model has lower values for this statistic, as compared to those of THE, for every test case.

Many of the above trends (with some exceptions) in comparison statistics are observed for the peak hour case (Figures 7-7 and 7-8).

Once again the results are in favor of the LP model (except the structural target case, for which THE yields superior results). This conclusion assumes that the

Figure 7-5: 24 Hour Trip Table Comparisons for Pulaski Network

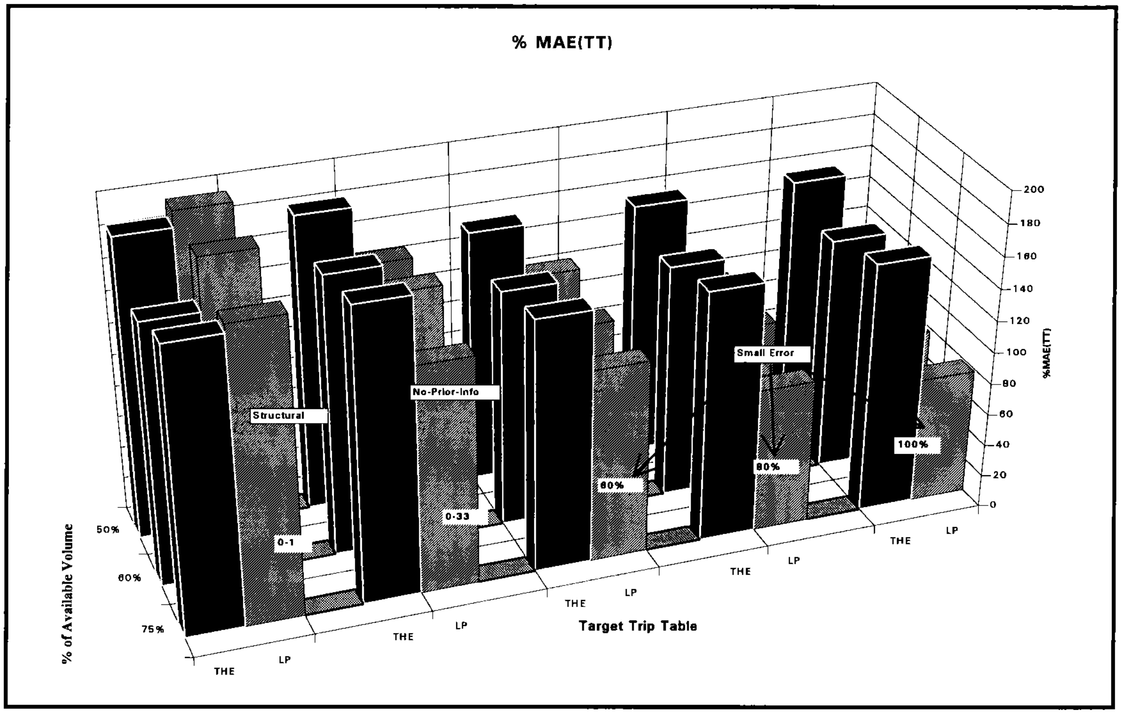


Figure 7-6: 24 Hour Volume Comparisons for Pulaski Network

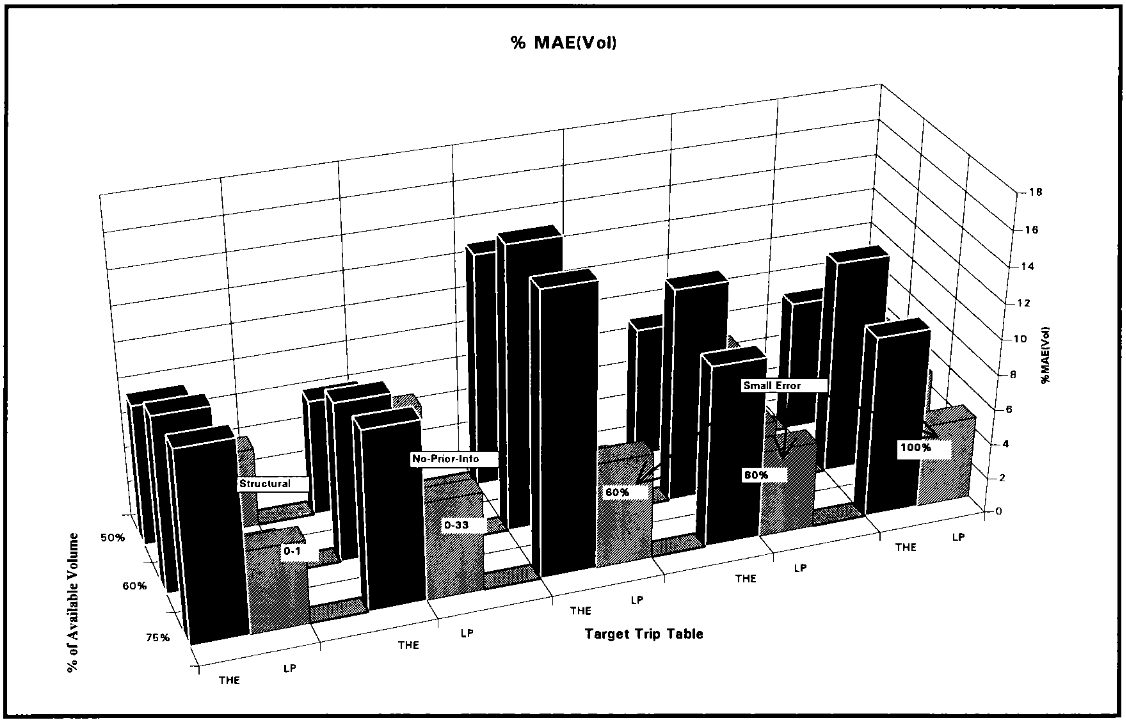


Figure 7-7: Peak Hour Trip Table Comparisons for Pulaski Network

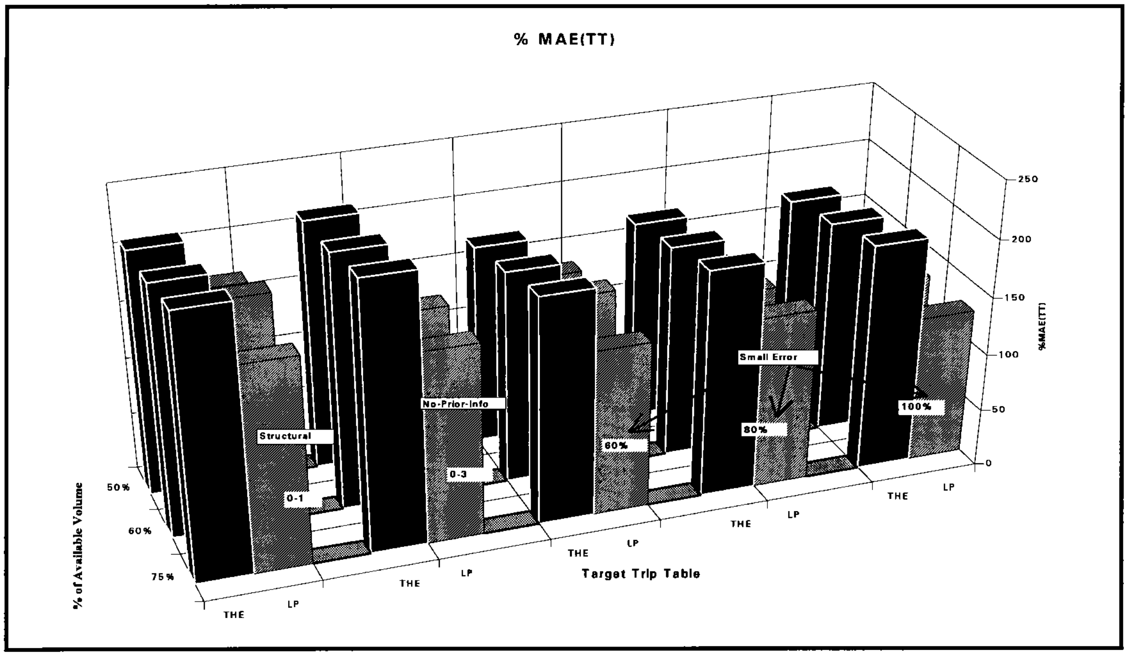
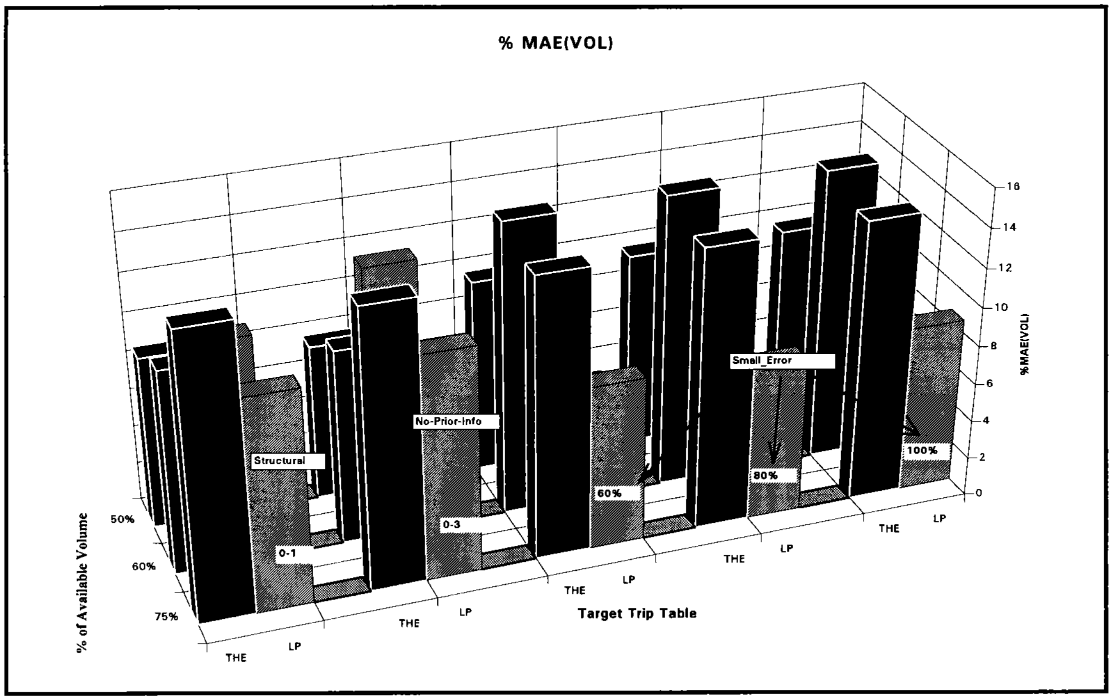


Figure 7-8: Peak Hour Volume Comparisons for Pulaski Network



VDOT surveyed table represents the “correct” or “true” trip table for the region. It must also be noted that the surveyed table itself was established through sampling, and inconsistencies or errors in these tables and the link volume data cannot be ruled out completely. This was further confirmed by indications from VDOT, and through some preliminary checks conducted by the study team.

7.4 Conclusions

This study evaluating the models that produce trip tables from ground counts has been a very useful and timely exercise, because planning agencies are looking for alternative ways to develop trip tables without expending considerable cost and manpower. Two models, The Highway Emulator (THE) and the Linear Programming (LP) models, that estimate trip tables utilizing traffic volumes in the network have been comprehensively evaluated. The Sample, Purdue and Pulaski networks were adopted for the case studies. The evaluation provided insight into several practical issues that will be faced by engineers when applying these models.

The following conclusions were reached, based on the application of the two models to the three case studies.

1. In general, the LP model results have proven to be superior, both in terms of closeness of modeled trip tables to the “correct/surveyed” tables, and in terms of replicating observed link volumes, for all the case studies. The exception to this is the structural target case, when THE produced better results, in terms of closeness of output tables to the “correct/surveyed” tables. This is based on the assumption that the “correct/surveyed” trip tables used for the case studies were in fact “correct/true”.

The ranges of % MAE(TT) values for the LP model, considering all the test cases (except the structural target case) for the sample, Purdue and Pulaski networks were, 0%--84%, 30%--81%, and 83%--197%, respectively. For THE, the corresponding values were, 13%--83%, 55%--94%, and 147%--234%, respectively. It must however be noted that these percentages are for a broad range of combinations of cases of percentage available target table and link volume information. Examining the trip table closeness for the small error target table cases with 100% (for Sample and Purdue networks) and 75% (for Pulaski network) volumes and 100% cell information, the %MAE(TT) values for LP and THE are 0%, 46%, 83% and 22%, 61%, 157%, respectively, for the sample, Purdue and Pulaski networks. Again, all the numbers above are based on the assumption that the "correct/surveyed" tables used for comparison purposes reflect "correct/true" travel patterns.

2. THE was superior to the LP model for the structural target case (almost all the cases), where the target contains 1/0 cell values, 1 for those cells which represent O-D interchanges that are feasible, and 0 for those that are not. This has practical implications in that if a region does not have a prior table available as target, then a structural target could be used.

3. A word of caution must be noted with regard to conclusion # 2 above. While one would be tempted to use THE with a structural target for applications where a prior table is not available, it must be noted that the modeled results of both THE and LP turned out be poor when compared with the "correct/surveyed" tables for all the cases, even though THE's results were better than those of LP. The ranges of %MAE(TT) values for THE for the sample, Purdue and Pulaski (24 hour case) networks were 39%-46%, 61%-68%, and 164%-189%, respectively; for the LP model, the corresponding values were 19%-93%, 80%-89%, and 183%-199%. Again, these values are

based on the assumption that "correct/surveyed" trip tables used for the case studies were in fact "correct/true".

4. In general, the LP model has proven superior in replicating observed link volumes. The ranges of %MAE(Vol) values for the LP model, considering all the test cases for the Sample, Purdue and Pulaski networks, were 0%, 2%-6%, and 2%-12%, respectively. For THE, the corresponding values were 2%-37%, 13%-23%, and 7%-16%, respectively. However, the true test of a model is how well it replicates realistic travel patterns; in other words, how close the results are to the "correct/surveyed" table.

5. In general, both THE and LP show improvement in results with greater input information, in terms of the target table. This highlights the importance of providing a good target table. With regard to variation of trip table error statistics (for example, %MAE(TT)) with percentage variation in volumes, for the Purdue and Pulaski (24 hour case) networks, mixed trends are exhibited. While for some cases this statistic decreases with increase in percentage available volumes, for others it increases. These trends may be attributable to two reasons. First, the link volumes may not be consistent with the surveyed O-D table, and second, there may have been inconsistencies or errors in observed volume data.

6. With regard to the computational effort required, THE has clearly proven to be superior to LP for larger networks. For instance, the run times for THE for Pulaski network were a fraction of those required for LP, even though the LP runs were carried out on a superior computer. However, for planning applications, run times may not be a major issue.

This study evaluated the strengths and weaknesses of the Linear Programming (LP) and The Highway Emulator (THE) models. These two models were evaluated based on their application to three networks, two of which were real. The test results indicate the general superiority of the LP model over THE; however, for cases when structural target has to be used, THE has generally proved superior to LP. In addition, the test results indicate the desirability of using as good and complete a target table as possible, in conjunction with complete (or as close to it as possible) link volume information for yielding better output trip tables. These general conclusions are based on the specific conclusions above. It must be kept in mind that these conclusions are based on tests on a specific and limited number of networks, and under the assumption that the data used in testing and evaluation were accurate enough. The adoptability of these models and the use of one model versus the other must be decided based on the above facts, and in the context of error rates reported in this study. However, this study has highlighted the value of such theoretical models for trip table estimation without performing conventional surveys. Further tests and validation of the models and ways to establish superior target tables can be potential areas for further study.

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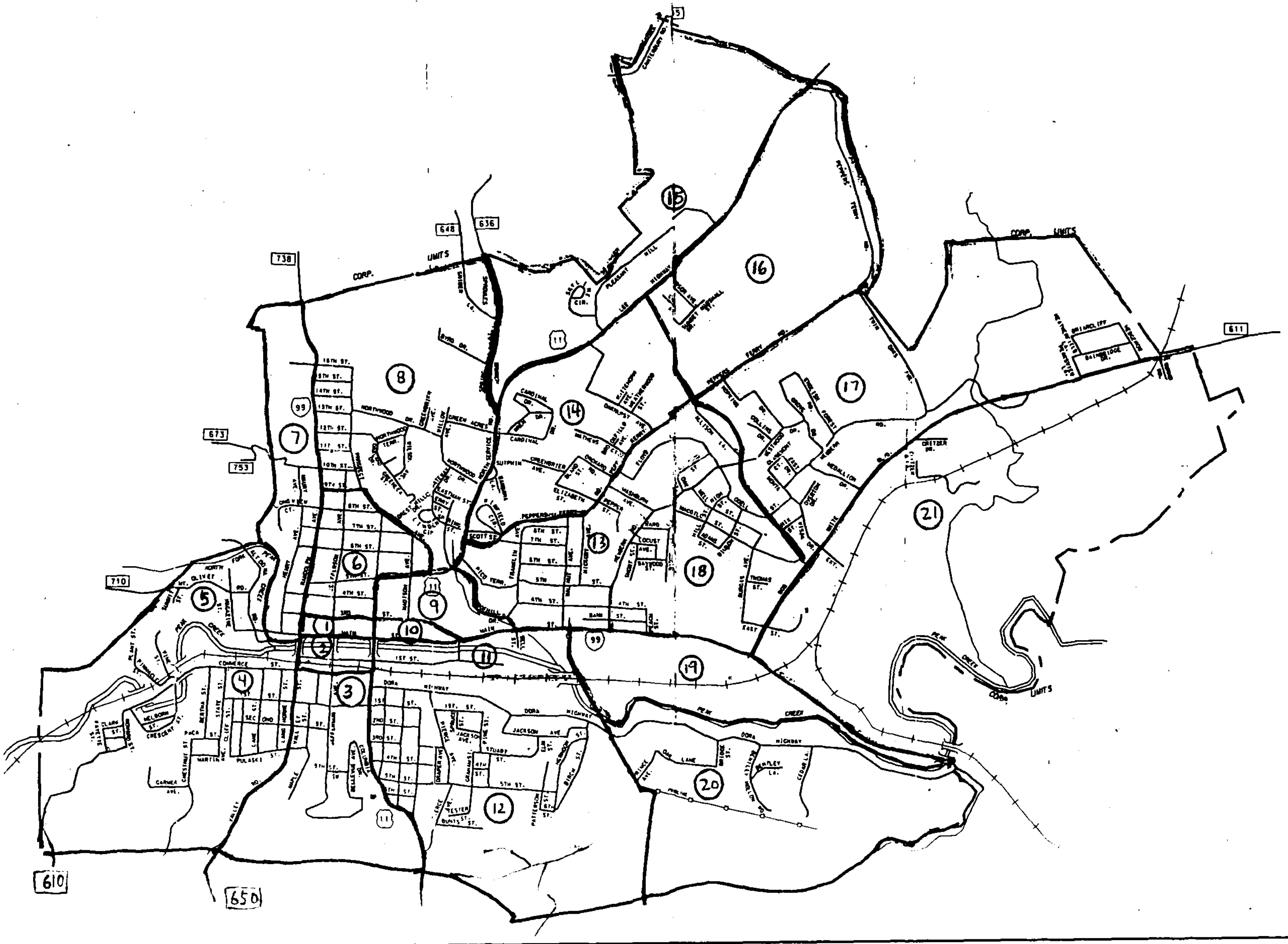
APPENDICES

Appendix 1: Pulaski Town Study Area (Source: VDOT)



APPENDIX 2: Surveyed Daily Trip Table for Pulaski Town (provided by VDOT)

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
Frm																																	
1	4	32	29	21	0	71	17	18	27	0	0	33	51	12	0	0	23	34	28	0	0	132	47	28	10	0	0	0	0	7	0	7	631
2	0	52	78	46	0	50	38	53	57	29	22	72	86	212	37	0	57	53	94	18	4	85	36	13	9	0	3	1	3	7	0	9	1224
3	33	18	71	160	27	22	29	65	0	52	23	113	37	142	21	23	13	25	22	0	12	103	67	38	23	0	0	1	7	18	4	9	1178
4	0	88	104	12	12	21	20	0	73	25	13	21	7	71	0	25	0	62	107	0	60	87	46	18	11	0	4	3	4	8	6	7	915
5	0	22	20	0	18	27	0	0	0	28	0	11	0	33	13	14	4	14	39	0	0	82	29	24	9	0	0	4	3	8	0	4	406
6	51	112	7	11	37	115	22	123	21	28	57	76	30	122	34	16	44	73	78	0	0	48	9	7	9	0	0	1	1	1	5	1	1139
7	17	0	35	0	0	30	7	18	40	0	32	0	46	52	4	6	13	16	75	0	9	35	13	8	0	0	0	1	1	4	4	1	467
8	22	80	73	35	6	94	20	109	26	62	13	5	96	180	10	52	50	66	142	0	25	175	46	25	7	0	3	5	3	15	4	9	1458
9	8	35	37	37	0	15	50	25	9	0	0	84	20	82	14	6	30	9	22	0	21	102	56	36	24	0	0	1	5	7	3	9	747
10	31	16	62	25	0	18	0	24	9	4	8	42	34	24	4	0	25	48	35	0	16	59	35	8	7	0	0	0	1	3	3	3	544
11	8	27	13	4	0	29	16	18	0	0	16	31	23	73	0	0	34	17	16	0	0	87	44	12	0	0	0	1	3	1	0	4	477
12	0	90	153	32	10	42	0	12	61	60	40	0	59	190	16	36	28	35	133	0	23	86	53	11	18	0	0	3	3	8	9	6	1217
13	81	87	32	0	0	34	24	107	41	28	31	60	116	261	55	69	56	84	141	0	89	170	114	52	7	0	3	3	4	7	0	9	1765
14	54	210	108	62	42	110	70	207	55	67	55	206	213	657	77	38	209	232	172	0	104	620	260	79	27	0	0	7	9	7	13	18	3988
15	4	33	16	0	0	46	4	7	18	0	0	25	54	40	8	8	4	12	22	0	8	113	3	3	5	0	0	0	0	1	0	7	441
16	4	4	0	13	16	31	5	20	5	0	0	27	47	93	8	20	61	9	20	0	0	251	21	36	8	0	0	3	1	3	0	4	710
17	22	71	18	0	0	29	11	41	50	21	13	16	66	191	5	66	78	79	103	0	17	119	150	31	3	0	0	1	3	3	3	6	1216
18	53	56	41	17	0	55	16	50	25	25	0	36	136	173	4	14	43	90	148	16	50	94	131	48	8	0	3	1	3	7	6	9	1358
19	39	44	53	73	52	73	56	169	24	9	22	137	140	164	23	0	103	117	173	42	14	85	225	67	8	0	0	6	7	8	0	13	1946
20	0	20	0	0	0	0	0	0	0	19	0	0	19	36	0	0	0	0	39	39	0	21	4	5	0	0	0	0	1	1	0	0	204
21	0	11	0	38	0	7	0	29	36	10	0	19	86	155	8	0	35	35	4	0	0	39	205	62	9	0	0	1	0	4	9	4	806
22	87	58	71	51	49	32	24	108	68	43	63	53	117	431	92	178	72	71	58	17	27	0	600	1416	1234	0	197	226	288	652	163	318	6864
23	56	46	36	42	44	18	7	46	56	30	46	51	108	303	8	28	197	107	142	17	82	676	0	1058	168	0	143	0	63	237	101	60	3976
24	43	18	31	11	9	9	4	11	39	20	33	11	32	91	9	37	25	63	64	3	54	932	1496	0	0	0	0	222	172	180	0	155	3774
25	21	37	29	20	18	26	3	27	24	16	13	34	25	54	4	22	5	17	46	0	8	728	203	0	63	0	0	147	71	49	0	128	1838
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	5	0	22	6	0	0	5	0	0	0	5	0	0	0	0	3	5	0	0	3	0	0	0	0	0	0	90	0	187	0	53	384
28	0	1	7	3	3	0	1	2	0	1	1	1	3	5	1	3	1	3	6	0	0	422	0	134	107	0	0	0	0	20	0	0	725
29	0	3	7	1	2	0	0	0	1	1	1	1	1	5	0	3	2	1	3	1	0	422	62	106	53	0	0	0	0	0	0	0	676
30	2	11	11	7	6	3	6	13	2	3	2	3	7	13	1	3	2	12	10	2	0	783	100	308	18	0	45	23	7	0	0	0	1403
31	0	0	0	0	0	7	0	17	6	3	3	3	0	10	0	3	3	3	10	0	0	207	0	0	0	0	0	0	39	0	169	0	483
32	3	6	7	3	1	0	0	9	2	3	6	3	9	22	4	2	2	11	16	0	2	339	46	269	59	0	0	0	0	0	0	0	824
Total	643	1293	1149	746	358	1014	450	1333	775	587	513	1179	1668	3897	460	672	1222	1403	1968	155	628	7102	4101	3902	1904	0	401	751	702	1453	502	853	43784

APPENDIX 3: Surveyed Peak Hour Trip Table for Pulaski Town (provided by VDOT)

(3:30PM--4:30PM)

To Frm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
1	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	1	7	2	0	0	0	0	0	1	0	1	38
2	0	0	0	0	0	7	13	7	7	0	0	0	15	16	0	0	4	0	29	0	0	1	3	1	0	0	0	1	0	1	0	0	105
3	11	0	11	12	0	0	0	17	0	0	0	20	0	42	0	0	0	8	0	0	0	4	12	3	0	0	0	2	0	1	0	3	146
4	0	0	12	0	0	0	0	0	0	0	0	0	0	5	0	0	0	7	12	0	0	6	3	1	0	0	0	0	0	1	0	1	48
5	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	7	5	2	0	0	0	0	0	1	0	0	39
6	0	0	0	0	0	0	0	19	0	0	0	0	0	27	0	0	0	7	0	0	0	2	2	1	0	0	0	0	0	1	0	0	59
7	0	0	8	0	0	7	0	0	0	0	8	0	0	0	0	0	0	0	8	0	0	2	3	0	0	0	0	0	0	1	0	0	37
8	0	5	12	0	0	0	0	17	0	0	0	0	15	20	0	0	0	8	12	0	0	13	7	1	0	0	0	1	0	1	0	1	113
9	0	0	0	0	0	0	16	0	0	0	0	0	0	15	3	5	8	8	0	0	9	0	11	4	0	0	0	0	0	2	0	4	85
10	0	0	51	0	0	0	0	0	0	0	0	9	0	0	0	0	4	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	66
11	8	0	0	0	0	0	0	5	0	0	0	0	7	8	0	0	0	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	33
12	0	0	20	11	0	7	0	0	0	0	0	0	7	21	0	0	4	0	9	0	0	2	4	1	0	0	0	0	0	1	0	0	87
13	15	15	0	0	0	0	0	13	0	0	7	17	21	46	4	0	4	7	0	0	22	5	24	3	0	0	0	0	0	1	0	1	205
14	0	23	11	0	0	8	0	27	0	0	0	55	7	91	11	5	21	8	21	0	0	24	34	3	0	0	0	0	0	1	0	1	351
15	0	0	11	0	0	0	4	0	0	0	0	0	7	4	0	0	0	3	0	0	4	5	0	0	0	0	0	0	0	0	0	0	38
16	0	0	0	0	13	0	0	7	0	0	0	0	0	9	0	0	0	0	7	0	0	6	0	3	0	0	0	0	0	1	0	1	47
17	0	8	0	0	0	0	0	0	0	0	4	0	4	8	0	0	4	0	13	0	0	8	11	1	0	0	0	0	0	1	0	0	62
18	0	8	0	0	0	0	0	7	7	8	0	9	12	0	0	0	5	0	27	0	3	3	21	2	0	0	0	0	0	1	0	2	115
19	7	19	12	12	0	15	8	23	12	0	0	11	15	15	0	0	4	16	0	0	0	3	15	2	0	0	0	0	0	1	0	1	191
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
21	0	0	0	0	0	0	0	5	0	0	0	0	20	38	7	0	0	19	0	0	0	0	39	3	0	0	0	0	0	1	0	1	133
22	2	2	1	5	4	2	1	12	0	0	2	1	4	19	7	2	5	3	1	0	0	0	109	138	140	0	0	45	74	51	0	34	664
23	0	0	3	2	5	0	1	5	1	3	2	5	10	24	0	0	12	7	5	1	4	175	0	163	0	0	0	0	0	15	0	0	443
24	1	0	1	1	1	1	0	2	1	0	1	1	1	1	2	2	1	1	0	0	1	195	114	0	0	0	0	16	0	3	0	4	351
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	58	0	6	0	0	0	0	0	0	0	0	66
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	0	0	0	0	0	0	0	0	0	0	77
30	0	1	0	1	1	0	0	1	0	1	1	0	1	1	0	0	0	0	1	1	0	23	3	1	8	0	41	1	2	0	0	0	89
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	1	1	0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	0	1	0	0	26	0	2	19	0	0	0	0	0	0	0	55
Total	45	82	154	44	36	66	43	168	28	13	25	130	146	411	35	14	76	121	146	2	43	649	429	346	167	0	41	66	76	87	0	55	3744

Appendix 4: 24 HOUR TRIP TABLE FOR PULASKI NETWORK (LP, Structural)

(Obtained Via Linear Programming (LP) Model)

File Name:	LPFORM1.XL2	Model:	LP	Version:	Simple24h (SUN), March 95
Network:	Pulaski Town, VA	Input Volume:	24 Hour	Iterations:	19668
O-D Zones:	Defined by VDOT	Seed Table:	0/1 (Structural)	Sigma:	0.1
Run Time	24 Hr. 8 Min.	Machine:	SUN Sparc		
Volume Avail:	75 Percent			Date:	May, 1995

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
From																																	
1	0	1	1	0	0	164	76	1	1	1	1	190	1	1	1	1	2	70	0	80	1	2064	1	1040	1	1	1	1	0	412	1	1	4116
2	869	0	1	1	1	1	0	1	336	1	1	1	0	0	1	1	0	0	0	1	1	1	355	0	1	0	1	0	0	254	1	1	1831
3	591	0	0	0	1	539	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	530	1679
4	1	1	0	0	1	1	0	0	1	0	1	1	1	423	1	1	0	1	1	0	1	0	1	1	1	1	1	1	0	136	0	1	579
5	1198	0	1	1	0	0	1	0	1	0	0	1	1	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1216
6	522	1	1	476	1	0	0	0	1	1	1	1	1	0	1	1	313	260	5	1	1	629	425	470	1	1	216	307	0	0	1	1	3639
7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1	518	0	0	0	0	0	1	0	524
8	181	1	901	0	1	0	0	0	67	1	0	1	0	1	0	1	1	1	1	0	1	1	1	568	1	251	228	0	0	617	0	1	2827
9	0	0	1	1	1	1	0	748	0	0	1	0	1	0	1	0	0	22	1	1	1	1	1	216	0	1	1	1	0	0	0	0	1001
10	1	1	0	1	0	1	0	564	0	0	1	1	0	0	1	1	281	1	25	1	1	268	0	778	1	1	1	1	0	0	0	0	1931
11	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	0	3	1	1	1	485	1	0	1	1	1	1	0	0	1	1	511
12	1	1	1	1	0	0	0	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	332	1	1	0	1	1	0	0	0	1	353
13	1	1	0	1	1	1	1	0	0	0	1	1	0	1	0	123	120	1	1	1	1	444	0	469	1	1	1	1	0	1	1	71	1246
14	0	1	1	1	0	1	1	1	0	1	135	0	0	0	0	0	1	0	0	1	1	0	0	1	159	289	1	1	0	1	1	1	599
15	177	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	224	1	1	426
16	1	0	1	1	1	683	1	1	1	1	0	1	0	1	0	0	0	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	705
17	1	0	1	1	1	345	1	0	1	0	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	0	1	1	0	1	1	0	365
18	0	1	1	0	1	0	1	1304	1	0	0	251	0	0	1	1	1	0	0	0	1	603	1	1	1	0	1	1	0	0	159	1	2332
19	1	1	1	1	1	1	1	0	2	0	3	1	1	0	0	1	1	1	0	1	0	0	1	1	0	0	0	1	0	0	1	1	23
20	1	1	1	0	0	0	0	1	1	0	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1	0	1	1	0	0	231	0	250
21	1	1	0	1	153	1	1	1	1	1	0	1	1	0	1	1	178	1	1	1	0	0	319	1	1	1	1	1	0	0	1	59	730
22	341	0	1534	1	1	1831	1	1	0	817	0	1	40	1	0	1	209	227	1	1	1	0	763	1	0	0	490	1	0	206	1	1	6472
23	1	1	1	0	1	0	1	0	458	0	0	1	1	0	1	0	462	0	1	1	1	2435	0	1	724	1	0	77	0	1	0	1	4171
24	118	306	1	1	1	1	0	14	757	0	1636	1	789	1	0	0	1	0	1	0	1	0	1	0	1	1	1	1	0	0	1	117	3752
25	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1803	0	0	1	1	1	0	0	1	0	1825
26	0	0	1	0	0	1	1	1	242	0	1	1	1	1	100	1	234	1	1	0	1	1	1	0	1	0	1	1	0	0	0	1	594
27	1	0	1	1	1	311	59	157	1	1	1	1	1	1	1	1	202	0	1	0	1	1	0	161	0	0	0	1	0	0	0	0	906
28	1	1	1	1	332	1	0	1	1	1	1	1	1	1	0	1	0	260	1	0	1	0	1	1	1	1	1	0	0	0	26	1	639
29	1	1	1	1	0	1	1	273	1	0	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1	419	0	0	1	1	708
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0	306	495	0	0	0	664	0	0	0	1470
31	0	0	0	1	0	1	1	1	1	1	0	1	1	1	0	1	1	331	0	0	1	1	1	1	0	1	0	1	0	1	0	1	350
32	0	1	0	0	1	1	1	1	275	0	1	1	1	264	0	1	1	319	0	0	1	1	0	0	0	1	0	1	0	1	1	0	874
Total	4011	325	2456	495	504	3890	151	3073	2155	831	1792	466	848	704	115	148	2014	1506	47	96	26	6943	4015	4023	1916	559	956	826	664	1858	435	796	48644

Appendix 5: 24 HOUR TRIP TABLE FOR PULASKI NETWORK (LP, Small Error Target)

(Obtained Via Linear Programming (LP) Model)

File Name:	LPFORM2.XL2	Model:	LP	Version:	Simple24h (SUN), March 95
Network:	Pulaski Town, VA	Input Volume:	24 Hour	Iterations:	48030
O-D Zones:	Defined by VDOT	Seed Table:	Small Err. 100% Cells	Sigma:	0.8
Run Time	52Hr. 55 Min.	Machine:	SUN Sparc		
Volume Avail:	75 Percent			Date:	July, 1995

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
From																																	
1	0	20	201	12	0	143	182	14	53	0	0	157	42	7	0	0	56	8	250	0	0	108	33	856	7	0	0	0	0	213	0	2	2364
2	717	0	55	33	0	46	19	52	41	21	19	68	50	190	30	0	40	36	565	11	3	74	31	6	6	0	1	0	1	4	0	7	2126
3	31	13	0	134	21	17	28	60	0	49	21	89	26	101	18	0	11	17	11	0	10	100	61	26	19	0	0	0	4	105	1	5	978
4	0	75	71	0	0	43	18	0	47	21	9	15	5	65	0	0	0	49	71	0	0	80	5	12	8	0	3	1	0	9	5	3	615
5	0	20	14	0	0	309	0	0	0	21	0	9	0	20	8	10	1	10	34	0	0	71	27	23	4	0	0	167	0	4	0	2	754
6	40	79	4	11	29	0	19	3	18	22	37	632	21	200	24	14	314	41	770	0	0	720	8	5	2	24	611	0	0	0	357	74	4079
7	9	0	30	0	0	21	0	0	0	0	0	0	0	27	0	0	0	12	72	0	0	30	0	5	0	0	0	0	0	0	3	0	209
8	14	66	69	23	0	69	0	0	0	44	9	2	84	170	0	0	295	149	116	0	23	160	912	18	6	0	2	4	446	11	3	6	2701
9	283	21	32	30	0	12	32	16	0	0	0	57	11	69	9	4	24	5	17	0	15	228	38	23	13	0	0	0	2	5	2	6	954
10	324	15	43	18	0	12	0	0	5	0	7	33	20	15	2	0	700	33	19	0	14	389	34	6	4	0	0	0	0	2	0	0	1695
11	5	23	9	2	0	18	13	15	0	0	0	21	19	62	0	0	26	355	740	0	0	81	37	46	0	0	0	0	2	0	0	3	1477
12	1	66	111	23	0	37	0	8	37	49	25	0	43	113	9	24	52	33	82	0	15	85	38	9	16	0	0	2	0	5	7	5	895
13	73	80	30	0	0	486	16	99	34	18	20	55	0	250	0	0	37	69	87	0	0	148	86	32	4	0	1	1	0	4	0	5	1635
14	167	192	85	59	0	85	49	0	42	49	39	154	169	0	62	36	157	182	165	0	0	508	167	64	25	581	0	4	0	0	12	17	3070
15	3	27	39	0	0	40	0	0	13	0	0	14	48	24	0	0	11	10	17	0	6	0	2	0	3	0	0	0	0	197	0	0	454
16	2	2	0	11	0	9	2	15	3	0	0	26	47	81	0	0	58	5	17	0	0	237	16	20	6	0	0	2	0	2	0	2	563
17	12	61	13	0	0	21	0	34	41	12	8	10	42	170	2	0	0	67	73	0	0	102	91	28	2	0	0	0	0	1	1	5	796
18	131	45	115	13	0	794	12	38	8	17	0	26	97	146	9	0	41	0	104	12	0	88	114	44	0	0	1	0	1	6	4	8	1874
19	39	132	107	67	14	78	47	1471	1230	177	19	384	133	116	13	0	75	85	0	33	0	74	0	45	248	0	0	3	4	6	0	9	4609
20	0	19	0	0	0	0	0	0	0	17	0	0	14	31	0	0	0	0	37	0	0	16	0	4	0	0	0	0	0	0	0	0	138
21	0	5	0	0	0	4	0	24	31	6	639	14	0	0	0	0	32	0	0	0	0	3	184	0	5	0	0	0	0	3	5	1	956
22	51	47	64	33	0	1535	20	80	56	34	49	50	90	414	0	18	70	66	35	10	23	0	605	1168	1192	0	196	165	0	428	128	244	6871
23	38	34	29	38	0	17	2	629	40	23	44	30	64	218	0	24	167	88	92	9	359	458	0	1015	155	0	110	0	0	279	69	107	4138
24	176	3	20	8	0	0	2	6	286	16	22	10	569	89	9	0	17	55	46	2	0	593	1303	0	0	0	0	154	169	125	0	105	3785
25	15	33	25	19	0	16	2	16	14	15	10	25	113	44	3	15	30	12	398	0	6	634	154	0	0	0	0	127	2	36	0	113	1877
26	0	0	0	0	0	296	0	85	0	0	0	0	0	0	0	0	0	0	262	0	0	0	0	0	0	0	0	0	0	0	0	0	643
27	0	3	0	13	4	0	0	2	0	0	0	4	0	0	0	0	1	2	0	0	2	621	0	0	0	0	0	57	0	130	0	68	907
28	0	0	4	1	2	5	0	1	0	0	0	0	1	4	0	1	0	2	72	0	0	375	0	109	85	0	0	0	0	15	0	0	677
29	0	1	3	0	0	104	0	0	0	0	0	0	0	3	0	2	0	0	2	0	0	299	56	81	36	0	0	125	0	0	0	0	712
30	0	5	41	5	2	1	0	12	0	2	1	0	5	509	0	0	0	8	7	0	0	530	0	292	0	0	31	15	5	0	0	0	1471
31	0	0	0	0	0	109	0	14	5	1	2	2	0	5	0	0	1	1	8	234	0	164	0	0	0	0	0	0	0	0	0	0	546
32	0	6	4	2	0	92	0	5	115	2	6	1	5	18	0	0	0	18	14	0	1	318	29	160	50	0	0	0	0	0	0	0	846
Total	2131	1093	1218	555	72	4419	463	2699	2119	616	986	1888	1718	3161	198	148	2216	1418	4183	311	477	7294	4031	4097	1896	605	956	827	636	1590	597	797	55415

Appendix 6: PEAK HOUR TRIP TABLE FOR PULASKI NETWORK (LP, Structural Target)

(Obtained Via Linear Programming (LP) Model)

File Name:	LPFORM3.XL2	Model:	LP	Version:	Simple1h (SUN), March 95
Network:	Pulaski Town, VA	Input Volume:	Peak Hour (3:30-4:30)	Iterations:	31286
O-D Zones:	Defined by VDOT	Seed Table:	0/1 (Structural)	Sigma:	0.1
Run Time	41 Hr. 4 Min	Machine:	SUN Sparc		
Volume Avail:	75 Percent			Date:	May, 1995

To From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
1	0	0	1	0	0	23	1	0	0	1	1	43	21	1	0	0	0	1	27	0	1	1	1	1	0	1	0	0	0	0	1	1	127
2	1	0	1	1	0	1	4	17	0	1	1	1	1	1	0	0	0	0	0	11	0	0	0	0	1	1	0	0	0	15	1	0	59
3	0	0	0	1	0	1	1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	112	0	0	0	11	0	1	0	37	1	0	173
4	1	1	1	0	0	6	0	0	0	1	1	0	1	0	0	0	1	1	0	8	1	6	1	1	1	0	1	1	0	1	0	0	35
5	1	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	1	1	1	1	0	1	0	41	0	0	1	0	54
6	0	1	93	0	0	0	0	37	1	0	1	1	1	0	20	0	16	20	1	1	1	54	1	0	1	1	23	1	0	16	0	0	291
7	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1	0	1	7	1	0	0	0	0	17
8	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0	0	1	1	213	69	1	0	6	0	0	0	0	0	296
9	1	0	1	0	0	1	1	37	0	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0	1	1	1	0	0	1	1	1	55
10	1	1	1	0	0	0	0	2	0	0	1	53	1	0	0	0	69	7	0	1	1	0	0	0	1	21	1	1	0	0	0	1	163
11	1	1	1	0	0	1	1	1	1	0	0	1	1	1	0	0	0	0	28	1	0	1	2	243	1	0	1	0	87	1	0	0	375
12	0	1	0	1	0	1	1	0	1	1	1	0	1	1	0	0	0	4	1	1	1	0	1	1	1	0	1	1	0	0	0	0	21
13	31	1	0	1	0	0	0	33	0	0	1	2	0	0	0	0	1	0	1	0	0	35	1	0	1	1	8	0	0	1	0	1	119
14	1	1	1	0	0	1	0	1	0	1	0	1	1	0	0	0	1	0	1	1	1	1	1	0	0	1	0	1	0	0	0	0	16
15	0	0	0	0	0	0	0	0	1	0	0	0	25	0	0	0	1	0	0	0	1	1	1	2	0	0	0	0	0	0	0	0	32
16	1	0	0	0	0	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1	1	0	38	1	0	1	0	0	0	1	1	56
17	1	0	1	0	0	1	0	33	77	1	1	1	1	0	0	1	0	1	0	1	0	21	1	0	1	0	0	0	0	0	0	1	144
18	0	28	1	1	0	0	0	67	1	1	0	1	1	13	0	0	1	0	0	0	0	58	1	1	1	0	1	1	0	0	4	39	221
19	1	0	0	1	0	1	0	1	0	1	1	1	0	0	0	0	1	0	0	1	0	2	1	1	1	1	1	1	0	1	0	0	18
20	1	0	0	1	0	0	0	0	0	1	1	1	1	5	0	1	1	1	1	0	0	5	1	9	1	0	1	15	0	0	1	1	49
21	1	1	1	0	0	1	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	76	0	1	0	1	1	0	0	1	1	92
22	1	1	114	1	0	291	1	0	6	1	1	1	60	27	0	0	50	41	0	1	1	0	0	0	1	0	1	1	0	1	1	1	604
23	1	0	1	1	0	1	0	24	0	0	179	0	1	40	0	1	1	1	1	1	9	20	0	1	174	1	1	1	0	23	0	1	484
24	1	1	1	1	0	0	0	28	0	0	1	0	1	0	0	0	1	0	1	1	0	183	1	0	1	0	1	5	0	0	1	1	230
25	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	7	2	1	0	84	0	0	0	1	0	0	0	17	1	0	120
26	1	0	34	0	0	0	1	1	42	0	1	6	1	1	0	0	0	0	1	15	1	0	0	1	0	0	1	1	0	1	1	0	110
27	1	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	55	0	1	0	1	0	0	0	1	67
28	1	1	1	1	0	1	0	1	1	1	0	1	1	0	0	0	1	48	0	1	1	1	1	0	1	1	0	0	0	3	1	0	69
29	1	0	1	1	1	18	1	1	1	1	1	0	0	0	0	0	0	13	0	1	1	0	1	0	1	1	1	0	0	0	1	0	47
30	1	1	32	1	0	1	0	0	0	0	0	0	0	1	0	0	1	3	1	0	0	0	0	0	0	1	31	0	0	0	0	0	74
31	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	51
32	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	12	1	1	1	1	0	17	1	1	0	1	0	0	0	0	40
Total	54	43	288	60	1	353	14	287	136	17	198	120	127	96	20	3	151	166	71	52	26	593	309	442	194	48	90	76	87	118	18	51	4309

Appendix 7: PEAK HOUR TRIP TABLE FOR PULASKI NETWORK (LP, Small Error Target)

(Obtained Via Linear Programming (LP) Model)

File Name:	LPFORM4.XL2	Model:	LP	Version:	Simple1h (SUN), March 95
Network:	Pulaski Town, VA	Input Volume:	Peak Hour (3:30-4:30)	Iterations:	38719
O-D Zones:	Defined by VDOT	Seed Table:	Small Err. 100% Cells	Sigma:	0.9
Run Time	98Hr. 26 Min.	Machine:	SUN Sparc		
Volume Avail:	75 Percent			Date:	Aug., 1995

To From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
1	0	0	9	0	0	31	0	0	0	0	4	0	13	14	0	0	0	37	94	0	0	1	0	11	0	0	0	0	0	0	0	0	214
2	0	0	0	0	0	0	0	17	0	0	0	0	14	20	0	0	6	7	17	0	0	1	0	0	0	0	0	0	0	0	0	0	82
3	0	0	0	7	0	0	6	10	0	36	0	14	0	7	7	0	31	0	8	0	0	0	2	0	0	0	0	0	0	0	0	0	128
4	0	0	9	0	0	0	0	0	0	0	0	7	0	0	7	0	0	0	10	0	0	2	1	1	0	0	0	0	0	1	0	0	38
5	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	11	0	0	0	33
6	15	6	0	0	0	0	4	0	0	0	0	14	0	4	0	0	0	0	29	0	0	118	0	0	0	0	54	9	0	0	0	0	253
7	0	8	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	21
8	0	3	15	0	0	13	0	0	0	0	4	0	11	19	0	0	17	5	19	0	4	8	65	4	0	0	0	0	0	39	0	0	226
9	0	4	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	5	21	0	0	0	0	1	0	0	0	0	0	0	0	0	76
10	0	0	0	0	0	0	0	0	0	0	0	77	0	11	0	0	69	6	0	0	0	8	1	0	0	0	0	25	0	0	0	1	198
11	0	0	0	0	0	0	5	0	0	0	0	0	4	0	0	0	2	0	0	0	0	1	2	183	0	0	0	0	0	0	0	0	197
12	0	0	0	0	0	0	0	0	0	5	0	0	6	38	0	0	0	7	9	0	0	0	2	0	0	0	0	0	0	0	0	0	67
13	0	8	10	0	0	0	0	12	8	0	5	4	0	4	5	0	2	7	34	0	0	2	5	1	0	0	0	0	0	1	0	0	108
14	0	14	29	2	0	17	0	0	12	0	6	12	37	0	2	0	7	0	9	0	0	18	0	1	0	0	0	0	0	9	0	1	176
15	0	0	0	0	0	0	0	0	1	0	0	0	3	9	0	0	0	0	0	6	5	6	0	0	0	0	13	0	0	0	0	0	43
16	51	0	5	0	0	0	0	0	3	0	0	0	0	5	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	66
17	0	1	0	0	0	0	0	54	5	2	0	3	1	16	0	0	0	4	2	0	0	4	10	0	0	59	0	0	0	0	0	0	161
18	6	0	16	4	6	4	0	47	4	0	0	0	4	6	1	0	0	0	10	0	0	2	5	1	0	0	28	0	0	0	27	11	182
19	0	26	0	7	0	0	7	9	0	6	0	4	0	19	0	0	9	19	0	0	0	0	4	0	163	0	0	0	0	0	0	1	274
20	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6
21	0	0	0	0	0	0	0	24	0	0	0	0	15	0	3	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	45
22	0	0	17	5	0	184	0	11	0	0	2	1	3	20	0	4	6	1	2	0	0	0	107	125	0	0	0	47	53	14	0	24	626
23	4	1	10	1	0	1	2	5	129	1	1	3	17	21	0	0	6	18	9	0	35	107	0	110	0	0	0	0	0	2	0	0	483
24	2	0	1	0	0	2	0	0	1	1	0	0	0	2	0	0	0	2	1	1	0	113	101	0	0	0	0	4	0	0	0	1	232
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131	0	0	0	0	0	0	0	5	0	0	136
26	0	0	40	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	10	100
27	0	1	0	0	0	15	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	63
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	11	0	0	0	0	0	12	0	0	55
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	0	0	0	0	0	0	0	1	0	0	57
30	0	0	0	1	0	0	0	0	0	0	0	53	0	0	0	0	0	1	1	0	0	32	0	2	0	0	7	0	0	0	0	10	107
31	21	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
32	28	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	25	0	1	0	0	0	0	0	0	0	0	57
Total	127	72	191	27	6	285	69	189	174	51	22	192	128	215	25	4	155	121	281	7	44	670	309	453	200	59	102	85	65	129	27	59	4543

Appendix 8: 24 HOUR TRIP TABLE FOR PULASKI NETWORK (THE, Structural Target)

(Obtained Via The Highway Emulator (THE) Model)

File Name:	THEFORM1.XL2	Model:	THE	Version:	Wequcal2.exe	
Network:	Pulaski Town, VA	Input Volume:	24 Hr. Vol. Based	Iterations:	Max Entr Process	15
O-D Zones:	Defined by VDOT	Seed Table:	0/1 (Structural)		Assignment	15
Run Time	69 Minutes	Machine:	486DX2-66		Calbration	15
Volume Avail:	75 Percent			Date:	May, 1995	

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
From																																	
1	0	1560	155	40	4	317	44	22	15	16	9	5	9	171	4	12	384	351	354	476	48	531	349	439	15	28	50	61	63	352	13	24	5921
2	2500	0	1119	1	0	0	1	3	2	2	1	1	1	24	0	2	53	49	49	49	6	74	48	61	1	1	0	0	0	5	2	3	4058
3	131	940	0	25	0	56	43	0	0	0	0	0	0	0	0	0	0	0	0	1223	0	0	0	0	0	164	32	1	2	336	0	0	2953
4	110	57	83	0	1	46	36	60	0	1	0	0	0	2	0	1	4	4	5	42	1	6	5	5	1	15	1	2	1	281	0	1	771
5	0	0	0	0	0	0	0	0	1	1	0	1	0	11	0	1	24	22	22	30	3	33	22	28	1	0	0	202	17	0	1	1	421
6	230	85	84	21	2	1	0	0	30	1	0	0	0	338	8	24	218	21	20	8	3	1051	21	25	1	15	26	33	34	0	26	47	2373
7	24	49	48	12	1	1	0	0	0	0	0	0	0	0	0	0	0	6	5	0	1	0	6	7	0	9	15	19	19	0	0	0	222
8	15	8	0	17	2	1	0	0	1	12	7	4	2	2	0	0	54	411	414	362	209	7	1515	514	11	12	21	26	27	0	0	1	3655
9	28	14	1	2	1	0	0	0	0	10	13	7	2	0	0	0	0	76	78	664	10	0	76	96	21	2	3	4	5	0	0	0	1113
10	3	1	0	0	0	0	0	20	4	0	1	1	5	157	4	11	238	218	219	70	29	489	216	272	2	0	1	0	1	0	12	22	1996
11	0	1	0	1	0	0	0	3	2	2	0	0	6	107	2	8	236	215	217	49	30	333	214	270	1	1	0	0	0	0	8	15	1721
12	2	2	0	12	0	0	0	8	6	6	2	0	4	65	1	5	146	133	134	1	19	201	133	3	3	8	14	1	1	0	5	9	924
13	28	14	1	3	0	0	0	2	37	9	18	7	0	1	0	18	2	118	119	45	16	746	117	147	22	2	3	4	4	3	0	1	1487
14	220	105	8	21	2	676	0	5	22	164	201	53	0	0	0	0	2	32	86	33	7	3	46	107	163	14	26	32	32	1	0	0	2061
15	2	1	0	0	0	8	0	0	0	2	2	0	0	0	0	0	1	17	45	17	3	1	24	55	2	0	0	1	0	0	0	0	181
16	8	4	1	0	1	25	0	0	1	6	8	2	15	0	0	0	1	8	24	9	2	0	12	29	6	1	1	1	1	0	0	0	166
17	92	44	3	9	1	194	0	85	118	31	57	22	3	12	1	1	0	0	0	0	1	300	1	0	68	6	11	13	14	0	4	6	1097
18	246	117	9	23	2	0	3	340	316	82	152	60	26	242	26	12	46	0	86	32	0	520	0	106	182	16	29	36	36	25	72	131	2973
19	293	139	11	27	2	1	3	405	375	98	181	71	31	177	18	9	1	101	0	1	0	379	1	1	217	19	34	43	43	29	53	96	2859
20	34	76	1795	315	1	0	0	226	164	161	76	1	4	19	3	1	0	11	0	0	0	42	0	4	0	221	395	18	18	0	140	251	3976
21	27	12	1	3	0	0	0	60	33	9	17	6	3	9	0	1	0	0	0	0	0	19	7	0	20	2	3	3	4	3	3	4	249
22	384	183	15	36	3	1180	0	8	39	287	349	93	727	1	1	0	300	409	1091	413	80	0	582	1353	285	25	45	56	56	1	0	1	8003
23	441	210	17	41	4	0	6	991	567	147	274	106	47	145	15	7	5	0	2	0	17	310	0	2	328	29	51	64	65	45	43	78	4057
24	410	196	15	38	4	0	5	567	527	137	255	12	44	248	26	12	2	142	1	13	0	531	2	0	304	27	48	60	60	41	75	133	3935
25	2	5	0	18	0	0	0	14	9	10	4	2	5	106	2	8	236	216	218	0	30	328	214	271	0	13	23	1	1	0	8	15	1759
26	92	48	645	18	0	39	30	50	0	1	0	0	0	2	0	0	4	3	4	36	0	5	4	4	2	0	22	1	1	235	0	1	1247
27	139	72	106	1	0	60	44	77	0	1	0	0	1	2	0	0	6	6	5	54	1	8	5	7	2	19	0	1	2	357	0	1	977
28	0	0	0	0	0	0	0	1	6	6	3	2	4	67	2	4	151	138	139	187	18	209	137	172	6	0	0	0	2	1	5	10	1270
29	0	0	0	0	4	0	0	0	3	4	2	1	2	40	1	3	88	81	82	109	11	123	80	101	4	0	0	1	0	1	3	5	749
30	116	237	231	58	6	3	0	0	0	0	0	0	0	0	0	0	0	28	28	0	4	0	27	35	0	41	74	91	93	0	0	0	1072
31	7	4	0	1	0	22	0	0	1	5	7	2	0	0	0	0	2	44	116	169	9	0	62	144	5	0	1	1	1	0	1	0	604
32	12	5	1	1	0	36	0	0	1	9	11	3	0	0	0	0	4	70	188	274	14	0	100	233	9	1	1	2	2	0	0	0	977
Total	5596	4189	4349	744	41	2666	215	2947	2280	1220	1650	462	941	1948	114	140	2208	2930	3751	4366	572	6249	4026	4491	1682	691	930	778	605	1716	474	856	65827

Appendix 9: 24 HOUR TRIP TABLE FOR PULASKI NETWORK (THE, Small Error Target)

(Obtained Via The Highway Emulator (THE) Model)

File Name:	THEFORM2.XL2	Model:	THE	Version:	Wequcal2.exe	
Network:	Pulaski Town, VA	Input Volume:	24 Hr. Vol. Based	Iterations:	Max Entr Process	15
O-D Zones:	Defined by VDOT	Seed Table:	Small Err, 100% Cells		Assignment	15
Run Time	70 Minutes	Machine:	486DX2-66		Calbration	15
Volume Avail:	75 Percent			Date:	May, 1995	

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
From																																	
1	0	1560	326	99	0	358	57	119	50	0	0	18	88	46	0	0	411	570	517	59	1	555	317	274	12	11	3	2	2	202	2	33	5692
2	2500	0	1169	3	0	34	17	38	14	11	19	12	19	178	4	0	163	136	390	1805	3	62	48	12	2	0	1	0	0	19	0	10	6669
3	275	940	0	105	1	36	50	0	0	0	0	0	0	0	0	0	0	0	0	1223	0	0	0	0	0	83	1	0	0	206	0	0	2920
4	2	397	198	0	0	59	66	0	0	1	0	1	0	1	0	0	0	3	6	5	1	1	1	1	1	2	13	0	0	174	0	0	933
5	0	0	0	0	1	0	0	0	0	4	0	1	0	7	1	1	5	13	60	4	0	23	17	15	0	0	0	202	19	0	0	1	374
6	259	261	3	3	3	0	0	0	69	2	5	1	5	875	33	37	136	123	208	2	0	375	9	7	0	1	0	0	0	0	89	2	2508
7	157	1	44	0	0	2	0	0	0	0	0	0	1	0	0	0	0	2	18	0	0	0	1	1	0	1	0	1	0	0	0	0	229
8	46	153	4	32	2	11	0	1	19	81	23	1	77	113	1	5	200	370	1000	35	518	94	936	61	5	2	11	18	8	0	6	7	3840
9	101	260	9	26	0	0	0	0	0	1	2	118	7	0	0	0	0	28	121	178	28	0	93	60	60	2	0	0	8	0	0	0	1102
10	28	15	1	1	0	0	0	140	9	0	4	6	20	126	3	0	198	294	321	15	47	420	148	28	1	0	1	0	0	0	45	24	1895
11	1	23	0	1	0	0	0	12	0	0	0	4	36	234	0	0	505	164	235	15	1	267	280	56	0	1	0	0	0	0	1	16	1852
12	0	47	0	107	0	0	0	5	9	17	18	1	11	74	1	4	79	74	255	0	13	49	43	0	34	8	2	1	0	0	14	5	871
13	122	95	1	0	0	0	0	15	77	22	38	11	0	85	1	53	1	88	160	1	30	652	56	23	1	0	1	1	0	1	0	1	1536
14	172	445	5	10	2	1315	0	122	50	93	172	60	48	0	8	9	11	183	213	1	25	446	53	31	22	0	0	3	3	0	33	24	3559
15	1	6	0	0	0	69	0	0	2	0	0	0	4	2	0	0	1	25	56	3	4	1	2	2	1	0	0	0	0	0	0	0	179
16	1	1	0	0	0	65	0	2	0	0	0	1	59	10	0	1	2	3	13	0	0	2	2	6	1	0	0	0	0	0	0	0	169
17	54	178	1	0	0	25	0	248	222	37	35	5	2	29	1	3	0	1	19	0	3	300	34	3	2	1	0	0	1	0	2	3	1209
18	375	345	4	6	0	0	1	162	227	102	1	30	78	400	9	9	285	0	301	295	0	291	0	48	11	1	4	0	3	4	63	67	3122
19	355	421	10	52	13	1	7	1029	444	65	265	250	178	189	36	1	70	275	0	271	4	141	49	17	19	2	0	8	9	8	1	41	4231
20	1	1042	1795	36	1	0	0	4	1	472	5	0	14	40	0	0	0	0	27	0	0	29	1	0	0	620	156	2	2	0	1	1	4250
21	0	11	0	5	0	0	0	211	109	11	0	5	16	20	1	0	21	0	0	0	0	7	239	2	4	1	0	0	0	0	6	2	671
22	172	112	3	6	2	546	0	67	60	62	217	21	818	417	2	1	300	283	194	474	24	0	795	2353	1010	0	138	89	133	0	15	14	8328
23	263	164	3	14	4	0	0	773	370	111	333	28	39	115	4	5	279	0	49	35	145	330	0	169	283	1	163	0	50	104	188	71	4093
24	391	112	3	5	1	0	0	32	445	98	225	9	23	99	9	14	11	121	30	2	7	898	331	1	0	1	0	251	270	86	0	360	3835
25	3	38	0	139	1	0	0	14	5	9	11	39	8	46	0	4	13	38	210	0	9	575	268	0	0	13	3	48	16	0	1	176	1687
26	71	23	742	7	0	16	15	23	0	0	0	0	0	0	0	0	1	0	0	206	0	0	0	0	1	0	27	1	0	106	0	1	1240
27	0	6	0	4	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	928	0	1	948
28	0	0	0	0	0	0	0	0	0	0	0	0	2	8	0	1	1	14	39	21	0	635	0	405	44	0	0	0	0	8	1	0	1179
29	0	0	0	0	4	0	0	0	0	0	0	0	0	6	0	1	6	1	13	15	0	372	133	202	14	0	0	0	0	0	0	0	767
30	63	193	56	19	3	1	0	0	0	0	0	0	0	0	0	0	0	6	7	0	0	0	24	104	0	5	422	151	49	0	0	0	1103
31	1	1	0	0	0	202	0	27	14	4	21	1	1	13	0	0	2	27	119	80	0	14	1	0	0	1	0	0	32	0	0	0	561
32	4	14	0	0	0	2	0	6	2	4	26	0	6	22	0	0	1	47	121	41	1	14	62	525	51	0	0	0	0	0	0	1	950
Total	5418	6864	4377	680	38	2742	213	3055	2198	1207	1420	623	1560	3155	114	149	2702	2889	4702	4787	864	6553	3943	4406	1579	758	946	780	605	1846	468	861	72502

Appendix 10: PEAK HOUR TRIP TABLE FOR PULASKI NETWORK (THE, Structural Target)

(Obtained Via The Highway Emulator (THE) Model)

File Name:	THEFORM3.XL2	Model:	THE	Version:	Wequcal2.exe	
Network:	Pulaski Town, VA	Input Volume:	PM Peak Hour (3:33-4:30)	Iterations:	Max Entr Process	15
O-D Zone:	Defined by VDOT	Seed Table:	0/1 (Structural)		Assignment	15
Run Time	68 Minutes	Machine:	486DX2-66		Calbration	15
Volume Avail:	75 Percent			Date:	July, 1995	

To From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
1	0	140	20	3	0	72	3	7	2	3	3	0	3	11	0	1	65	27	25	57	4	82	35	45	3	2	4	6	5	14	0	0	642
2	246	1	114	0	0	12	9	1	0	0	1	0	1	0	0	1	5	3	2	18	0	7	3	4	1	0	1	0	0	34	0	0	464
3	13	65	0	0	0	10	8	1	0	0	1	0	0	1	0	0	4	2	2	113	0	6	2	3	0	31	0	0	1	29	0	0	292
4	4	1	1	0	0	3	2	5	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	1	0	2	0	0	10	0	0	57
5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	1	2	2	1	4	1	3	0	0	0	22	7	0	0	0	47
6	12	4	9	1	0	0	0	0	3	1	0	0	0	19	1	1	18	3	2	5	0	148	4	5	0	0	2	3	2	0	0	1	244
7	1	3	8	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	2	2	2	0	0	0	24
8	2	1	0	1	0	2	0	0	0	2	1	0	33	1	0	0	4	12	12	21	12	2	123	21	1	1	1	2	2	0	0	0	257
9	3	2	0	0	0	0	0	0	1	0	2	0	1	0	0	0	0	9	7	40	1	0	10	14	2	0	0	1	0	0	0	0	93
10	6	4	0	1	0	0	0	7	7	0	0	1	1	6	0	0	30	13	11	69	2	43	16	21	3	1	1	1	1	0	0	0	245
11	1	1	0	0	0	0	0	1	3	1	0	0	3	4	1	0	61	25	23	18	3	37	32	43	1	0	0	0	0	0	0	0	258
12	2	2	0	2	0	0	0	3	0	1	2	0	1	2	0	0	13	5	5	1	0	16	7	3	49	1	4	0	0	0	0	0	119
13	9	5	0	1	0	1	0	47	9	2	3	0	0	0	1	1	0	4	5	2	1	113	6	7	5	0	2	1	2	0	1	1	229
14	20	14	0	2	0	58	0	9	1	14	10	0	0	0	0	0	0	1	4	4	0	8	0	9	11	1	3	4	3	0	0	0	176
15	1	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	4	2	0	0	0	6	1	0	0	0	0	0	0	0	17
16	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	2	0	0	0	0	0	0	0	0	7
17	2	2	0	0	0	4	0	40	2	0	1	0	0	0	0	0	1	0	0	0	0	27	1	1	1	0	0	0	1	0	0	0	83
18	15	11	0	1	1	1	0	38	18	2	6	1	1	150	7	1	0	0	9	6	0	169	0	16	8	1	3	3	2	1	21	73	565
19	5	3	0	0	1	0	0	11	5	1	2	0	0	0	0	0	3	2	1	0	0	0	2	2	2	0	1	1	1	0	0	0	43
20	25	26	197	22	0	2	0	31	5	7	27	1	1	0	0	0	12	12	5	0	1	0	6	3	0	13	40	4	3	0	1	2	446
21	2	2	0	0	0	1	0	0	3	0	1	1	0	0	0	0	1	0	1	0	0	0	11	1	2	0	0	1	0	1	0	0	28
22	41	28	0	4	1	118	0	17	2	28	21	0	115	2	0	0	24	7	102	69	1	0	5	191	22	3	6	8	7	0	0	0	822
23	70	49	0	6	2	6	1	7	82	12	28	1	4	1	0	0	36	0	15	11	26	0	0	30	38	4	11	13	12	6	0	0	471
24	27	19	0	2	1	2	0	66	31	5	11	1	2	0	0	0	16	17	6	1	1	0	9	0	14	2	4	5	5	2	0	0	249
25	4	4	0	3	0	0	0	5	0	1	4	2	1	3	0	0	22	9	8	0	1	28	11	15	0	2	6	0	1	0	0	0	130
26	3	0	85	0	0	2	1	3	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	1	0	0	1	0	6	0	0	120
27	6	0	1	2	0	5	3	6	0	0	0	0	0	0	0	0	1	0	0	40	0	0	0	0	2	0	0	0	0	14	0	0	80
28	0	0	0	0	0	0	1	0	0	1	1	0	1	2	0	0	16	7	6	14	1	20	8	11	1	0	0	0	0	1	0	0	91
29	0	0	0	0	3	0	0	0	1	0	0	0	1	1	1	0	9	4	4	8	0	12	5	7	0	0	0	1	0	0	0	0	57
30	3	15	31	4	1	10	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	2	3	0	2	7	9	7	0	0	0	97
31	1	0	0	0	0	3	0	0	0	0	1	0	11	0	0	0	0	6	3	3	0	1	5	6	1	0	0	0	0	0	0	21	62
32	1	1	0	0	0	4	0	0	0	1	1	0	18	0	0	0	0	10	6	4	1	0	8	12	0	0	1	0	0	0	10	0	78
Total	525	403	466	56	10	320	28	306	175	82	128	8	201	204	11	5	344	180	274	555	56	723	312	485	170	64	101	88	64	118	33	98	6593

Appendix 11: PEAK HOUR TRIP TABLE FOR PULASKI NETWORK (THE, Small Error Target)

(Obtained Via The Highway Emulator (THE) Model)

File Name:	THEFORM4.XL2	Model:	THE	Version:	Wequcal2.exe	
Network:	Pulaski Town, VA	Input Volume:	PM Peak Hour (3:33-4:30)	Iterations:	Max Entr Process	15
O-D Zones:	Defined by VDOT	Seed Table:	Small Err. 100% Cells		Assignment	15
Run Time	71 Minutes	Machine:	486DX2-66		Calbration	15
Volume Avail:	75 Percent			Date:	July, 1995	

To From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
1	0	140	28	2	0	77	1	1	2	7	1	0	1	1	1	0	41	79	27	47	1	80	64	37	0	4	3	1	3	19	0	0	668
2	246	0	112	0	0	27	29	1	0	0	0	0	1	2	0	0	5	0	50	9	0	1	0	0	0	0	0	0	0	4	0	0	487
3	24	57	0	1	0	1	0	3	0	0	1	0	0	10	0	0	1	2	0	114	0	6	3	1	0	20	0	0	0	40	0	0	284
4	0	0	8	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	13	0	1	0	0	0	0	0	0	0	22	0	0	49
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	8	1	0	0	0	0	21	2	0	0	0	36
6	2	2	2	0	0	0	0	27	0	0	0	0	1	58	0	0	3	49	21	0	1	17	19	14	0	0	1	0	0	0	0	0	217
7	1	0	15	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	25
8	1	6	0	1	0	3	0	0	0	2	1	0	51	3	0	0	10	1	29	15	75	7	73	0	0	1	1	2	0	0	0	0	282
9	2	1	0	0	0	0	0	0	0	0	1	0	0	3	0	0	13	4	1	50	0	0	5	2	0	1	0	0	0	0	0	0	83
10	3	0	2	0	0	0	0	4	2	0	0	0	0	8	2	2	103	0	3	62	0	38	1	2	0	1	0	0	0	0	2	1	236
11	0	0	0	0	0	0	0	0	1	0	0	0	32	29	0	0	23	0	15	10	0	60	7	1	0	0	0	0	0	0	1	0	179
12	0	0	0	9	0	1	0	0	0	0	0	0	2	5	0	0	45	0	36	1	0	4	1	0	3	0	1	0	0	0	0	0	108
13	49	13	0	0	0	0	0	55	0	0	3	0	0	0	1	0	0	0	0	0	1	101	1	0	0	0	0	0	0	0	0	0	224
14	1	25	0	0	0	108	0	59	1	1	0	1	0	0	3	1	0	1	23	0	0	93	0	0	0	0	0	0	0	0	0	1	318
15	0	0	0	0	0	0	0	0	0	0	0	0	7	0	1	0	0	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0	15
16	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	8
17	2	25	0	0	0	0	0	17	0	0	5	0	0	21	0	0	0	0	11	0	0	27	0	0	0	0	1	0	0	0	0	0	109
18	1	18	0	1	0	0	0	8	25	2	0	0	1	95	5	0	0	1	90	0	0	214	0	1	0	0	0	0	0	0	9	80	551
19	48	50	0	8	0	7	0	43	70	0	0	0	2	0	0	0	5	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	237
20	2	41	197	12	0	0	0	3	6	20	41	0	1	0	0	0	9	2	6	0	0	0	0	0	0	29	23	3	6	0	1	0	402
21	6	1	0	1	0	0	0	2	3	0	1	0	9	0	0	0	0	0	1	0	1	0	54	1	0	1	0	1	0	0	0	0	82
22	9	2	0	2	0	79	0	46	0	4	3	0	114	33	0	0	24	11	4	7	0	0	29	321	119	1	0	12	44	2	0	0	866
23	17	4	1	19	2	1	0	4	10	12	51	2	9	1	0	0	118	0	57	2	7	0	0	154	1	3	1	1	1	10	0	0	488
24	97	2	0	5	1	0	0	17	51	0	2	0	1	0	0	0	1	2	1	0	0	2	41	0	1	2	1	43	1	0	0	1	272
25	0	11	0	4	0	0	0	0	2	6	11	3	0	2	0	0	32	1	21	0	1	6	1	1	0	8	7	1	1	0	0	1	120
26	0	0	94	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	1	0	0	0	2	0	0	120
27	1	0	1	0	0	1	1	16	0	0	0	0	0	0	0	0	0	0	0	59	0	0	0	0	0	0	1	0	0	9	0	0	89
28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	84	0	2	0	0	0	0	0	0	0	0	89
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	6	0	52	0	0	0	0	0	0	0	0	0	0	59
30	8	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	1	0	0	74	0	2	0	0	0	96
31	0	1	0	0	0	3	0	1	1	2	1	0	2	0	0	0	3	7	2	19	0	0	0	1	0	0	0	0	0	0	0	20	63
32	1	1	0	0	0	2	0	0	0	16	0	0	1	1	0	0	2	4	8	10	0	3	1	0	7	0	0	0	0	0	12	0	69
Total	521	402	462	66	4	320	31	316	174	74	122	6	235	272	13	3	441	172	417	446	87	807	302	539	131	72	114	85	60	108	25	104	6931