

## 6.0 EVALUATION OF THE AND LP MODELS FOR PULASKI NETWORK

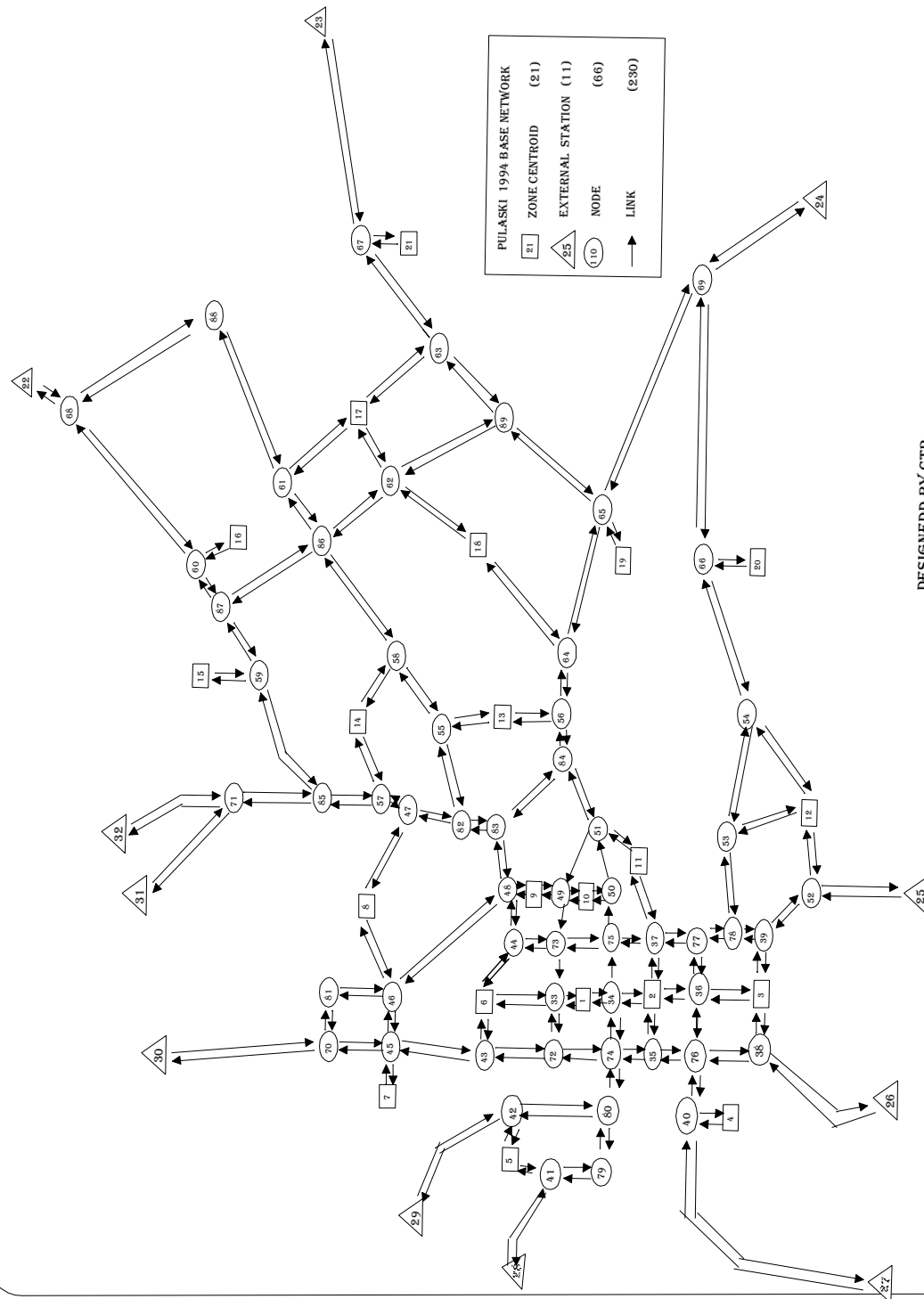
### 6.1 Introduction

This chapter details the application of THE and LP models' on the real network of Pulaski, Virginia. The Pulaski network provided an opportunity for a realistic validation of these models, since VDOT had provided the 24-hour and peak-hour surveyed trip tables for comparison purposes. The network details and data collection have also been detailed, along with the applications of models, results, analyses, and their discussion. The results on LP model's sensitivity to the user input parameter  $\sigma$  have also been detailed.

### 6.2 Pulaski Network

Located in the central area of Pulaski County, Southwestern Virginia, the town of 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 the population and the activity centers in and around the area, in the original network provided by VDOT. This network was reduced by the Center for Transportation Research by eliminating redundancies and other information that was 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). Data on network characteristics, such as link lengths, free flow speeds, and capacities were also provided by 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, for an earlier study conducted by the Virginia Tech Center for Transportation Research. The details of this survey are also included in this chapter.

# PULASKI 1994 BASE NETWORK



DESIGNED BY CTR  
VERSION: 10/22/94

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

### 6.2.1 Network Volume Data Collection

In order to facilitate volume input for the O-D models, VDOT surveyed 24-hour traffic volumes on 175 out of the 230 links of the Pulaski network (defined for this study) using counters, in 1994. 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-hour) and the peak-hour trip tables, the corresponding volume data were used in the models. The period between 9:00 AM on June 14, 1994 and 9:00 AM on June 15, 1994 was chosen as the 24-hour data for consideration. Since complete data for the above period was not available for some stations, data collected during a 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 the 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 abstractions 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% (approximately) of the links. This may be considered reasonable and realistic, since similar situations could be expected for such real-life applications. This also created an opportunity to evaluate the performance of the models in the case of 25% missing volumes. For the present study, these link volumes have been used directly for the model runs.

### 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, and
- (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. For the town of Pulaski these tables were readily available through an Origin-Destination (O-D) survey that was conducted by VDOT (assisted by the Center for Survey Research at Virginia Tech) through mail (Center for Survey Research, 1994). For this research work, the “surveyed” tables have been assumed to be “true”/“correct” and have been used for comparison purposes.

The second purpose was also of significant importance in this research. The motivation in conducting this research was the premise that the quality of the input target/seed table would significantly enhance the modeled output table. To establish a more realistic trip table, the trip generation and trip distribution steps of the traditional four-step planning process were used through the application of MINUTP software. This table was then provided as target/seed information to the models for guiding their solution.

### 6.3 Evaluation Criteria

In order to compare and judge the test results of the models, two measures of closeness are used. 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 VDOT surveyed table (assumed to be “true”/“reasonably good”). 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 “true” table (if available) as possible.

### 6.3.1 Replication of Observed Link Volumes

One of the most important measures of the quality of a 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 models were obtained as byproducts of trip table estimation procedures. For cases where less than 100% observed volumes were used, the replication criteria were 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:

$$\% \text{ RMSE} = \sqrt{\frac{\sum_{a \in A_v} (V_{\text{assign}}^a - V_{\text{obs}}^a)^2}{n}} * \frac{100 * n}{\sum_{a \in A_v} V_{\text{obs}}^a}$$
$$\% \text{ MAE} = \frac{\sum_{a \in A_v} |V_{\text{assign}}^a - V_{\text{obs}}^a|}{\sum_{a \in A_v} V_{\text{obs}}^a} * 100$$

where

$V_{\text{assign}}^a$  = assigned volume on link a

$V_{\text{obs}}^a$  = 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 the replication of observed link volumes. Ideally, values of zero for each of these measures mean perfect replication.

### 6.3.2 Closeness of Estimated Trip Tables to the “True” or “Correct”/“Reasonably Good”/“Surveyed” Tables

The validity of a solution trip table from a synthetic model can be evaluated best 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. There are several reasons why, 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.” In this research, such surveyed tables provided by VDOT were used.

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 ( $f$ ) 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  $f$  are used in the analysis for trip table comparisons. These measures of closeness are defined below:

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

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

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

(Note: The above definition of  $\mathbf{f}$  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 the tables under comparison (modeled) are 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.

## 6.4 Test Cases

The LP and THE models' were tested separately for several cases of availability of link volumes. Because the seed table developed using MINUTP contained all the cell values, this complete trip table with 100% cell values was the only target case used. These tests were carried out for both the 24-hour as well as the peak-hour cases. The model results were judged by measuring how close they were to the surveyed trip table and observed link volumes, both provided by VDOT. 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. Since, the primary objective of this research effort was to enhance the performance of the synthetic models in the absence of any prior trip table information, it was of particular interest to compare the closeness of the output tables obtained through the new methodology to those obtained using a structural target table, the results of which were available through the earlier research effort (supplying a structural table as target is an option in the absence of prior/old table). This shed light on the performance of the models' with respect to the relative quality of the target tables.

As detailed in the earlier chapters, the target/seed trip tables used for the study area were obtained using the socio-economic data in conjunction with travel demand modeling through MINUTP software. These target tables were assumed to be a better representation of the travel pattern for the Pulaski study area. Even though the seed tables were input with 100% cell information, the percentage of link volumes available were varied. The percentages of links with missing volume information were based on the assumption that 100% volume information may generally be unavailable. The study of sensitivity of the models to volume information was also a motivation.

Because of higher computational demands of the LP model for this network, higher power SUN/SPARC server 1000 and 20 machines were used for LP runs. THE runs could, however, be made on an IBM-compatible PC.

## 6.5 Discussion of Model Results

For each of the 24-hour and peak-hour cases, the results have been analyzed and compared for different test cases. The sensitivity of these models to various levels of link volume information was also studied. The sensitivity analysis for LP model in terms of user input parameter sigma ( $\sigma$ ) was also analyzed. A detailed discussion of the model results for various cases is presented below, separately for the 24-hour and peak-hour cases.

### 6.5.1 Daily/24-hour Trip Table

A daily trip table or a 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 (obtained through MINUTP) was used as the target/seed table. The discussions that follow evaluate the



performances of the LP and THE models' for the three cases of available link volumes (75%, 60% and 50%). The models have been judged based on their ability to match the VDOT-surveyed table as closely as possible, as well as their capability to replicate the observed volumes. The discussion of results center around these two criteria for all the cases. The models' performances have also been compared with the structural target case, for which the results were already available through the earlier research.

#### (a) Trip Table Comparisons

Examining the performances of both the LP and THE models through %MAE (Trip Table) (Figure 6-2), %RMSE (Trip Table) (Figure 6-3), and PHI (Trip Table) (Figure 6-4), the following observations can be made:

The LP model with the TG-TD target table (derived through MINUTP) shows a consistently improved performance in terms of the closeness of the output tables to the VDOT-surveyed table, as compared to the structural target table case. Considering Figure 6-2, it is observed that for LP, the % MAE (Trip Table) values are dropping by 53% (198.7 to 145.43) for 50% link volume, 56% (196.09 to 139.62) for 60% link volume and 40% (183.46 to 143.29) for 75% link volume, on using a TG-TD target table (as compared to the structural target case). The performance of THE on using TG-TD target on the other hand is poorer than the structural target case for all the cases of available link volume. Referring to Figure 6-3, again it is noticed that for LP, the %RMSE(Trip Table) values decrease on using a better target/seed table, as compared to the structural target case. THE performance, however, deteriorates. Thus, a trend similar to %MAE is noticed. Examining Figure 6-4 on the PHI statistic, the most noteworthy observation is with regard to the LP model. The provision of the TG-TD table as target significantly reduces the error rates as compared to the structural target case. The percentage decrease in PHI values range from 73% to 77%. Thus, the use of the TG-TD table has proven

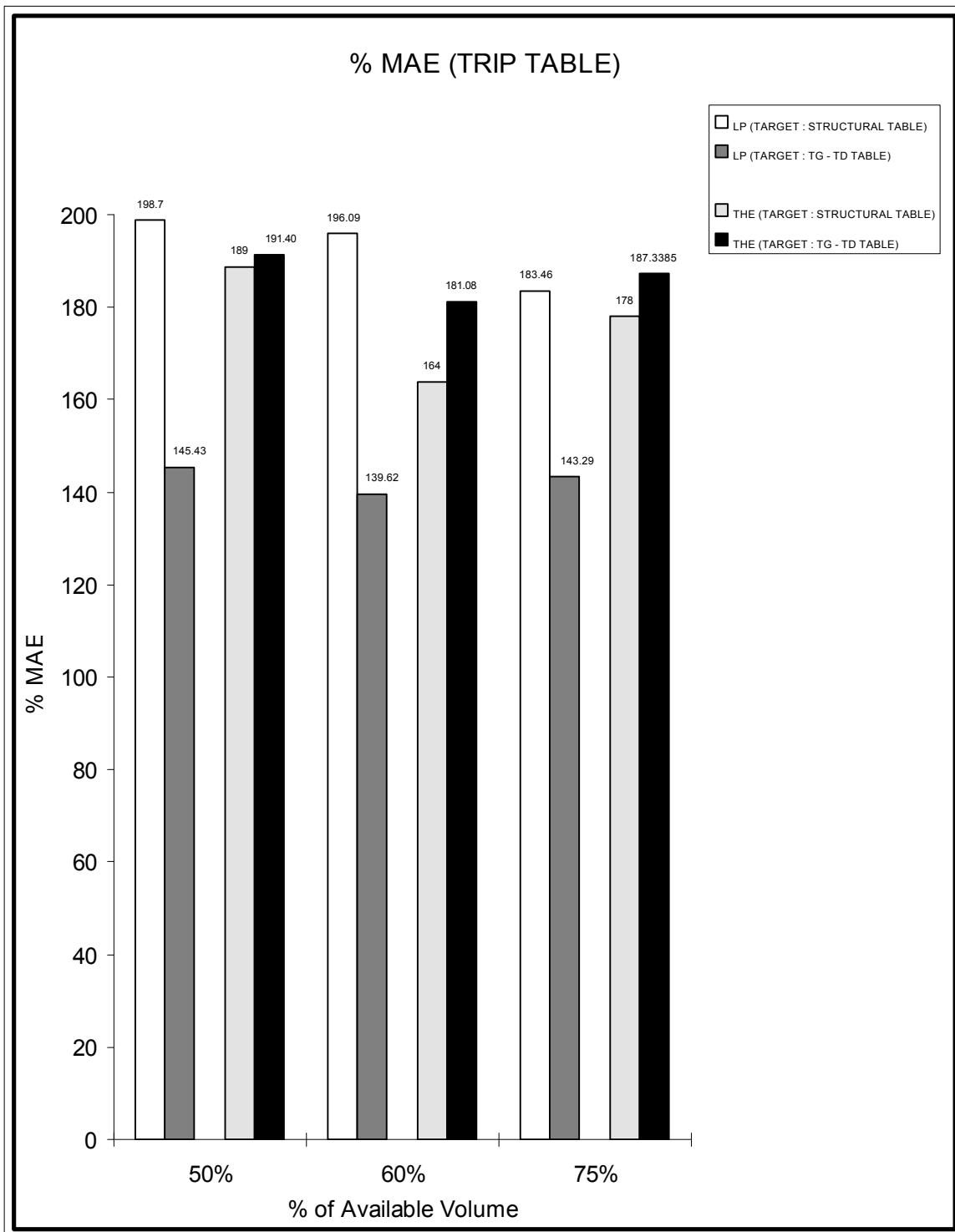


Figure 6-2 Trip Table Comparisons (Modeled vs Surveyed)  
24-Hour Case (% MAE)

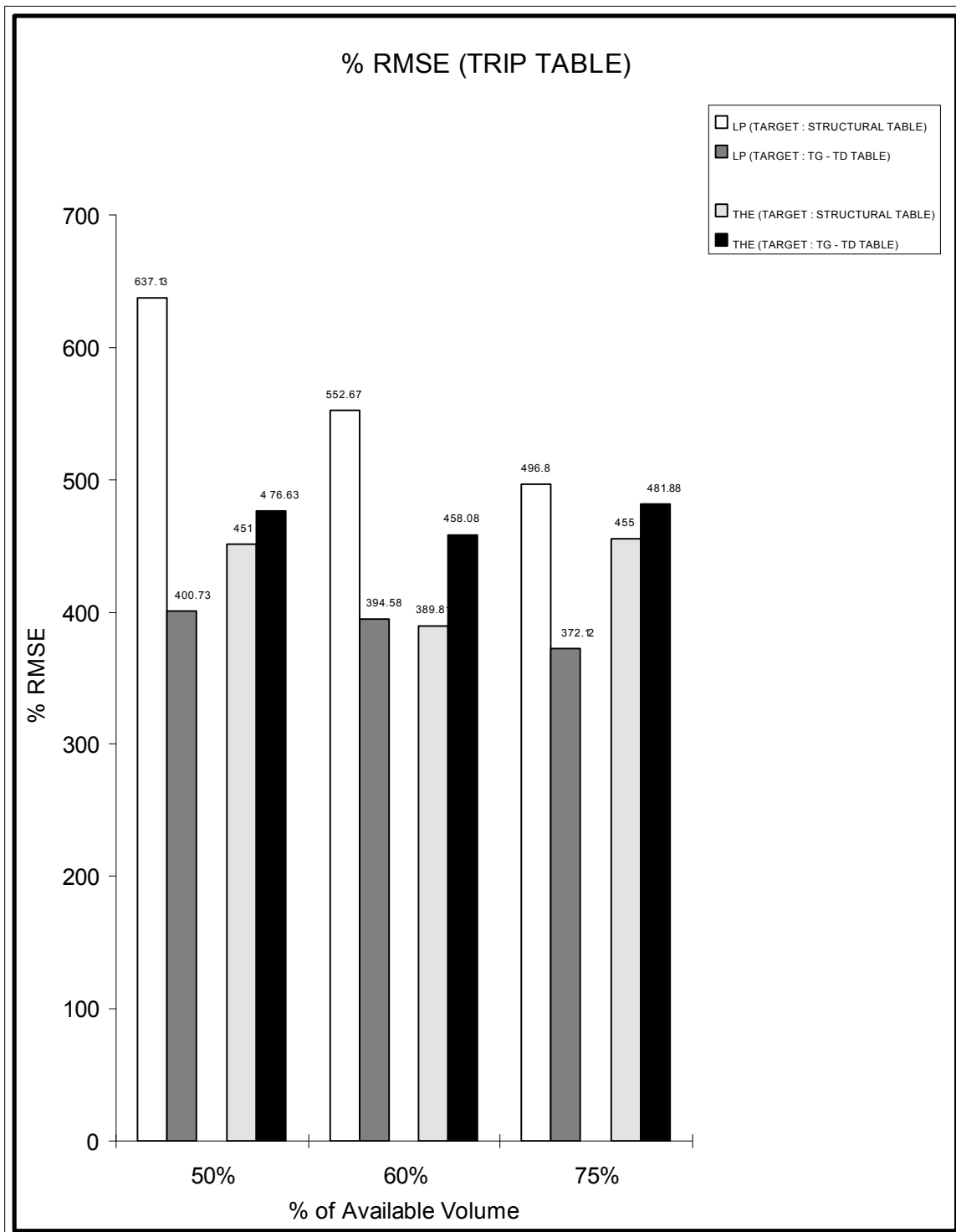


Figure 6-3 Trip Table Comparisons (Modeled vs Surveyed )  
24-Hour Case (% RMSE)

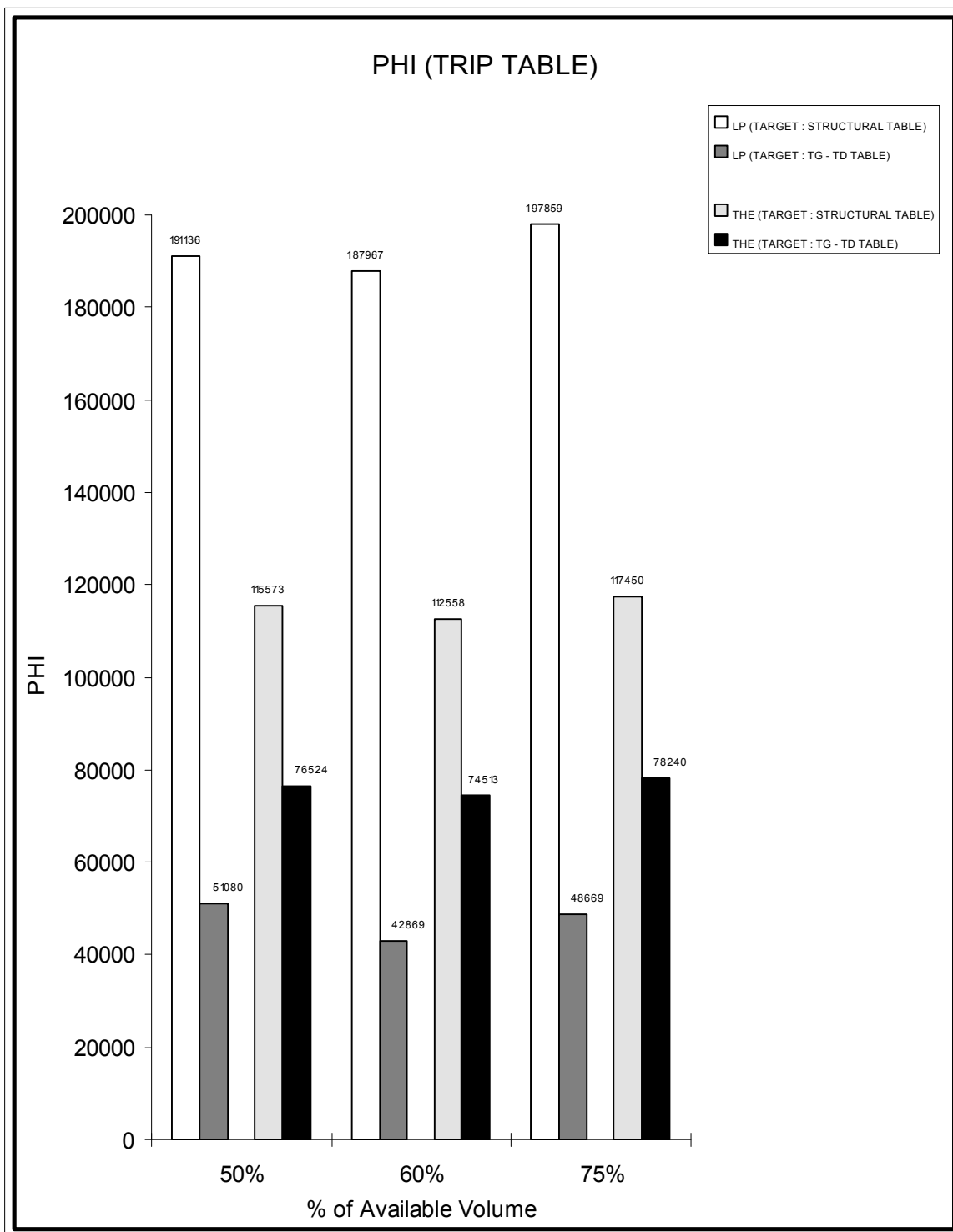


Figure 6-4 Trip Table Comparisons (Modeled vs Surveyed )  
24-Hour Case (PHI)

to be valuable in enhancing the performance of the LP model. Another interesting point here is that the performance of THE with the TG-TD table has improved over that of the structural target case, though not as significantly as LP.

- In general, it can be concluded by observing the three measures of closeness statistics that the LP modeled trip tables are significantly superior to those of THE in terms of their closeness to the VDOT-surveyed table, when the TG-TD table is used as target. This inference is true for each of the three cases of volume availability.
- Observing the values of trip table closeness statistics with respect to variation in available link volumes, although a mixed trend is noted, both for LP and THE results, the variations are only small. This may be due to inconsistencies of the surveyed trip tables. with the observed volumes or to inconsistencies/errors in the observed volumes.

#### (b) Link Volume Comparisons

The ability of the models to replicate the observed volumes is measured by two closeness rates, namely %MAE (Volume) and %RMSE (Volume). These are shown in Figures 6-5 and 6-6, respectively. These charts lead to the following conclusions:

- For the LP model, %MAE increases slightly for two cases of available volumes (50% and 75% available volume) and appreciably for the third case (60% available volume), as compared to the structural target case. This may be attributed to the fact that for the TG-TD target case, greater belief is placed on the target table (as compared to the structural table) through the user specified parameter  $\sigma$ , with the result that the LP compromises slightly on the link volume replication objective to satisfy the trip table deviation objective. THE model results also show a mixed trend, though different from that of LP. However, it must be noted that the %MAE rates, in general are in the lower ranges, thus not causing great concern. The %RMSE trend for both the models is similar to that of %MAE.

- The LP model's ability to replicate volumes is clearly superior to that of THE, as indicated for the different cases of available volumes. For LP, the %MAE (Volume) values range from 4.80 to 4.88, for the different cases of available volume (on using a TG-TD target table), whereas for THE, the values range from 8.92 to 10.32.
- THE model's ability to replicate link volume improves slightly for the 60% and 75% link volume cases, but deteriorates for the 50% volume case (when compared to the structural target case).
- % RMSE (Volume) (Figure 6-6) exhibits general trends similar to those of % MAE. One exception is that for the 50% volume availability case, THE performance (with TG-TD table) is marginally superior to that of LP.
- In general, for both the models, the link volume replication errors are only in the lower ranges, and may not be of major concern.

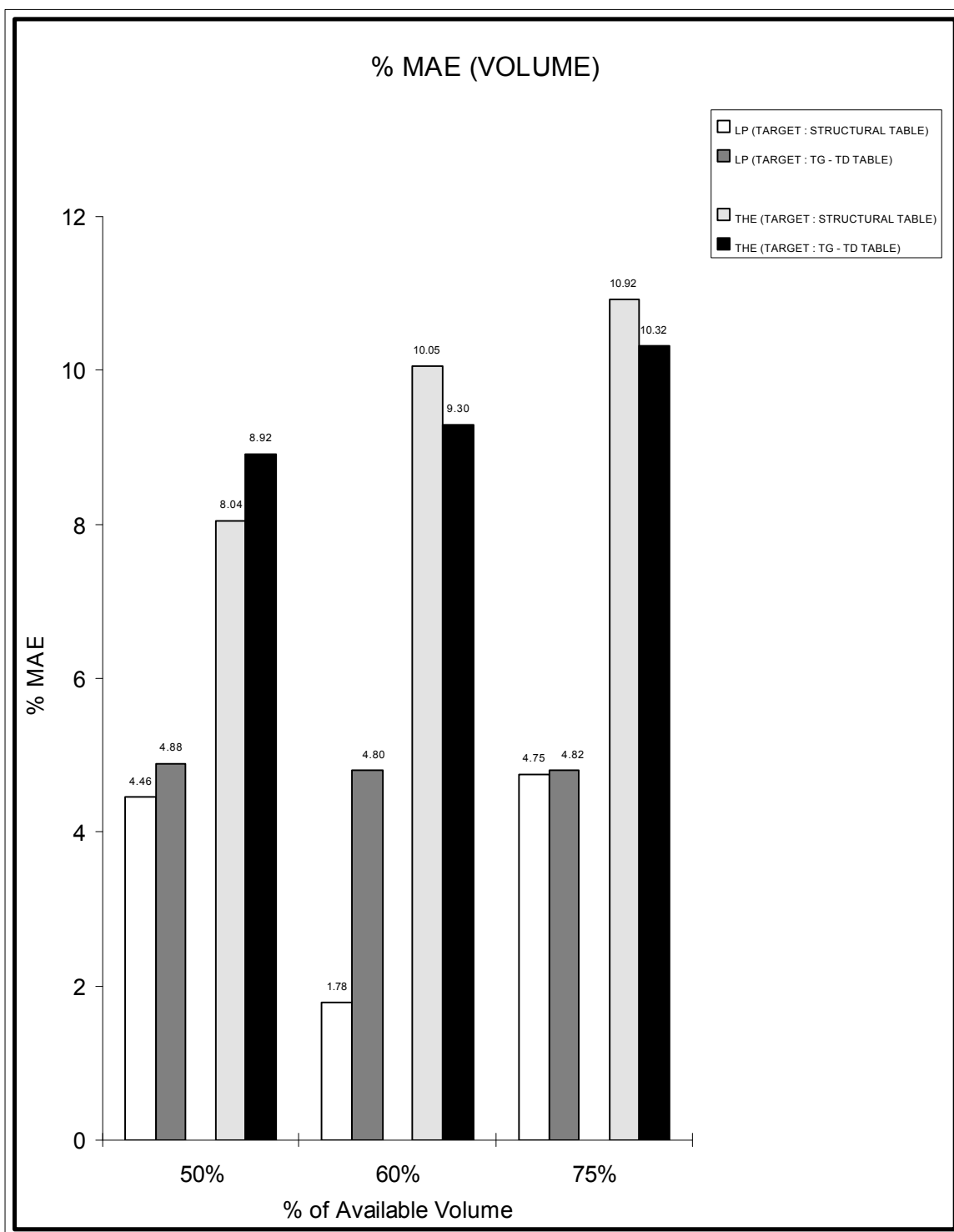


Figure 6-5 Volume Comparisons (Modeled vs Observed)  
24-Hour Case (% MAE)

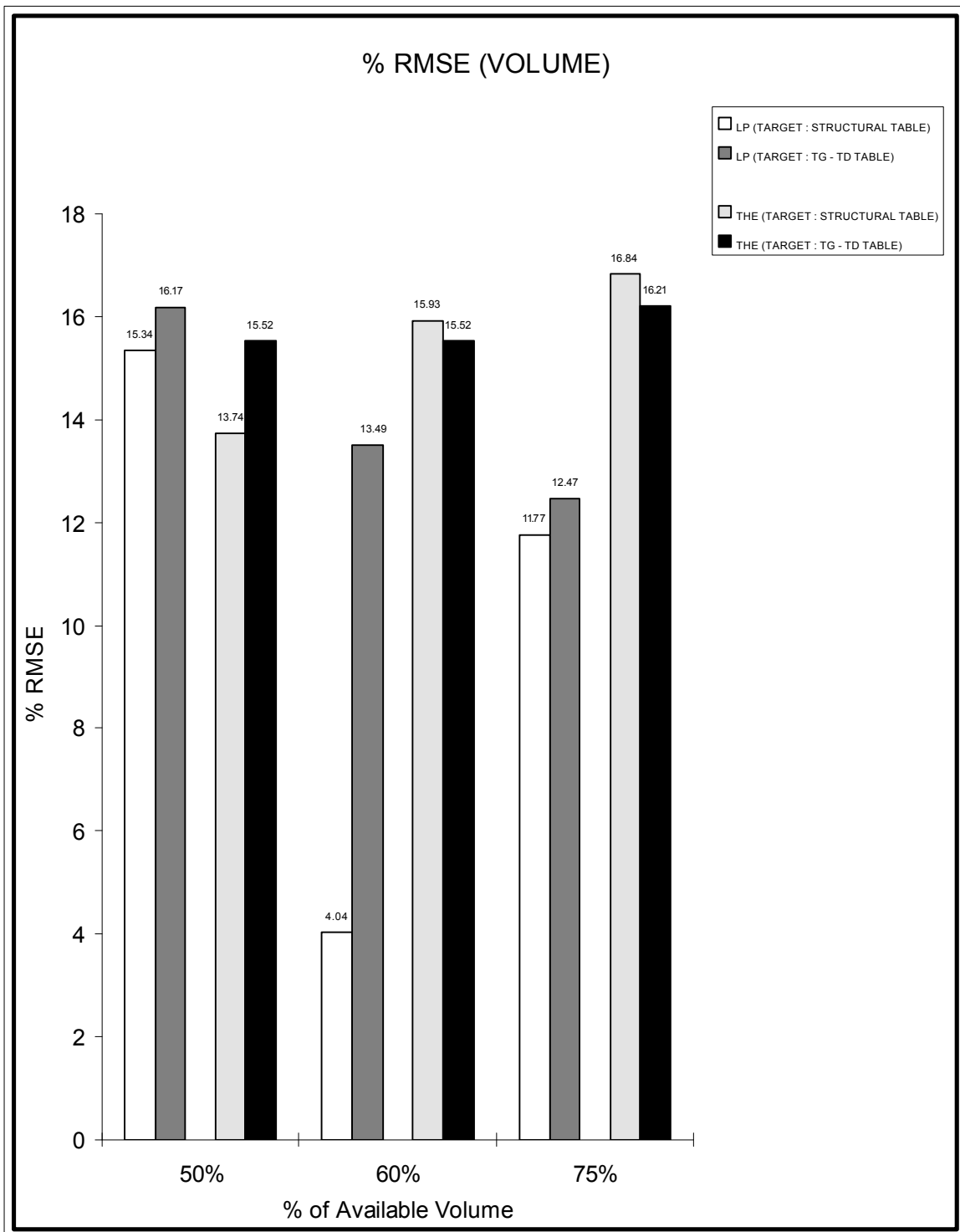


Figure 6-6 Volume Comparisons (Modeled vs Observed)  
24-Hour Case (% RMSE)



## 6.5.2 Peak-Hour Trip Table

A peak-hour trip table is one that shows the O-D travel patterns during the peak-hour. In order to establish such a table using observed volumes, corresponding peak- hour link volumes were used. In addition, a peak-hour trip table was used as the target/seed table. Similar to the 24-hour case, this seed table was derived using the trip generation and trip distribution steps of the travel demand modeling, using MINUTP software. The same criteria as used for the 24-hour case were used for evaluating the models' results for the peak-hour case also.

The comparison charts for % MAE (Trip Table), % RMSE (Trip Table), PHI (Trip Table), % MAE (Volume), and % RMSE (Volume) are shown in Figures 6-7 through 6-11, respectively. Many of the trends in the results are in general similar to the 24-hour case. A brief summary of these results are presented below.

For the TG - TD target cases, the trends were similar to that for the 24-hour case (with some exceptions), for the trip table comparisons. Again, LP showed improvements over the structural target table case with regard to closeness of the output trip table, though these improvements were lesser than those for the 24-hour case. Also, as compared to THE, the closeness rates for LP are lower for all the cases of available link volumes. For the peak-hour case also, the LP modeled results in terms of PHI (Trip Table) statistics show appreciable improvements, as compared to the structural target case. The PHI values are found to decrease by 44% to 49% for the three cases of available link volumes, as compared to the structural table case. For THE, this drop is not significant. LP again proved to be superior to THE in terms of its closeness to the VDOT-surveyed table. The above inferences are endorsed by examining Figures 6-7, 6-8, and 6-9.

In terms of replicating the observed volumes, THE model results (TG-TD target case) are marginally better than LP for the 50% and 60% volume cases, as noticed from the %MAE

(Volume) and %RMSE(Volume) statistics (Figures 6-10 and 6-11), respectively. However, for the 75% volume case, LP yields better results than THE. Again, similar to the 24-hour case, it should be noted that for both the models, these errors are only in the lower ranges.

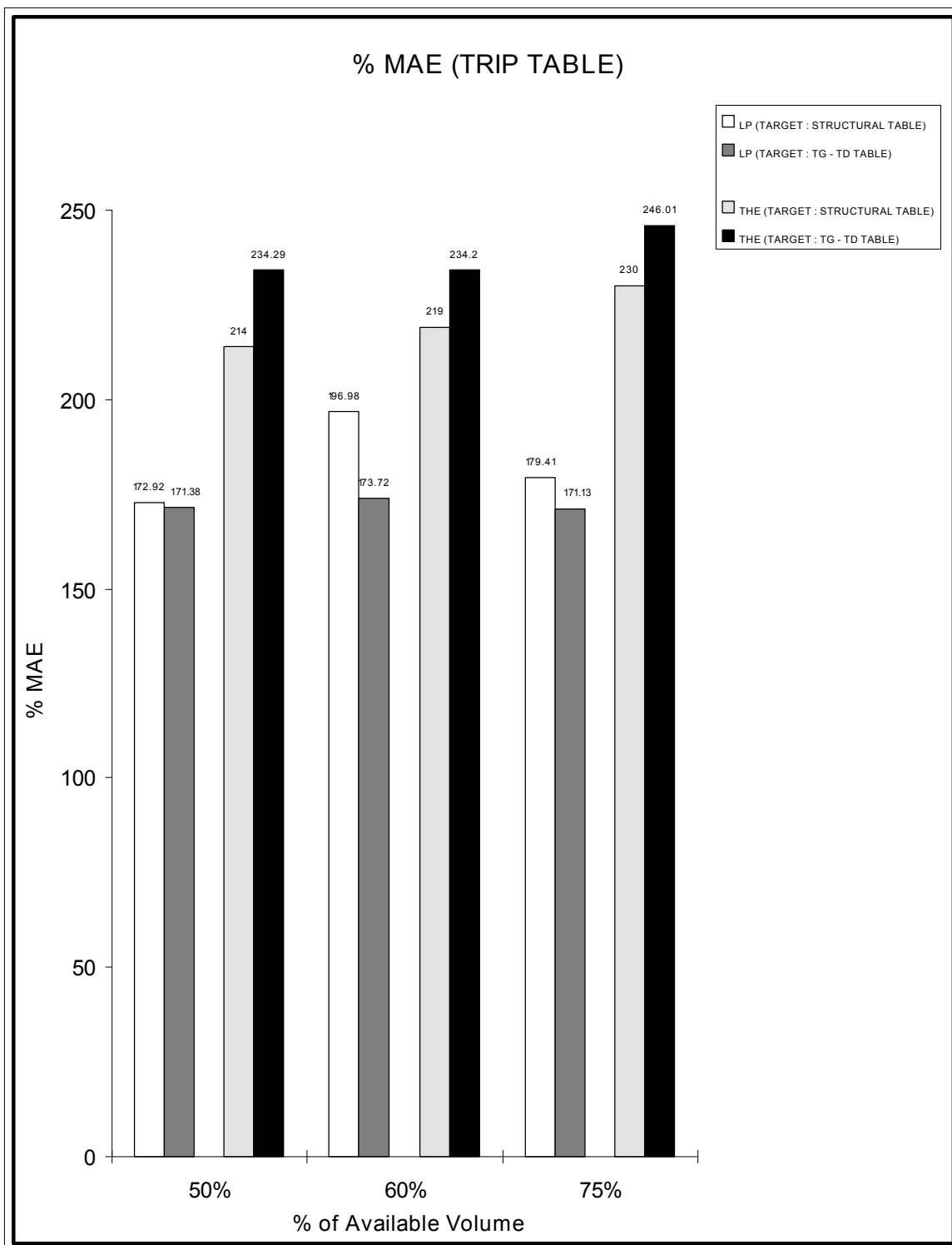


Figure 6-7 Trip Table Comparisons (Modeled vs Surveyed )  
Peak-Hour Case (% MAE)

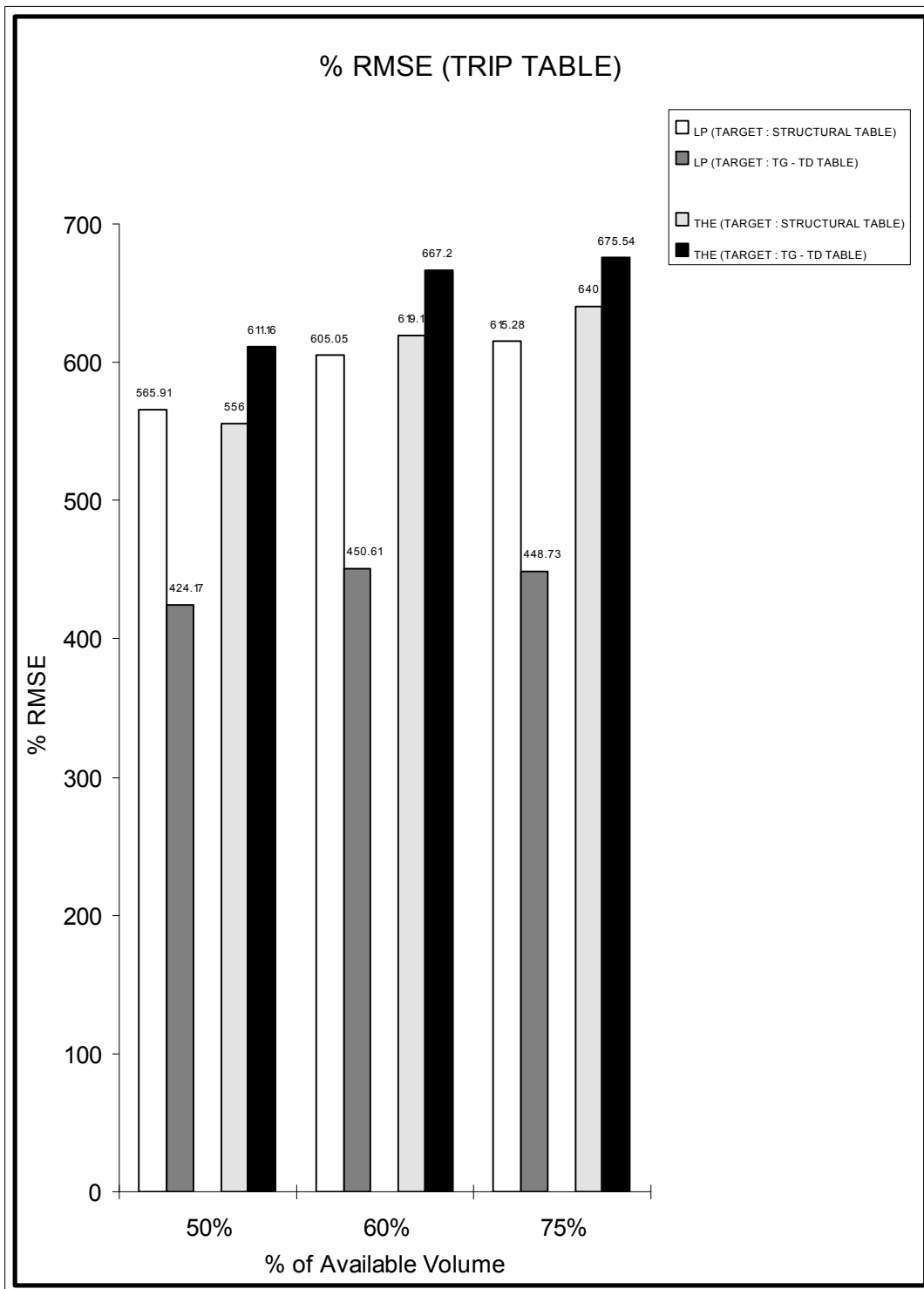


Figure 6-8 Trip Table Comparisons (Modeled vs Surveyed )  
Peak-Hour Case (% RMSE)

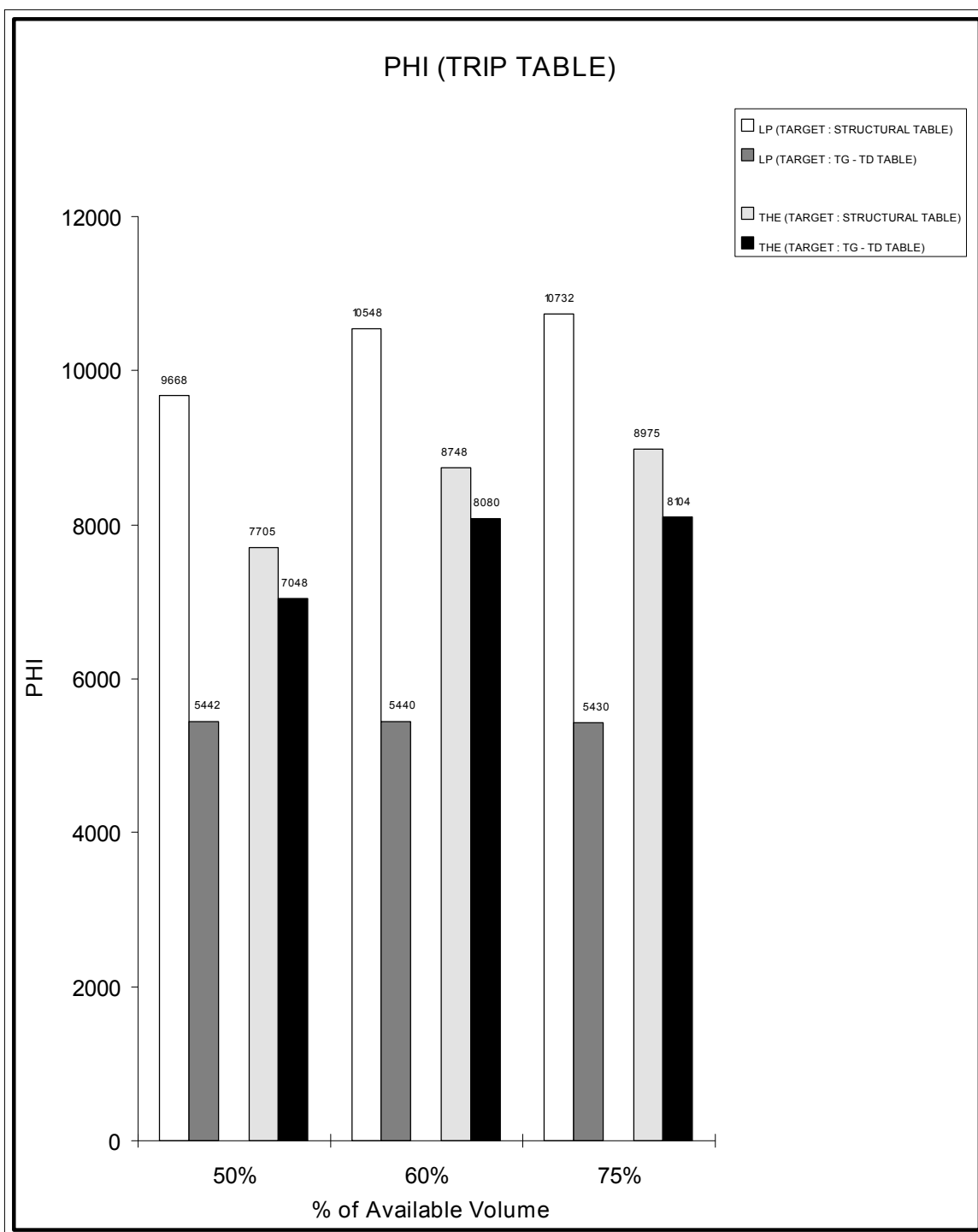


Figure 6-9 Trip Table Comparisons (Modeled vs Surveyed )  
Peak-Hour Case (PHI)

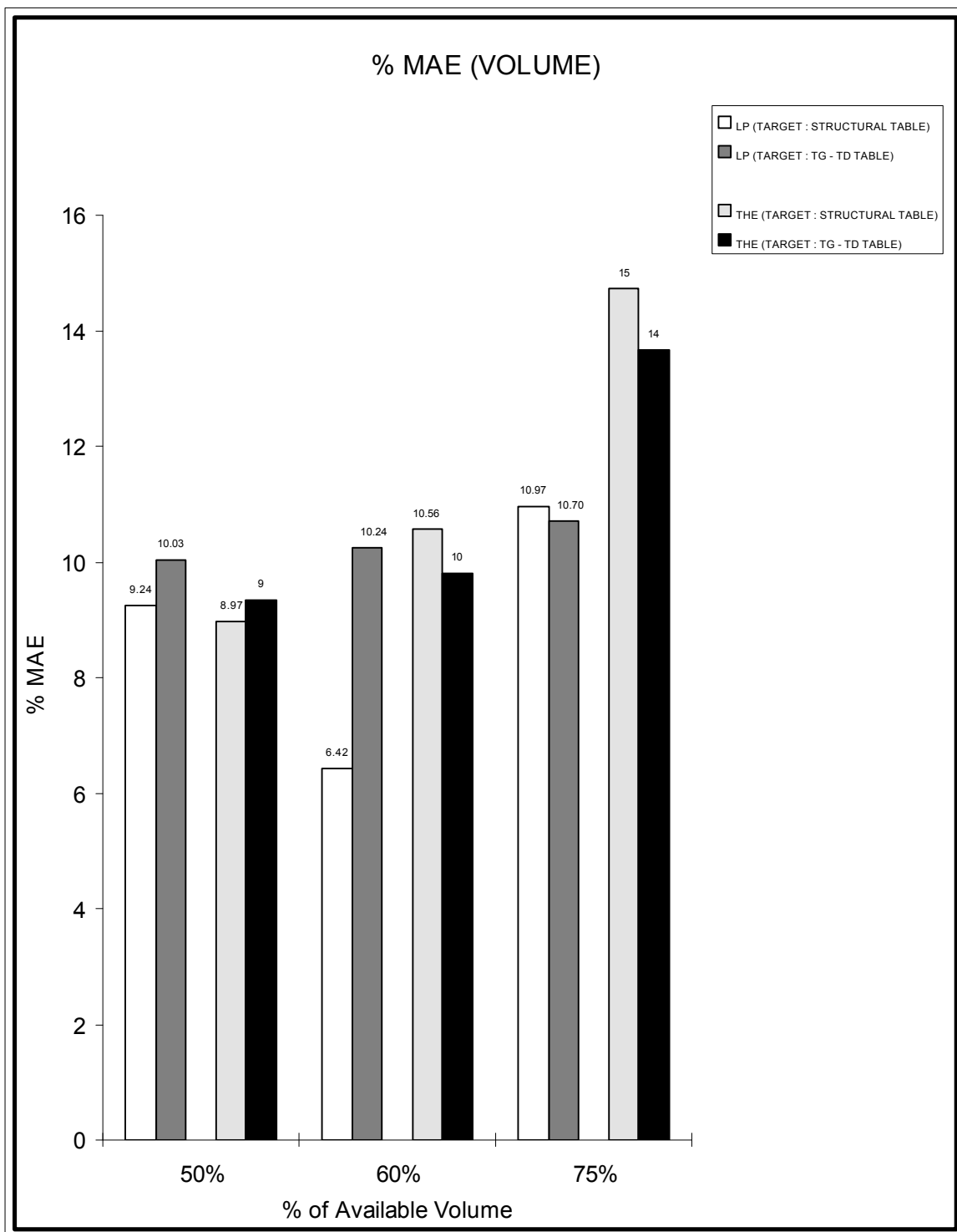


Figure 6-10 Volume Comparisons (Modeled vs Observed)  
Peak-Hour Case (% MAE)

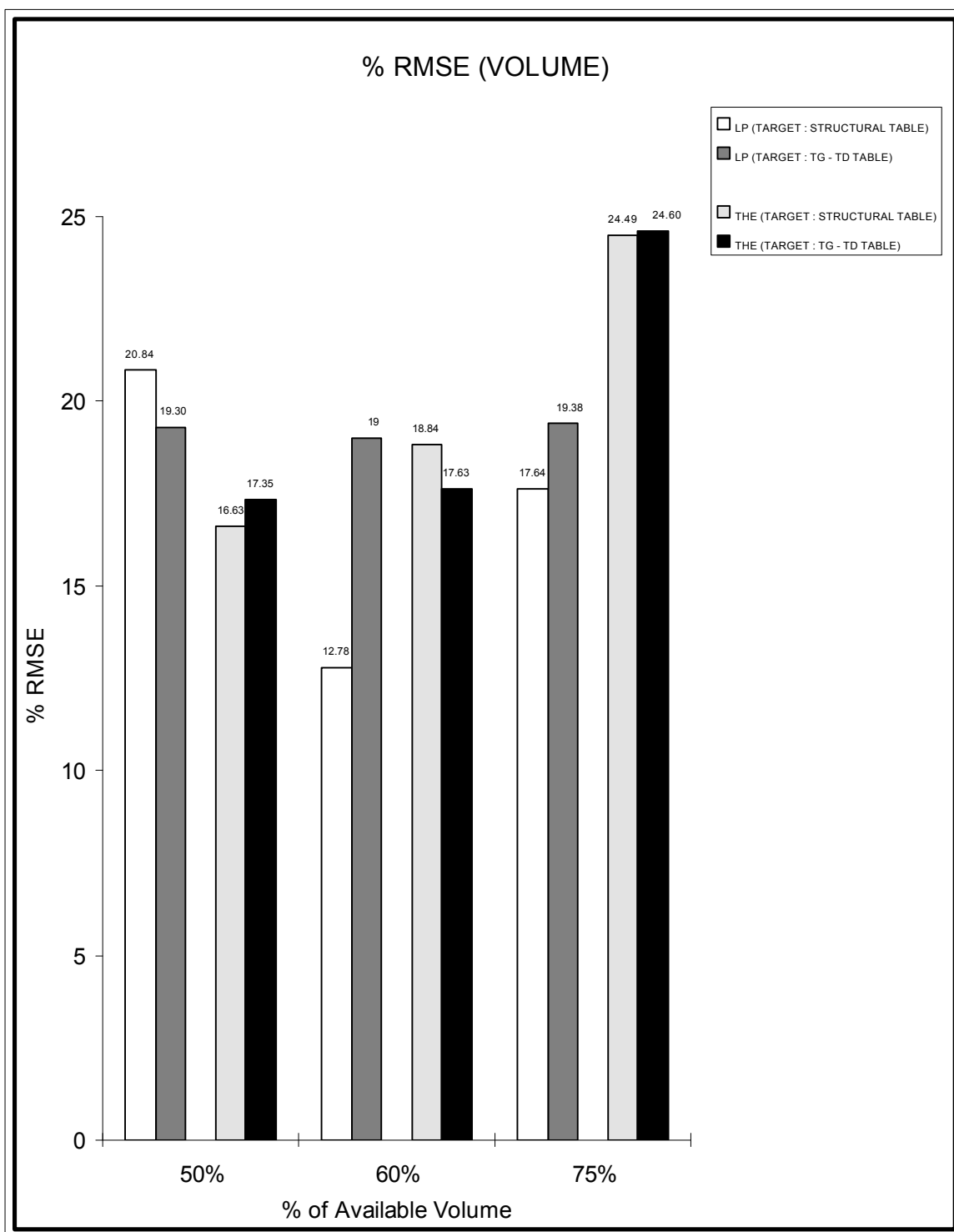


Figure 6-11 Volume Comparisons (Modeled vs Observed)

Peak Hour Case (% RMSE)

## 6.6 Sensitivity of the LP Model to the Sigma ( $\sigma$ ) Value Variations

### 6.6.1 Introduction

The LP model used in this research estimates an O-D trip table utilizing the link volume and prior target/seed table information. Based on the linear programming principle, the model employs a nonproportional-assignment assumption to determine a user equilibrium solution that 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 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 volume data, there might not exist a trip table that can exactly duplicate the link flows. Accordingly these features are accommodated in the LP model through suitable artificial variables and objective penalties. Variations in these penalties can also be used to reflect biases in selecting among alternative viable O-D trip tables. 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 corresponding O-D trip table (Sherali, Sivanandan and Hobeika, 1994a). Accordingly, the objective penalties can suitably be incorporated by the user by specifying a reasonable value for parameter  $\sigma$ . The  $\sigma$  value ranges from 0 to 1, and is based on the relative confidence placed by the user in the target/seed table. The sensitivity analysis of the  $\sigma$  parameter was performed in context of the LP model for Pulaski case study. A brief discussion on the influence of sigma  $\sigma$  value on the LP model is presented below.



## 6.6.2 Significance of $\sigma$ Value in LP Model Runs

The LP model has two objectives : (1) to replicate the observed link volumes, and (2) to match the target/seed trip table as closely as possible. The second objective is achieved by the LP model by penalizing any deviation from target/seed table via a penalty parameter  $M_\sigma \geq 0$ . The value chosen for  $M_\sigma$  guides the relative penalty imposed for deviations from targeted table and observed link volumes. As the parameter  $M$  is used for penalizing the deviations from observed link flows,  $M_\sigma$  has been represented as  $\sigma M$  ( $M_\sigma = \sigma M$ , where  $0 \leq \sigma \leq 1$ ) in the LP model formulation. This helps the user in selecting a value of  $\sigma$  to reflect the relative degree of importance placed in minimizing the trip table deviations versus the link flow deviations. Thus, the LP model can incorporate the user's degree of belief on the target/seed. Accordingly, a low value for  $\sigma$  (say, 0.1) will signify a lesser belief in the input target/seed table, and may result in considerable deviations between the modeled and the target/seed trip table. On the other hand assigning a high value for  $\sigma$  (say, 0.9), signifies greater belief in the target/seed table, and will cause the LP model to extract a trip table that is closer to the target table. The effect of  $\sigma$  value on the model behavior can be tested by again using %MAE, %RMSE and PHI, to determine the closeness of modeled trip tables to the target/seed tables. This sensitivity analysis will provide guidance on the specification of the value of  $\sigma$  by the user, in addition to validating the working of the LP model with respect to the  $\sigma$  parameter.

In this research effort, the investigation of the influence of  $\sigma$  value on the LP model results was performed by using a range of values of  $\sigma$  and running the model. Values of 0.9, 0.8, 0.7 and 0.6 were used both for the 24-hour and peak-hour cases, for different availability of volume information. Again, the TG-TD table was input as target/seed for guiding the output trip table. The effect of  $\sigma$  value was judged based on the closeness of the output trip table to the input target/seed table. This closeness was measured using the PHI values. Referring to Figures 6-12, it is observed that on decreasing the  $\sigma$  values i.e., by placing lesser confidence in the target/seed trip table, the PHI values increases. This trend is as expected, since a higher value

of  $\sigma$  signifies a greater confidence in the target table, resulting in the LP model to yield results closer to this target. This trend is seen to be true for each of the cases of available link volumes. It is observed that  $\sigma$  value of 0.9 results in the lowest PHI (Trip Table) and 0.6 highest among the test cases. Similar general trends are seen for the peak-hour case too (Figure 6-13).

The above sensitivity analysis has helped confirm the functioning of the LP model and the influence of  $\sigma$  on the output tables. It has also provided some guidance to the user on the choice of  $\sigma$  value. Hence higher value of  $\sigma$  is thus recommended when the user has greater belief in the target table and vice-versa.

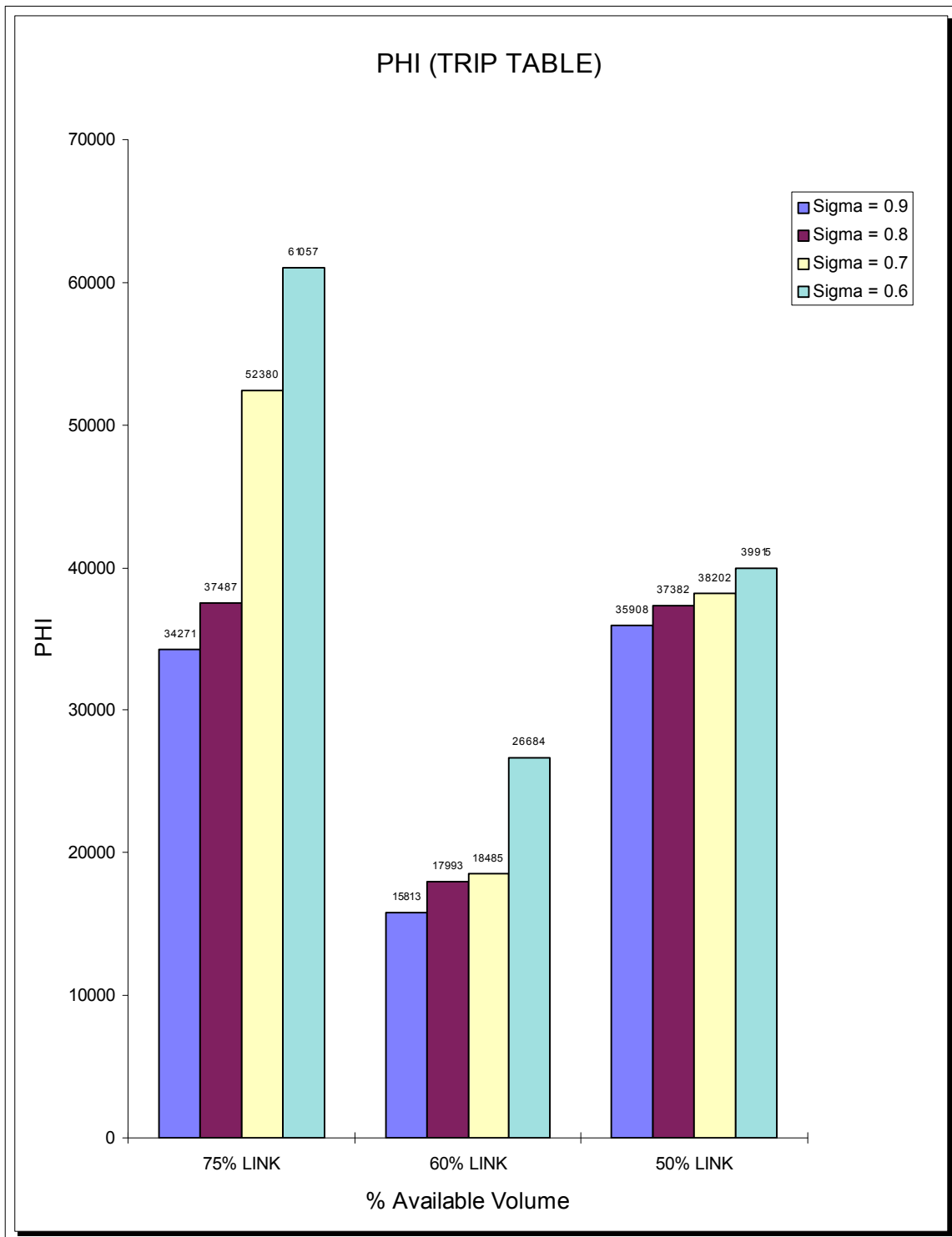


Figure 6-12 Sigma ( $\sigma$ ) Value Variations for  
24-Hour Case (PHI)

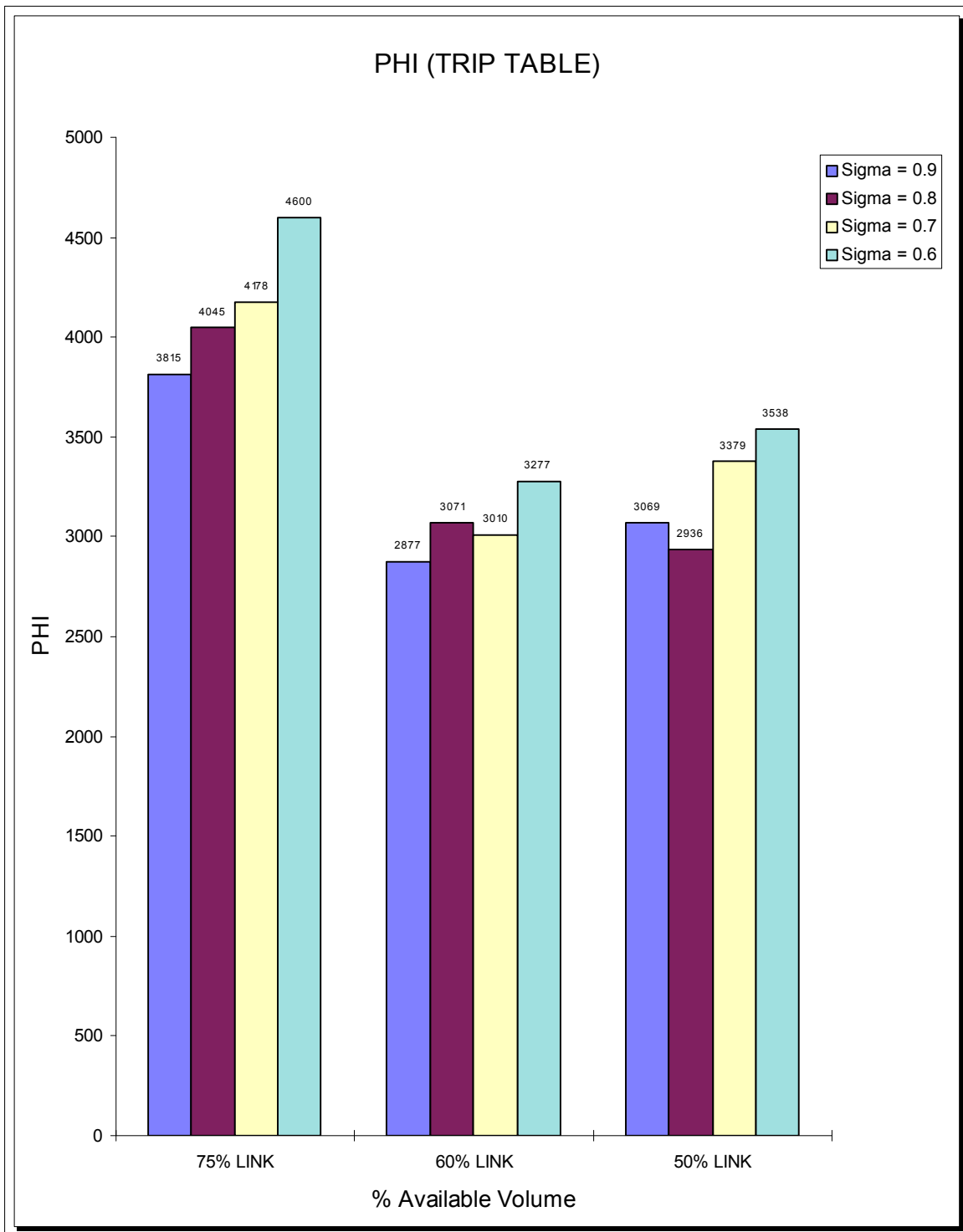


Figure 6-13 Sigma ( $\sigma$ ) Value Variations for LP  
Peak-Hour Case (PHI)