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Bayesian updating of simulated household travel survey data for small/medium metropolitan areas

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BAYESIAN UPDATING OF SIMULATED HOUSEHOLD TRAVEL SURVEY DATA FOR SMALL/MEDIUM METROPOLITAN AREAS

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This work is dedicated to my husband and my parents

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ABSTRACT

This thesis tests an approach for generating simulated travel survey data that has local characteristics incorporated in it. Travel survey data are generally required for estimating and calibrating travel demand models for a region. The high cost associated with travel surveys puts them beyond the budget of most small/medium MPOs. Therefore simulation of travel survey data provides a viable alternative for these data starved regions to generate data. The simulated data is produced by combining socio-demographic data along with a national survey data set. Updating the simulated data distributions with the distributions obtained by surveying a small sample of local households, adds a local element to the simulated data set. The updating procedure using a small local sample of households is tested for two regions, which had previously conducted household travel surveys. The local sample was drawn from the travel survey and results obtained after updating were compared to those from the travel surveys in order to assess the performance of updating. Comparisons of trip attributes (trip rates, mode shares, departure times and trip lengths) in the two study areas show the updating has succeeded in bringing the updated values closer to the survey values in the majority of cases. The anomalies, which were seen in a few cases, were attributed to the lack of representativeness of the local sample, the inability of the simulation to capture all variations and the contextual differences between the regions. The concept of updating a simulated travel data set using local sample distributions in order to generate an updated simulated travel data set is explained here. While updating in general was found to move the updated trip attributes in the correct direction and towards the survey values, further testing such as comparing the population values estimated from the survey data and the

updated simulated data need to be carried out in order to generate conclusive evidence on the benefit of updating. The main beneficiaries of this method are small/medium metropolitan areas who can use this method to produce synthetic travel data for running their travel demand models at a much lower expense.

1 INTRODUCTION

Household travel surveys are the primary means of providing data for travel behavior research and travel demand modeling. These surveys provide information that describes travel trends, which, in addition to helping us understand the performance of the existing transportation system, also help in identifying problem areas (Stopher, 1995). The information gathered by the surveys will enable transportation planners to improve travel-forecasting methods. In the early sixties and seventies, transportation surveys were largely concerned with acquiring large databases of travel patterns and traffic flows in the simplest way possible. This however changed during the latter half of the seventies, when more sophisticated survey procedures were developed. The data obtained from travel surveys have been used in all modeling aspects but especially for calibrating and estimating travel demand models.

Household travel surveys therefore form a very important part of the data collection process. However these surveys are besieged with problems such as rising costs and high levels of non-response. A sample size of 2,000-3,000 households is needed for model estimation and calibration (Cambridge Systematic Inc., 1996). The cost of surveying a completed household ranges from $175-$200 (Cambridge Systematic Inc., 1996). Therefore, costs in the range of $350,000- $600,000 have to be incurred in order to conduct a travel survey. Most small and medium MPOs do not have the budget to conduct a travel survey. Apart from cost, there are other problems with conducting high quality household travel surveys. The foremost among them is the problem of non-response. Response rates are used as an indicator of the overall quality of the survey (Zimowski et al., 1997). A scan of recent travel surveys shows response rates ranging from 26% - 40%. Low response rates introduce bias into the survey estimates and affect the level of confidence that can be placed in the estimates.

Survey methods have undergone many changes recently. In the United States, conventional survey methods initially relied on face-to-face interviews for collecting data. Rising costs and personal safety issues led to the emergence of telephone and mail based surveys. Computer Assisted Telephone Interviewing (CATI) is the most popular method used today to collect travel data (NCHRP Research Results Digest, 2002). The advantage of CATI and other telephone and mail based surveys is the lack of face-to-face contact with the respondents. However, response rates are significantly lower for surveys that do not involve direct contact with the respondent.

The changing face of American Society has adversely affected household travel surveys. In recent years, there has been an influx of immigrants from Non-English speaking countries. This has contributed to a drop in response rates. The average American lifestyle has also undergone changes. Rising levels of employment due to the increased participation of women in the labor force have made it harder to locate a respondent at home, in order to administer a survey. The increasing use of caller identification systems to screen calls has also had an impact on survey response rates (Stopher et al; 2001).

Given the nature of problems associated with travel surveys, all MPOs will face the problems of lack of data in the future. The problems with data will adversely affect modeling efforts. Therefore there is a compelling need to explore other avenues for generating data. The prospect of using simulated data for model estimation and calibration has been outlined earlier (Greaves and Stopher, 2000; Greaves, 2000).

Greaves, in his research work, outlined a method for simulating household travel survey data for Baton Rouge, Louisiana. By comparing the simulated data to the household travel survey data from Baton Rouge, Greaves proved that generating simulated data was a superior approach compared to borrowing models and using national averages. Another research paper (Stopher et al; 2001) applied this procedure to two regions, Dallas-Fort Worth and Salt Lake. While this research demonstrated that the procedure of simulating household data worked very well for Dallas-Fort Worth and Salt Lake, it produced statistics, which did not represent the local conditions very accurately. One of the recommendations was that updating the simulated data using a local sample was a concept worth pursuing.

In this research, the earlier work in Dallas-Fort Worth and Salt Lake is extended by performing updating of simulation data and re-simulating it for these regions. This research work outlines the idea of updating and provides a methodology for performing the updating. The research presented here shows that this method, if used in conjunction with the earlier methods that have been outlined for simulating a data set, produces a data set that has local characteristics incorporated in it. This data set can be used by MPOs in the absence of travel survey data to estimate their models and generate regional travel characteristics.

This thesis is divided into five sections. Section 1 (this section) – Introduction – deals with the background for the necessity of travel data and provides a solution for generating synthetic travel data, which is representative of local conditions. Section 2 - Literature Review – briefly recaptures the prior work done in the area of generating simulated data and updating models. Section 3 – Methodology – describes the procedure for updating.

Section 4 - Results and Analysis – outlines the results obtained by performing the updating procedure and compares them with the results obtained without updating.

Section 5 - Conclusions and Recommendations – presents the conclusions arrived at by the author and outlines areas for further work.

2 LITERATURE REVIEW

Travel demand models are data hungry. The data for these models are usually obtained by conducting household travel surveys and collecting information about individual travel patterns. The problems associated with travel surveys and the need for local data are the driving force behind the exploration of other possibilities for generating data for these models. Most regions that do not have the ability to conduct a travel survey, must borrow models that have been previously estimated for other regions and adjust the parameters until the model reflects the local conditions accurately. The model parameters are updated using local data. A review of model updating procedures is presented below.

2.1 Model Updating

Atherton and Ben-Akiva applied Bayes' theorem for updating model parameters with local parameter estimates to obtain an updated set of parameters (Atherton and Ben-Akiva, 1976). A work trip mode choice model calibrated for Washington D.C. (1968) was updated to reflect the conditions of New Bedford, Massachusetts (1963) and Los Angeles (1967). Bayesian updating, however, does not take into account the transfer bias, which occurs due to differences between model parameters in the estimation and application contexts.

Transfer Scaling accounts for transfer bias by adjusting model constants and scales (Badoe and Miller, 1995). Transfer Scaling assumes that parameter estimates are obtained from the estimation context data and are independent of the application context data. The application data are used for application context constants and scales (Badoe and Miller, 1995). Gunn et al. (1985) applied the transfer scaling schemes successfully to a set of four models in The Netherlands. Koppelman et al., (1985) applied the transfer scaling procedures to transfer models intraregionally within the Washington D.C area as well to interregional transfers among the metropolitan areas of Washington D.C., Baltimore and Minneapolis-St. Paul.

The Combined Transfer Estimator is an extension of the Bayesian process that accounts for the transfer bias (Ben-Akiva and Morikawa, 1987). This method of updating is best used if the magnitude of transfer bias is small or negligible. The combined transfer estimator reduces to the Bayesian estimator when there is no transfer bias. Joint Context Estimation estimates the parameters using both application and estimation data sets. The advantages of this updating procedure over the conventional transfer scaling procedures are that biases caused by the estimation context within the application context are eliminated, because the application data are also used for estimation (Badoe and Miller, 1995).

Four methods of updating disaggregate travel choice models were compared (Badoe and Miller, 1995) and it was concluded that the combined transfer estimation procedure yielded the best results. The joint context estimation yielded results, which were comparable to the results obtained from the combined transfer procedure. However, joint context estimation has large computational requirements. Badoe and Miller (1995) also conclude that if the application context sample size exceeds 400-500 observations, then updating is not a preferred option over model estimation. For small sample sizes (i.e., under 1,000) all four updating procedures performed well.

2.2 Data Updating

While model transfer has been popular, little work has been done on the topic of data transferability and updating. Most regions believe that they are unique and, as a result, there is resistance to borrowed data. A literature review for data transferability yields very few reviews. In a research study (Wilmot and Stopher, 2001), a sample of 108 households sampled from the Baton Rouge Personal Transportation Survey (BRPTS) was used to update trip rates, mode shares, and trip lengths that were obtained from the Nationwide Personal Transportation Survey (NPTS), which was conducted in 1995. Bayesian method was used for the process of updating. Wilmot and Stopher found that while updating is possible, the weights used for Bayesian updating play an important role. They also found that a small sample size led to a substantially lower weight in the updating process as the Bayesian method uses the inverse of variance as weight.

2.3 Simulation

Another way to obtain travel data for a region is by means of simulation. In his research, Greaves outlined and tested a concept for generating a simulated travel survey data set (Greaves, 2000; Greaves and Stopher, 2000). The main principle behind the creation of the simulated data set was the notion that there was a relationship between regional sociodemographic characteristics and observed travel behavior. The objective of the simulation was to predict trip rates, mode shares, departure times and trip lengths for a study area. These formed the dependent variables and the Classification and Regression Tree (C&RT) method was used to develop homogenous groups of the data with respect of each of the dependent variables. Within each of the respective categories, the dependent variables (trip rates, mode shares, departure times and trip lengths) were found to display some variation. In order to simulate the values of these variables accurately, it was deemed necessary to capture this variation in some way. Therefore, discrete frequency distributions of the values of the dependent variables were created. This was achieved by noting the occurrence of the values of the dependent variables within each category developed. These frequency distributions were then reconstructed as cumulative frequency distributions based on 100,000 observations.

For developing the simulation, the 1995 Nationwide Personal Transportation Survey (NPTS) provided the input for the simulated travel data. This survey was conducted between May 1995 and July 1996. The population surveyed was all people five years and older; people living in group quarters were excluded. Households were selected as the unit of analysis for simulating trip purpose, travel mode, departure time and trip length. The Public Use Microdata Sample from the 1990 Decennial Census (PUMS90) was used to generate the synthetic sample for the simulation. The PUMS90 data set is derived from the census long form, which is administered to about one in twelve households. The household and person records in the PUMS90 data set that had PUMAs (Public Use Microdata Areas) corresponding to Baton Rouge were extracted. A random sample of households was drawn from the PUMS90 sample for each cell in the sampling scheme such that the cell totals matched those of the Baton Rouge Personal Transportation Survey (BRPTS). Since each household was required to have an equal probability of selection, the PUMS90 data was expanded to the population using the weights present for each household. The sample obtained from the PUMS90 was divided into the same categories that were used to construct the frequency distributions for each dependent variable. A random number generator was used to produce a random number, which fell within a probability range and thus indicated the value of the particular attribute being simulated.

This process was repeated for each attribute, until a simulated travel data set was created. In order to validate this procedure, Greaves reproduced trip rates, mode shares, departure times, and trip lengths using the PUMS90 sample for Baton Rouge, Louisiana and the NPTS distributions. The results obtained from the simulation were compared to the results obtained from a real survey conducted in Baton Rouge. The BRPTS, which was conducted in 1997 as an add-on to the NPTS from April to June 1997 and administered by the same group (Research Triangle Institute), using identical forms and procedures to the NPTS, provided statistics for comparison. The advantage of using the BRPTS was that the results of the simulation could be compared directly to the BRPTS because the same survey methodologies were employed. However, subsequent work did not have the benefit of the similarity in methodologies. Greaves concluded that a synthetic travel data set produced using the simulation approach generated data that were comparable to the data generated by conducting an actual survey. However, updating of the synthetic data was found to be critical in generating a data set that will reflect the local characteristics accurately.

By using the simulation approach to generate a simulated data set and updating it using a local sample, a simulated travel data set will be produced that will take more into account the characteristics of the local region. Because prior information, in the form of a simulated data set and local sample information, is available, these can be combined with the help of Bayesian methods. The procedure for generating a simulated travel survey data set, and updating it with a local sample to yield an updated simulated travel data set is explained in the following chapter.

3 METHODOLOGY

In order to perform Bayesian updating using a local sample and generating a simulated travel survey data set, the distributions, which drive the simulation, need to be updated. A simulated travel survey data set without updating also needs to be generated. The procedure for generating synthetic travel data sets without updating for Dallas–Fort Worth and Salt Lake is touched upon here. Also presented in this section, is the procedure to conduct Bayesian updating.

3.1 Simulation Without Updating

The simulations for the Dallas-Fort Worth and Salt Lake regions were performed using the simulation approach developed by Greaves (2000). The simulation for these two regions has been described in detail in another research work (Stopher et al., 2001). However, in order to get a clear perspective of the updating performed, it is necessary to outline briefly, the simulation procedure and the characteristics of these two areas.

3.1.1 Dallas-Fort Worth

The Dallas Fort-Worth region, whose MPO is the North Central Texas Council of Governments (NCTCOG), is a nine county region, encompassing the counties of Dallas, Denton, Collin, Tarrant, Ellis, Parker, Kaufman, Johnson and Rockwall. A travel survey was conducted in this region in 1996 and 3,996 households were surveyed. While the survey conducted in Dallas-Fort Worth collected information from all members in the household irrespective of age, the 1995 NPTS collected information from those household members who were above five years of age. The survey conducted in Dallas-Fort Worth employed an activity-based travel diary whereas the NPTS employed a trip-based diary. The population in the region at the time of administration of the survey was 4,384,327. The summary statistics for Dallas-Fort Worth and the NPTS are shown in Table 1. Dallas-Fort Worth shows a higher percentage of single-family dwellings than the NPTS. Also, non-car owning households are fewer and average vehicles, average workers per household and the percentage of home owners are higher than the NPTS. All other statistics were comparable to the NPTS.

Table 1: Summary Statistics from NPTS and Dallas-Fort Worth

Statistic	1995 NPTS	Dallas-Fort Worth
Average Age	35	35
Average Household Size	2.63	2.47
Percent in Single Family Dwellings	74%	78%
Percent from Non-Car-Owning Households	8%	5%
Average Vehicles per Household	1.73	1.84
Percent Females in Sample	51%	52%
Percent Home Owners	64%	68%
Average Workers per Household	1.33	1.40

3.1.2 Salt Lake

The Salt Lake region, comprising Salt Lake City, Provo and Orem, fall under the jurisdiction of the Wasatch Front and Mountainland Associations of Governments. A travel survey was conducted in the region in 1993, wherein 3,082 households were surveyed. Travel information was collected from all household members who were five years or older, using an activity-based diary. The population in 1993 in this region was 796,487. The summary statistics for Salt Lake as observed from the travel survey are shown in Table 2. Average household size in Salt Lake was observed to be much higher than the NPTS. Salt Lake has fewer non-car owning households and higher average vehicles per household. The percentage of homeowners in Salt Lake is considerably higher than the NPTS. All the other statistics matched those of the NPTS very well.

Table 2: Summary Statistics from NPTS and Salt Lake

Statistic	1995 NPTS	Salt Lake
Average Age	35	34
Average Household Size	2.63	3.14
Percent in Single Family Dwellings	74%	73%
Percent from Non-Car-Owning Households	8%	4%
Average Vehicles per Household	1.73	1.97
Percent Females in Sample	51%	53%
Percent Home Owners	64%	76%
Average Workers per Household	1.33	1.31

The PUMS90 person and household records which provided the source for the sociodemographic data for the simulation for the Dallas-Fort Worth and Salt Lake areas were extracted based on the PUMAs, such that they covered approximately the same area as the household travel survey. Group quarters were removed and many variables were recoded. A full description of the changes made to the PUMS files has been provided in the prior research work (Stopher et al., 2001). The household travel survey files also posed a number of problems and had to undergo extensive cleaning in order to make use of them. These changes have been documented in an earlier paper (Stopher et al., 2001).

A simulation sample was drawn from the PUMS records for Dallas-Fort Worth and Salt Lake, incorporating the same sampling scheme as used in the original survey. The household travel survey in Dallas employed a sampling scheme in which the sample was stratified by county, household size and vehicles. The household survey in Salt Lake had a sampling scheme that employed stratification of households by MPO area, household size and vehicles. The synthetic sample drawn from PUMS ensures that the sampling matrix employed in the survey is reproduced. Using this synthetic sample, and the distributions developed in prior research work (Greaves, 2000), simulated travel survey data sets were obtained for each of Dallas-Fort Worth and Salt Lake.

The resulting trip rates for Dallas-Fort Worth obtained from the simulation are found to be significantly different from the survey trip rates at the 99% confidence level (Stopher et al., 2001). In Dallas-Fort Worth there were about 278 households in the survey data that were non-mobile. However, the simulation predicted less than 100 households. The differences arose due to the varying survey methodologies that were employed that resulted in lower non mobility rates for the NPTS than the Dallas-Fort Worth survey. This difference in non-mobility rates was found to have an impact on the trip rates. Mode shares were overestimated in some categories, while in other categories they were underestimated (Stopher et al., 2001). Departure times were significantly different from the departure times in the survey especially in home-other and other-other categories (Stopher et al., 2001).

The resulting trip rates for Salt Lake obtained from the simulation were significantly different from the survey trip rates in home-work, home-shop, home-other and non home-other categories at the 95% confidence level (Stopher et al., 2001). The mode shares obtained from the simulation were significantly different in most of the categories from those in the survey. Departure time comparisons showed significant differences in home-school and home-college categories (Stopher et al., 2001). The resulting outputs from the simulations from Dallas-Fort Worth and Salt Lake are presented in the following chapter.

It is evident from the prior research work on simulating a travel survey data set for Dallas-Fort Worth and Salt Lake (Stopher et al., 2001), that significant differences exist between the survey values and the results produced after simulation, in some areas. This is not surprising because the distributions used for the simulation were derived from the 1995 NPTS, which is a data set consisting of households surveyed from across the nation.

In order to capture the characteristics of Dallas-Fort Worth and Salt Lake accurately, there is a strong need to incorporate local data into the simulation, so that the simulation will be able to capture local differences from the national data. The procedure for carrying out Bayesian updating using a small local sample of households is presented in the following section.

3.2 Updating

Updating refers to the combination of existing and new data to generate updated parameters. Earlier research showed that the transferability of travel demand models was greatly improved if travel data from a small sample of households in the region was available for updating. Models have been updated in the past but data updating is a relatively new concept. This section deals with updating distributions and using the simulation procedure (Greaves, 2000) for Dallas-Fort Worth and Salt Lake to generate updated trip rates, mode shares, departure times and trip lengths.

Bayesian updating has been used in the past to update models (Atherton and Ben-Akiva, 1976). Model parameters estimated on one sample are assumed to belong to the same population as parameters obtained from a similarly specified model, which have been estimated on another sample (Wilmot and Stopher, 2000). While Bayesian updating has been used to update model parameters, it can also be used to update data. It provides a means of combining data from two sources, to produce updated data that shows the influence of both. It is very useful when the local data are outdated or the size of the local sample is too small to produce reliable estimates. However, Bayesian updating requires that the data being combined from various sources should have the same underlying distribution.

One form of Bayesian updating involves the use of conjugate priors. When a conjugate prior is combined with the likelihood function of local data, the resulting distribution known as the posterior distribution is found to have the same functional properties as the prior (Maddala, 1977). A common assumption made is that the prior and the local data are normally distributed. Bayesian updating is ideal for use in this research because it enables the combination of prior data (the NPTS distributions) and local data (local sample distributions), to produce a posterior distribution (updated distribution) that integrates the characteristics of both distributions. The posterior distribution is normally distributed with the following characteristics (Atherton and Ben-Akiva, 1976):

$$\theta_2 = \frac{\dfrac{\theta_1}{\sigma_1^2} + \dfrac{\theta_s}{\sigma_s^2}}{\dfrac{1}{\sigma_1^2} + \dfrac{1}{\sigma_s^2}} \tag{1}$$

$$\sigma_2 = \sqrt{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_s^2}} \tag{2}$$

where, θ_1 = original statistic, θ_s = local statistic, θ_2 = updated statistic,

σ_1 = standard deviation of the original statistic

σ_s = standard deviation of the local statistic

σ_2 = standard deviation of the updated statistic

θ_2 is a weighted average of the original coefficient and the local coefficient. The weights used are the inverse of their respective variances. The weights can be altered depending on the confidence in either the original data or that of the local sample, in which case the method is known as Bayesian Updating with Subjective Priors.

Atherton and Ben-Akiva (1976) emphasized that the major advantage in the use of Bayesian updating was the cost reduction. Small-scale surveys by themselves may not be adequate for updating models, but advantages in terms of time and money can be achieved by using them in conjunction with prior information. Using the same approach, if the MPO conducts a small household survey consisting of 400 – 500 households, the cost incurred by the MPO would be $70,000 – $100,000. This compares to incurring a cost of $350,000 – $700,000 by surveying 2,000 – 3,000 households, because a sample of at least 2,000 households is required for modeling purposes. By using a small local sample survey to update the distributions obtained from the NPTS 1995 (Greaves, 2000), a simulated travel data set can be generated and used by a small/medium MPO for calibrating and estimating their travel demand models.

The Bayesian updating procedure using a small local sample of households is tested for Dallas-Fort Worth and Salt Lake in this thesis. The updating procedure involves various steps namely: (i) selection of the local sample, (ii) determining appropriate weights, (iii) creating distributions from the local sample, (iv) determining the weights for updating, (v) updating distributions, and (vi) using updated distributions for simulation of trip attributes (trip rates, mode shares, departure times, and trip length), (vii) statistical comparisons.

3.2.1 Selection of Local Sample

Since the aim of this research is to provide the MPO with good quality data while being inexpensive, the size of the local sample must be kept small. In his research, Greaves (2000) tested the updating approach for home-work mode shares using 200 households. He found that the mode shares derived from the update sample were not representative of the population, and therefore led to mixed results after updating. While larger sample sizes contribute towards the reduction of sampling error, the cost associated with them is comparatively large. Therefore, a tradeoff has to be achieved between sample size and cost. Since, this method is primarily aimed at small/medium MPOs and it was felt that sample sizes greater than 500-600, would not be very cost effective. While deciding on the sample size, a sampling scheme consisting of seven categories and a sample size of 525 households, with seventy-five households in each category was tested. The results after updating showed a need to change the sampling scheme. Therefore, a sampling scheme based on household size and vehicles and containing thirteen categories was employed, while retaining the sample size of 525 households for the purposes of local adjustments to the simulated results. As this procedure was being tested here, the sampling schemes from the survey were retained for the local sample. However, different sampling schemes that utilize any of the demographic variables can be employed.

- **Dallas-Fort Worth**

As mentioned earlier, the 1996 NCTCOG travel survey consisted of 3,996 households, which were stratified by county, household size and vehicles. Since the local sample size was small, there was a need for the sample to be representative of the population it was drawn from. A sample chosen by simple random sampling may have to be drawn repeatedly in order to be representative. However with variable fraction stratified random sampling, the sample tends to be more representative and therefore, this method was chosen as the sampling method. In a stratified sample, the means from each stratum are different and the sample variance within each stratum will be smaller than the sample variance for the entire population. Owing to the smaller variances, stratified sampling is considered for this analysis. The NCTCOG study area encompassed the nine counties of Dallas, Denton, Tarrant, Rockwall, Kaufman, Parker, Collin, Ellis and Johnson. For the purpose of presentation here, the sampling matrix from the 1996 NCTCOG travel survey has been aggregated to a single matrix, stratified by household size and vehicles only and this matrix is shown in Table 3. The simulation used in this research (Greaves, 2000) also employs a 13-category sampling scheme based on household size, vehicles and county.

Table 3: Sampling Scheme of Dallas-Fort Worth obtained from NCTCOG Travel Survey

<table>
<tr><td></td><td colspan="6">Household Size</td></tr>
<tr><td rowspan="5">Vehicles</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5+</td></tr>
<tr><td>0</td><td colspan="2">152 (3.8%)</td><td colspan="3">55 (1.38%)</td></tr>
<tr><td>1</td><td rowspan="3">978 (24.47%)</td><td>271 (6.78%)</td><td>113 (2.83%)</td><td colspan="2">144
(3.60%)</td></tr>
<tr><td>2</td><td rowspan="2">1075 (26.90%)</td><td>290 (7.26%)</td><td>300 (7.51%)</td><td>143 (3.58%)</td></tr>
<tr><td>3+</td><td>213 (5.33%)</td><td>164 (4.10%)</td><td>98 (2.45%)</td></tr>
</table>

The local sample consisting of 525 households was drawn as a disproportionate stratified random sample from the NCTCOG travel survey. This sample was stratified based on county, household size and vehicles. The composition of the final local sample stratified by household size and vehicles is shown in Table 4.

Table 4: Composition of Local Sample for Updating for Dallas-Fort Worth

<table>
<tr><td></td><td colspan="6">Household Size</td></tr>
<tr><td rowspan="5">Vehicles</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5+</td></tr>
<tr><td>0</td><td colspan="2">20 (3.81%)</td><td colspan="3">7 (1.33%)</td></tr>
<tr><td>1</td><td rowspan="3">129 (24.57%)</td><td>38 (7.24%)</td><td>15 (2.86%)</td><td colspan="2">19 (3.62%)</td></tr>
<tr><td>2</td><td rowspan="2">142 (27.05%)</td><td>37 (7.05%)</td><td>38 (7.24%)</td><td>19 (3.62%)</td></tr>
<tr><td>3+</td><td>27 (5.14%)</td><td>20 (3.81%)</td><td>14 (2.67%)</td></tr>
</table>

- **Salt Lake**

The 1993 household survey in Salt Lake consisted of 3,082 households, which were stratified by MPO area, household size and vehicles. The sampling scheme adopted in the travel survey has been aggregated to two stratification variables namely household size and vehicles for the purpose of presentation in this report and is shown in Table 5.

Table 5: Sampling Scheme of Salt Lake obtained from Travel Survey

<table>
<tr><td></td><td colspan="6">Household Size</td></tr>
<tr><td rowspan="5">Vehicles</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5+</td></tr>
<tr><td>0</td><td colspan="2">122 (3.96%)</td><td colspan="3">13 (0.42%)</td></tr>
<tr><td>1</td><td rowspan="3">548 (17.78%)</td><td>313 (10.16%)</td><td>54 (1.75%)</td><td colspan="2">84 (2.73%)</td></tr>
<tr><td>2</td><td rowspan="2">900 (29.20%)</td><td>199 (6.46%)</td><td>151 (4.90%)</td><td>225 (7.30%)</td></tr>
<tr><td>3+</td><td>162 (5.26%)</td><td>134 (4.35%)</td><td>177 (5.74%)</td></tr>
</table>

The local sample of 525 households was drawn as a disproportionate stratified random sample from the Salt Lake survey consisting of 3,082 households. The local sample was stratified by MPO area, household size and vehicles. The local sample was aggregated to a matrix with two stratification variables namely household size and vehicles and is shown in Table 6.

Table 6: Composition of Local Sample for Updating for Salt Lake

<table>
<tr><td></td><td colspan="6">Household Size</td></tr>
<tr><td rowspan="5">Vehicles</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5+</td></tr>
<tr><td>0</td><td colspan="2">21 (4%)</td><td colspan="3">3 (0.57%)</td></tr>
<tr><td>1</td><td rowspan="3">93 (17.71%)</td><td>53 (10.10%)</td><td>9 (1.71%)</td><td colspan="2">14 (2.67%)</td></tr>
<tr><td>2</td><td rowspan="2">153 (29.14%)</td><td>34 (6.48%)</td><td>26 (4.95%)</td><td>39 (7.43%)</td></tr>
<tr><td>3+</td><td>28 (5.33%)</td><td>22 (4.19%)</td><td>30 (5.71%)</td></tr>
</table>

3.2.2 Determining Appropriate Weights

In order to generate the synthetic travel data set the simulation utilizes distributions from the 1995 NPTS to simulate each trip attribute (trip rates, mode shares, departure times, and trip lengths). These distributions are updated using the local sample distributions. Therefore, in order to update the distributions from the 1995 NPTS, distributions have to be constructed from the local sample. The categories used for constructing the local sample distributions are identical to the categories used for constructing the 1995 NPTS distributions. The homogenous categories used in the NPTS method were obtained using the C&RT algorithm. The distributions originating from the local sample have to be weighted since the occurrence of households in each of the thirteen sampling categories is not equal because the local sample was drawn as a disproportionate stratified random sample. Therefore, in order to ensure that the local sample is representative of the entire population, it is necessary to assign weights to each of the sampling categories during analysis.

The weight for each sampling category is calculated as the ratio of the proportion of households in PUMS to the proportion of households in the local sample. The respective weights for each sampling category were applied to all the households that belonged to that category. These weights create a population that is similar to the population from the weighted PUMS data. The weights for each of the sampling categories for Dallas-Fort Worth and Salt Lake are shown in Table 7.

Table 7: Weights for Dallas-Fort Worth and Salt Lake

Category	Weights for Dallas-Fort Worth	Weights for Salt Lake
Sampling category 1	1.18	1.20
Sampling category 2	0.91	0.87
Sampling category 3	1.01	0.73
Sampling category 4	0.80	0.68
Sampling category 5	1.41	1.88
Sampling category 6	1.37	1.96
Sampling category 7	1.18	1.08
Sampling category 8	0.95	0.91
Sampling category 9	1.32	1.96
Sampling category 10	1.09	1.52
Sampling category 11	1.16	1.23
Sampling category 12	1.31	1.35
Sampling category13	1.27	1.48

3.2.3 Distributions from Local Sample

The weights shown in Table 7 were applied to the households, and weighted distributions were drawn from the local sample for both Dallas-Fort Worth and Salt Lake. The distributions for home-work for Salt Lake are presented in Figure 1.

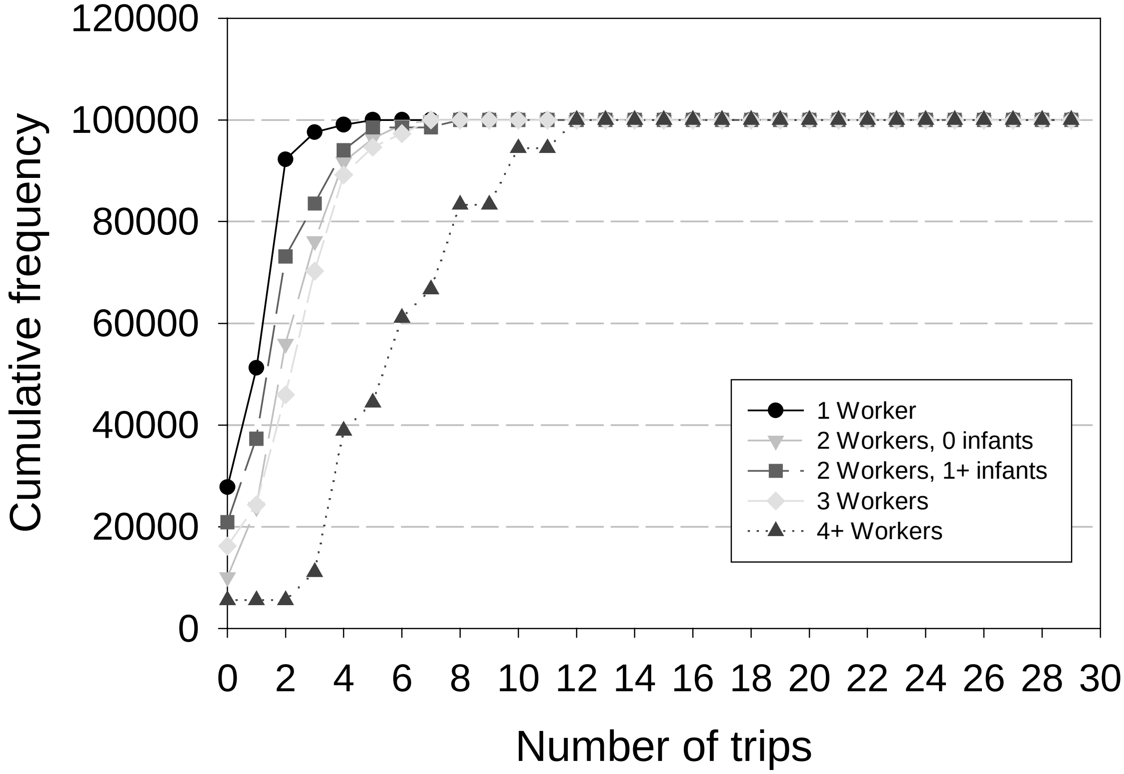

Figure 1: Local Sample Distributions for HBW Trip Purpose for Salt Lake

3.2.4 Determining Weights for Updating

The weights used in the Bayesian updating process are the inverse of the respective variances. The NPTS is an extremely large data set and is therefore expected to show less variability than the local sample, whose size is small and is expected to have more variance. By using the inverse of variances as weights, more weight is given to the NPTS data. Hence, the results obtained after updating using this weighting procedure will not be very different from those obtained from simulation without updating which uses the NPTS distributions alone. In order to incorporate local characteristics into the simulated data set, more weight needs to be given to the local sample. Therefore, subjective priors were used in this research. The weights used for the prior and local sample distributions are assumed to be equal, in an attempt to ensure that the updated distribution lies between the NPTS and the local sample distributions.

3.2.5 Updating Distributions

The NPTS distributions, which form the prior distributions, are combined with the local sample distributions to produce updated distributions, which form the posterior distributions using equal weights for the posterior and local sample distributions. The Bayesian updating equations used for the updating procedures are listed below:

$$\theta_2 = \frac{\frac{\theta_1}{\sigma_1^2} + \frac{\theta_s}{\sigma_s^2}}{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_s^2}} \qquad (3)$$

Using equal weights, the updating equation reduces to

$$\theta_2 = \frac{\theta_1 + \theta_s}{2} \qquad (4)$$

The NPTS distributions are updated using the local sample distributions to yield a set of updated distributions that lie between the original and the local sample distributions. The updated distributions for the “2 Workers-0 Infants” category for the HBW trip purpose for Salt Lake is shown in Figure 2. The inset shows a zoomed plot with up to 5 trips to illustrate that the updated distribution lies in between the local sample and the NPTS distributions. The weighting procedure used in this research, which employs equal weights for the NPTS and the local sample distributions, reduces the updated distributions essentially to a simple average of the prior and local sample distributions. This can be considered to be a special case of Bayesian Updating with subjective priors.

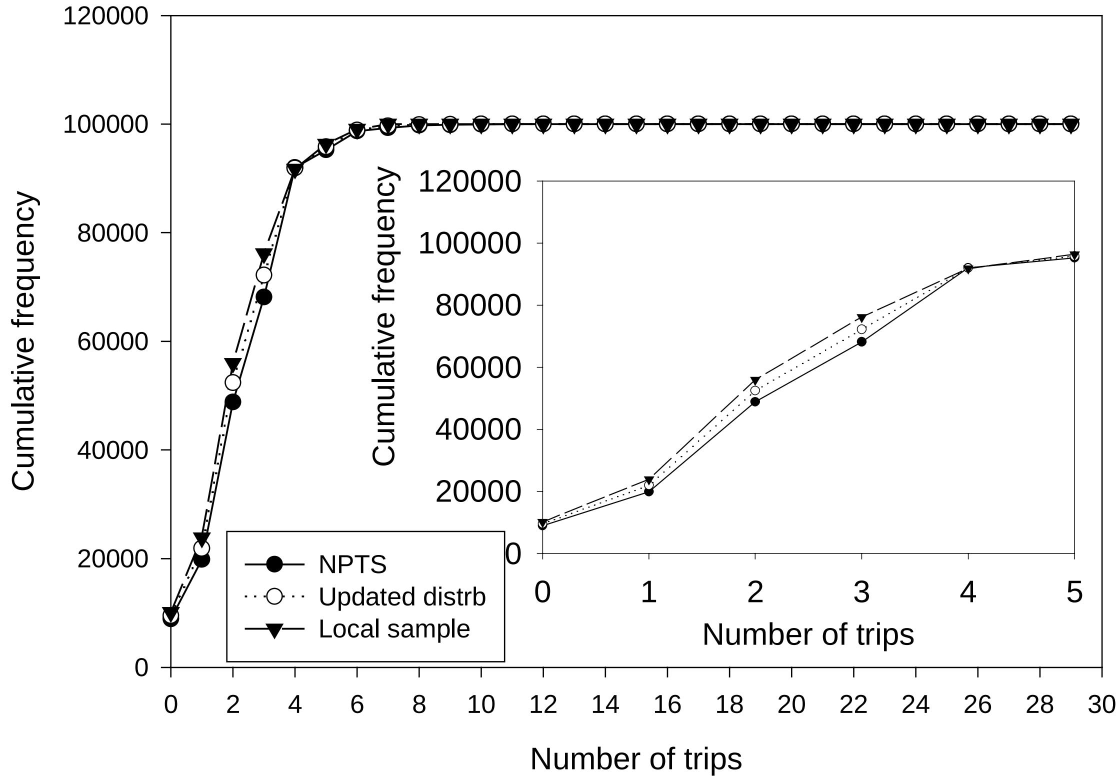

Figure 2: Updated Distributions for HBW Trip Purpose for Salt Lake

3.2.6 Updated Distributions for Simulating Trip Attributes

The updated distributions are reconstructed as cumulative frequency distributions and are input to the simulation procedure. The simulation procedure therefore draws from the updated distributions instead of the NPTS distributions. The simulation (Greaves, 2000) is run to generate updated trip rates, mode shares, departure times, and trip lengths. Care was taken to ensure that the same random numbers were used both before and after updating in order to ensure that direct comparisons of the results obtained before and after updating could be made. The updated trip attributes were compared statistically to those obtained using the NPTS distributions in order to determine the utility of updating the data distributions.

3.2.7 Statistical Comparisons

Trip rates obtained before and after updating were compared with trip rates from the household travel surveys using the z-test of difference between two means with known variances.

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

where, $\bar{x}_k$ = mean trip rate from source k

σ_k^2 = variance of trip rate from source k

n_k = sample size

Mode shares were compared using the z-test for testing the differences in proportions for large samples (Freund et al., 1997). This test assumes that sample proportions are normally distributed with mean *p* and variance *p(1-p)/n* for a large sample size *n*.

$$z = \frac{\frac{y_1}{n_1} - \frac{y_2}{n_2}}{\sqrt{p(1-p)(\frac{1}{n_1} + \frac{1}{n_2})}}$$

$$p = (\frac{y_1 + y_2}{n_1 + n_2})$$

where, y_k = number in population k choosing a particular mode

n_k = number in population k

Departure times before and after updating were compared using the Kolmogorov-Smirnov D-test. This test analyzes whether the two samples are from the same distribution and is based on the largest difference between the two cumulative distributions. Trip lengths, which represent the average travel times by purpose, were compared using the Z-test for difference between two means with known variances. Results obtained after adopting the outlined procedure are analyzed in the following chapter.

4. RESULTS AND ANALYSIS

The objective of updating was to obtain a set of trip attributes (trip rates, mode shares, departure times, and trip lengths) from the simulation, which were closer to the survey values than those obtained without updating. In order to assess the performance of the updating procedure, it was necessary to use the same random numbers before and after updating. Also, since each step of the simulation is based on the preceding step, it was essential to run the simulation after updating, changing one factor at a time while keeping all other factors constant. Therefore for simulation of mode shares after updating, the updated distributions were used for mode shares, while using the NPTS distributions for simulation of trip rates. This enabled the direct comparison of simulated trip attributes before and after updating. The results obtained from the simulation after updating for Dallas-Fort Worth and Salt Lake, while running the simulation in parts, are analyzed in this section. In addition, the cumulative effect of updating the distributions, while running the entire simulation after updating, is also reported in this chapter and the results obtained are analyzed.

4.1 Trip Rate Comparisons

4.1.1 Dallas-Fort Worth

Mean person trip rates for Dallas-Fort Worth are compared in Figure 3. The z-test of equal population means is used to test for significant differences between these values. The values are presented in Table A.1 in the appendix.

Without updating, most of the trip rates except for home-school and home-college are significantly different from the corresponding survey trip rates at the 95% confidence level. Households in Dallas-Fort Worth make fewer work trips, shopping trips and other trips compared with the simulation prior to updating. Because trip rates obtained from simulation without updating do not reflect local contextual differences such as transit service levels, size of the metropolitan area, etc., the trip rates obtained from the simulation without updating do not reflect trip rates from the survey accurately.

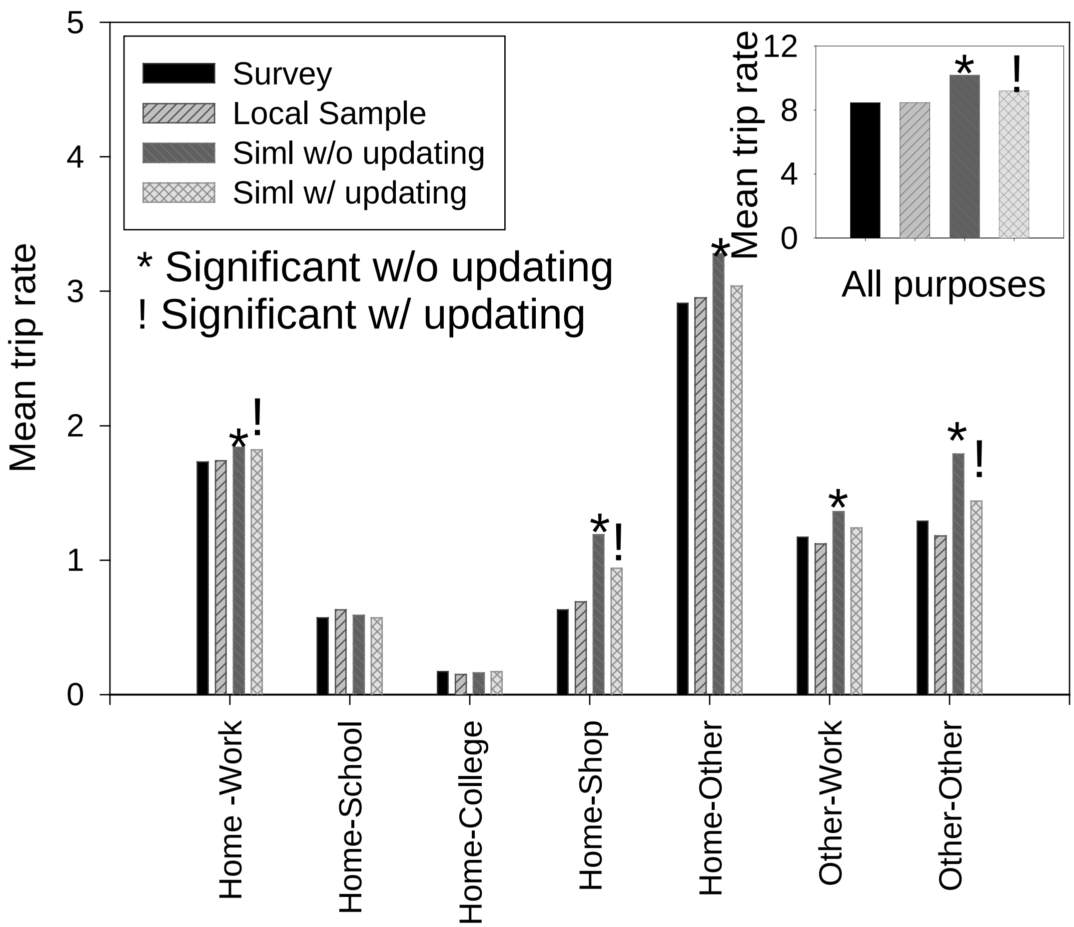

Figure 3: Comparison of Mean Trip Rates for Dallas-Fort Worth

Updating was found to improve the trip rates and bring them closer to the corresponding survey values. The home-work trip rate, which was found to be significantly different in simulation without updating, also exhibited a significant difference from the survey trip rate after updating. The home-shop trip rate before updating was found to exhibit a large significant difference when compared to the survey trip rate. Updating has brought the trip rate closer to the survey, but a significant difference still persists. While it is evident that updating has improved the trip rate, the improvement required for the trip rate to have an insignificant difference when compared to the survey trip rate is very large. Home-other and other-work trip rates, which were found to be significantly different when compared to the corresponding survey trip rates before updating, were found to have insignificant differences after updating and were found to move closer to the survey values. The other-other trip rate was found to have a large significant difference before updating. After updating, while the trip rate was still found to exhibit a significant difference, the magnitude of the difference was reduced. Further refinement of the updating procedure is necessary in order to bring the differences to an insignificant level, in order to build robust models.

4.1.2 Salt Lake

Trip rates by purpose are compared for Salt Lake and these comparisons are shown in Figure 4 and the values are presented in Table A.2 in the appendix. Home-school, home-college, home-other and other-other trips were found to be significantly different before updating for Salt Lake. Households in Salt Lake appear to make fewer home-work and home-shop trips but more home-school, home-college, home-other and other-other trips when compared to the simulation prior to updating. Household sizes in Salt Lake are among the highest in the nation (Riffkin and Nepstad, 1996) and therefore higher trip rates for home-other and other-work trip purposes and lower values for the home-work trip rate are a result of the larger household sizes. However, the simulation without updating has not fully captured these local effects. After updating, the simulated home-school trip rate was found to move closer to the survey trip rate, while remaining significantly different. Since Salt Lake has a large proportion of 5+ person households, it may be useful to experiment with higher categories of household size.

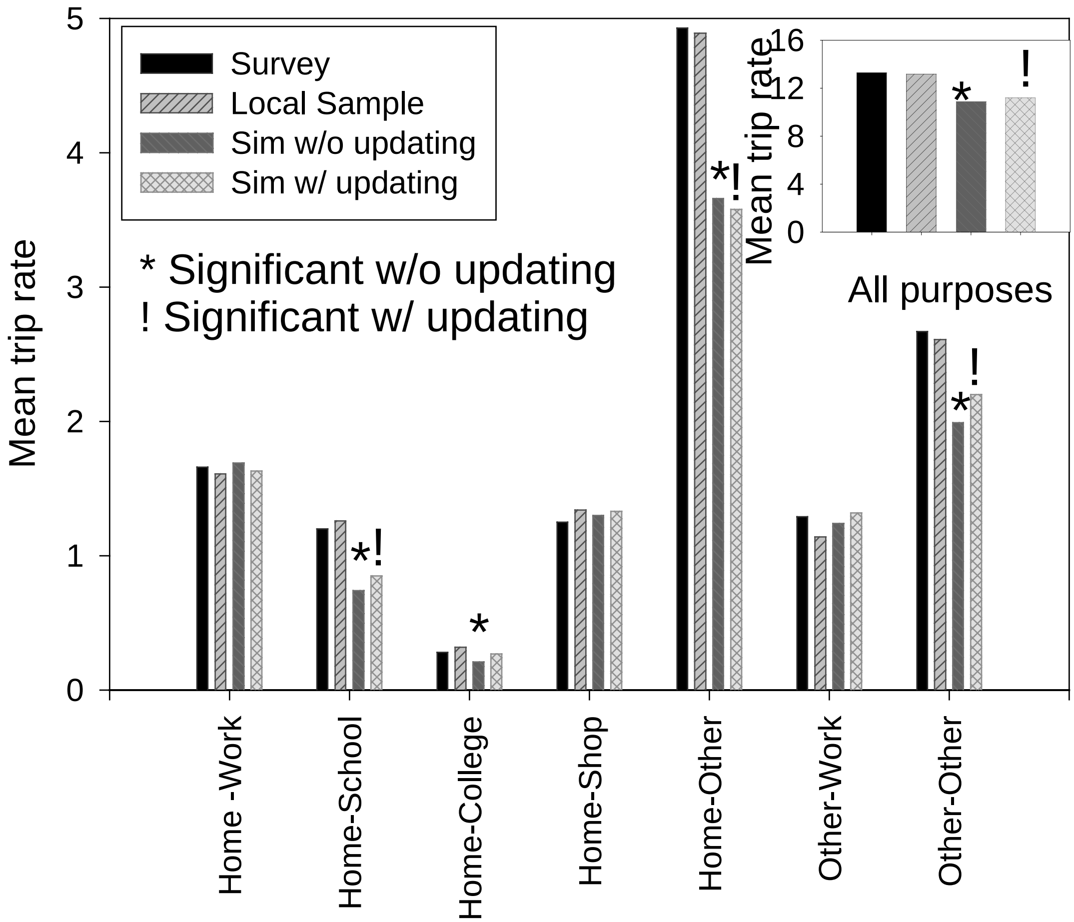

Figure 4: Comparison of Mean Trip Rates for Salt Lake

The home-college trip rate after updating did not exhibit a significant difference at the 95% confidence level. The home-other trip rate after updating was found to move away from the survey trip rate. The trip rates presented here are obtained from one simulation. However, it was observed that with repeated simulations, the trip rates fluctuated.

Because the simulation is based on the Monte Carlo principle, which utilizes random numbers to generate values repeatedly, a large number of repeated simulations may be needed for the home-other trip rate to move closer to the survey trip rate. It was also observed that the local sample did not have any observations in the 4 person, 0-1 school-age children, 2-3 infants category. The lack of representation of observations in the local sample also played a role in the simulation of trips for home-shop, home-other and other-other trips. The other-other trip rate was found to have a significant difference before updating; however, after updating, the trip rate exhibited less significant difference.

Incorporating local characteristics into the simulation has definitely improved the trip rates and brought them closer to the survey. However, significant differences still persist especially with home-other and other-other trips. These trip categories serve many purposes (social, recreational, personal business, etc.) and therefore it is very difficult to predict these trips by demographic factors alone.

While, updating has produced some improvements in the trip rates at the aggregate level, more comparisons are necessary in order to assess the performance of the updating procedure. The trip rates were compared across household size, number of workers in the household, number of school age children in the household and the number of vehicles in the household. These comparison variables are chosen because they are important variables in the simulation procedure and are found to have an influence on most trip purposes.

The results obtained after comparison are tabulated in the following pages. Each table reports the number of significant differences before and after updating. Four alternative situations were considered for comparison namely A, B, C and D. The description of these situations is presented in Table 8. These alternative situations were helpful in evaluating the performance of the updating procedure. If the updating procedure works as it is expected to then one would ideally expect to see the majority of cases falling in situations A and B.

Table 8: Description of Alternative Situations

Description of Alternative Situations	Alternative Situations
Insignificant w/o updating, Insignificant w/ updating	A
Significant w/o updating, Insignificant w/ updating	B
Insignificant w/o updating, Significant w/ updating	C
Significant w/ updating, Significant w/ updating	D

Five categories comprising 1, 2, 3, 4 and 5+ persons were chosen for comparison. The results are tabulated in Table 9 for Dallas-Fort Worth based on the significant differences between the trip rates obtained from the simulation and survey for various categories. The actual values are presented in Table A.3 in the appendix.

After updating it was observed that 42.5% of the trip rates did not need updating and did not change significantly as a result of updating. 22.5% of trip rates were improved to the point of no significant difference, while 32.5% remained significantly different after updating and 2.5% became significant after updating.

Table 9: Comparison of Significant Differences for Mean Person Trip Rates by Household Size for Dallas-Fort Worth

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-Work	5/5	-	-	-
Home-school	5/5	-	-	-
Home-college	2/5	1/5	1/5	1/5
Home-shop	-	-	-	5/5
Home-other	1/5	4/5	-	-
Other-work	4/5	-	-	1/5
Other-other	-	3/5	-	2/5
All purposes	-	1/5	-	4/5
Total	42.5%	22.5%	2.5%	32.5%

The distributions from the local sample with respect to those of the survey and those obtained from the simulation before updating determine the usefulness of the local sample in improving the simulated data obtained using updated distributions. The updating procedure adopts equal weights for the NPTS and the local sample distributions and Bayesian updating to provide updated distributions. These updated distributions are the basis for the simulation process. If the local sample is not representative of the population the updated distributions will move away from the survey. The instance of the one trip rate in the home-college trip purpose exhibiting a worsened trip rate after updating as opposed to before updating is related to the lack of representativeness of the local sample in reflecting the survey trip rate. A similar result was reported by Greaves for updating mode shares for Baton Rouge (Greaves, 2000).

Table 10 shows the number of significant differences by household size for the Salt Lake data, while the values are detailed in Table A.4 in the appendix. Updating has assisted in removing significant differences for 20% of the trip rates. 47.5% of total trip rates did not change as a result of updating and remained significant before and after updating. 25% of the total trip rates did not show the need for updating and 7.5% of trip rates deteriorated after updating. The increased number of trip rates for situation C for Salt Lake when compared to those of Dallas-Fort Worth data demonstrates an increased lack of representativeness of the Salt Lake local sample when compared to the population. The simulation prior to updating for Salt Lake shows more significant differences compared to the survey results than for Dallas-Fort Worth. Substantial differences are noticed in households with five or more people and also in home-other and other-other trip rates. Because large households are widespread in Utah, and the average household size for Salt Lake is higher than the national average, these results are not wholly unexpected. The use of a local sample to update the NPTS distributions has helped to reduce the number of differences for both Salt Lake and Dallas-Fort Worth. However, the performance of the local sample in reducing the difference is lower in the case of Salt Lake, which is reflected by greater percentages for situations C and D, owing to greater disparity before updating.

Table 10: Comparison of Significant Differences for Mean Person Trip Rates by Household Size for Salt Lake

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-Work	2/5	1/5	1/5	1/5
Home-school	-	-	1/5	4/5
Home-college	2/5	2/5	1/5	-
Home-shop	2/5	-	-	3/5
Home-other	-	1/5	-	4/5
Other-work	4/5	-	-	1/5
Other-other	-	3/5	-	2/5
All purposes	-	1/5	-	4/5
Total	25%	20%	7.5%	47.5%

Results obtained by comparing the trip rates by number of workers for Dallas-Fort Worth and Salt Lake are shown in Tables A.5 and A.6 respectively in the appendix. The trip rates were compared across four categories of 0, 1, 2 and 3+ workers. Table 11 shows the number of significant differences for Dallas-Fort Worth.

Table 11: Comparison of Significant Differences for Mean Person Trip Rates by Workers for Dallas-Fort Worth

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-Work	1/4	1/4	-	2/4
Home-school	4/4	-	-	-
Home-college	4/4	-	-	-

(Table 11 Continued)

Home-shop	-	-	-	4/4
Home-other	1/4	2/4	-	1/4
Other-work	1/4	2/4	-	1/4
Other-other	-	3/4	-	1/4
All purposes	-	1/4	-	3/4
Total	34.4%	28.1%	0%	37.5%

A review of the results indicated that many trip rates were overestimated before updating. Large differences were found in the 3+ workers category. Updating was found to be beneficial in reducing the difference. 28.1% of the trip rates were improved to exhibiting no significant differences, 37.5% of the trip rates exhibited significant differences and 34.4% did not show any change as a result of updating.

Table 12 shows the significant differences before and after updating for Salt Lake, while the values can be found in Table A.6 in the appendix. A similar pattern is found in the results compared to household size with substantial differences occurring in home-other and other-other trip rates. Home-work trips were overestimated and home-school trips were underestimated before updating. 53.1% of trip rates remained significantly different after updating while 12.5% of trip rates showed no significant differences after updating. 31.3% of the trip rates did not need updating and did not show any change after updating.

Table 12: Comparison of Significant Differences for Mean Person Trip Rates by Workers for Salt Lake

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-Work	2/4	-	-	2/4
Home-school	¼	-	-	3/4
Home-college	¼	2/4	1/4	-
Home-shop	¾	-	-	1/4
Home-other	-	1/4	-	3/4
Other-work	¾	-	-	1/4
Other-other	-	1/4	-	3/4
All purposes	-	-	-	4/4
Total	31.3%	12.5%	3.1%	53.1%

The percentage representation for situations C and D is more for Salt Lake when compared to that of Dallas Fort Worth. In addition, the percentage for situation B is smaller for Salt Lake. The results obtained from the simulation prior to updating for Dallas-Fort Worth showed fewer disparities, compared to the survey values, than Salt Lake, where the results obtained from the simulation prior to updating were significantly different in a many cases from their respective survey values. Therefore, fewer significant differences were seen in Dallas-Fort Worth after updating compared to Salt Lake, owing to fewer differences in Dallas-Fort Worth prior to updating.

Trip rates are also compared based on the number of children in the household. The number of school age children is important for predicting the number of school trips undertaken by a household and also other trips such as home-other, home-shop, etc. The instances of significant differences by the number of school age children for Dallas-Fort Worth are tabulated in Table 13, while the trip rates are presented in Table A.7 in the appendix.

Updating was found to have a small effect on simulated results when grouped under school age children as compared to the previous two groups. Dallas-Fort Worth trip rates were found to be over-predicted and most differences are noticed in home-shop and other-other trips before updating. Updating the distributions has resulted in eliminating the significance in only 12.5% of the trip rates, whereas 53.1% of the trip rates exhibited significant differences after updating.

These results suggest that the updating procedure using equal weights is only able to partially eliminate the significant differences. This updating procedure was found to work well when the differences prior to updating were small. In such cases, the significant differences after updating were eliminated. The simulation procedure used in this research had some inherent problems such as not being able to capture the home-shop and home-other trips very well, while trying to simulate trip attributes. While updating helped to bring the trip attributes closer to the survey values, elimination of all differences was not possible due to the problems with the simulation procedure itself.

Table 13: Comparison of Trip Rates per Household by School Age Children per Household for Dallas-Fort Worth

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-work	2/4	-	-	2/4
Home-school	2/4	-	1/4	1/4
Home-college	¾	-	-	1/4
Home-shop	-	-	-	4/4
Home-other	¼	2/4	-	1/4
Other-work	¾	-	-	1/4
Other-other	-	1/4	-	3/4
All purposes	-	1/4	-	3/4
Total	34.4%	12.5%	3.1%	50%

The number of significant differences in the comparison of trip rates by number of school age children for Salt Lake is shown in Table 14 and the trip rates are shown in Table A.8 in the appendix. 46.9% of the trip rates did not need updating and 18.8% of the trip rates were improved to the point where they no longer exhibited significant differences. 34.4% of trip rates were significant after updating. Home-other trips were consistently underestimated. This is not surprising as more trips are a result of higher household sizes. Total trips rates are also underestimated in all cases but especially in the case of the 3+ children category. After updating, the overall trip rates for 2 and 3+ children categories were found to worsen because of the local sample values. It was also observed that the trip rates for Dallas-Fort Worth based on school age children are worse when compared to Salt Lake.

Trip rates per household are compared by vehicles per household, which is also a classification variable for the simulation. The z-test is used to test whether significant differences exist, between the trip rates obtained from the survey, simulation without updating and simulation with updating.

Table 14: Comparison of Trip Rates per Household by School Age Children per Household for Salt Lake

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-work	4/4	-	-	-
Home-school	-	3/4	-	1/4
Home-college	¾	1/4	-	
Home-shop	¾	-	-	1/4
Home-other	-	-	-	4/4
Other-work	4/4	-	-	-
Other-other	¼	2/4	-	1/4
All purposes	-	-	-	4/4
Total	46.9%	18.8%	0%	34.4%

Table 15 shows the significant differences of trip rates compared by number of household vehicles for Dallas-Fort Worth. The tabulations of data have been provided in Table A.9 in the appendix. The trip rates prior to updating are again over-predicted but there are fewer differences compared to school age children and number of workers. Home-other, home-shop and other-other trips show most differences after updating mirroring the trend seen in earlier comparisons. 37.5% of trip rates were found to have no significant differences and 37.5% of the trip rates were significant after updating. 25% of the trip rates needed no updating. Overall the trip rates were overestimated.

Table 15: Comparison of Trip Rates per Household by Vehicles per Household for Dallas-Fort Worth

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-work	1/4	3/4	-	-
Home-school	4/4	-	-	-
Home-college	2/4	1/4	-	1/4
Home-shop	-	-	-	4/4
Home-other	1/4	2/4	-	1/4
Other-work	-	3/4	-	1/4
Other-other	-	2/4	-	2/4
All purposes	-	1/4	-	3/4
Total	25%	37.5%	0%	37.5%

Table 16 shows the number of significant differences of trip rates by the number of household vehicles for Salt Lake and the values are presented in Table A.10 in the appendix. School and college trips are underestimated and show significant differences after updating. Home-other and other-other trips are also consistently underestimated indicating a trend noticed with other comparisons. Overall the trip rates are underestimated as seen with the other comparisons. Again, this was due to the higher than average household size prevalent in Salt Lake. 50% of the trip rates needed no updating, 6.3% of the trip rates improved to show no significant differences and 43.8% of the trip rates showed significant differences after updating.

Table 16: Comparison of Trip Rates per Household by Vehicles per Household for Salt Lake

Trip Purpose	Insignificant w/o updating Insignificant with updating	Significant w/o updating Insignificant with updating	Insignificant w/o updating Significant with updating	Significant w/o updating Significant with updating
	A	B	C	D
Home-Work	4/4	-	-	-
Home-school	1/4	1/4	-	2/4
Home-college	2/4	1/4	-	1/4
Home-shop	4/4	-	-	-
Home-other	1/4	-	-	3/4
Other-work	4/4	-	-	-

(Table 16 Continued)

Other-other	-	-	-	4/4
All purposes	-	-	-	4/4
Total	50%	6.3%	0%	43.8%

Overall, the results suggest that the simulation prior to updating is not as effective for Salt Lake as it is for Dallas-Fort Worth. Generally work, school and college trips to some extent were well simulated after updating. Home-other, other-other and home-shop trip rates to some extent were overestimated in Dallas-Fort Worth and underestimated in Salt Lake. The major problem in Dallas-Fort Worth was the difference in non-mobility rates. For Salt Lake significant differences existed before and after updating. While, the updating procedure for Salt Lake brought the trip rates closer to the survey trip rates, significant differences remained in many cases. There were two reasons for the significant differences after updating. The first was the lack of representation of the local sample for some cells. Using the equal weights forced the trip rate after updating to move further away from the survey trip rate. The other reason was that the trip rates obtained from simulation without updating were either overestimated or underestimated by a large margin when compared to the survey. While, using this updating procedure reduced the margin of error, significant differences still existed. Trying out different weighting possibilities may alleviate the problem to a certain extent. Because the trip making characteristics of a household were found to be dependent on demographic variables (number of workers, presence or absence of school going children etc.), experimenting with a sampling scheme, which involves one or more of these variables, might prove to be worthwhile.

4.2 Mode Share Comparisons

Mode shares by mode and purpose are compared for Dallas-Fort Worth in Table 17. The z–test for difference between proportions is used to test for significant differences. These mode shares are compared across the seven modes of driver, passenger, public bus, school bus, bike/walk, rail and other.

Auto driver share was overestimated whereas passenger and public bus shares were underestimated by the simulation prior to updating for home-work trips. After updating all the mode shares except for public bus were no longer significantly different from the household travel survey results. For home-school trips Dallas had fewer transit trips and more auto passenger trips compared to the simulation before updating. After updating this trend continued, although these mode shares were observed to move much closer to the survey mode shares. For home-college trips, auto driver trips were over-predicted while passenger and school bus trips were under predicted before updating. After updating school bus mode shares were found to exhibit a difference. For home-shop and home-other trips, Dallas has more auto driver and fewer passenger and transit trips than those predicted by the simulation before updating. While the mode shares for home-shop trips showed substantial improvement after updating, mode shares belonging to home-other trips still showed significant differences.

Table 17: Comparison of Mode Shares for Dallas – Fort Worth

Trip purpose	Mode	Survey	Local Sample	Simulation without updating		Simulation with updating	Z-value
				Share	Z- value		
Home-work	Driver	88.8	88.7	89.8	-2.03*	89.5	-1.42
	Passenger	5.7	6.0	6.6	-2.20*	6.0	-0.69
	Public Bus	3.9	4.3	1.8	7.28*	3.2	2.08*
	School Bus	0.0	0.1	0.2	-2.56*	0.1	-0.74
	Bike/Walk	1.60	0.90	1.6	0.04	1.2	1.78
	Rail	0.00	0.00	0	0.00	0.0	0.00

(Table 17 Continued)

	Other	0.0	0.00	0	1.78	0.0	1.78
Home-school	Driver	5.0	4.30	4.4	0.99	4.8	0.37
	Passenger	49.2	46.50	37.6	7.90*	41.7	5.10*
	Public Bus	3.6	3.30	1.9	3.50*	2.2	2.81*
	School Bus	22.2	22.80	48.3	-18.54*	36	-10.30*
	Bike/Walk	20.0	23.10	7.8	12.06*	15.3	4.14*
	Rail	0.0	0.00	0	0.00	0.0	0.00
	Other	0.0	0.00	0	1.02	0.0	1.02
Home-college	Driver	69.3	78.90	75.3	-2.42*	71	-0.65
	Passenger	16.2	15.80	10.3	3.14*	15.1	0.55
	Public Bus	3.6	1.30	4.8	-1.10	4.5	-0.84
	School Bus	3.6	1.30	0.9	3.22*	1.1	2.99*
	Bike/Walk	7.3	2.60	8.3	-0.71	8.3	-0.71
	Rail	0.0	0.00	0	0.00	0.0	0.00
	Other	0.0	0.00	0.3	0.00	0.0	0.00
Home-shop	Driver	77.5	75.80	74.0	3.30*	75.9	1.48
	Passenger	17.6	15.90	20.9	-3.36*	18.5	-0.92
	Public Bus	0.7	0.60	0.7	-0.11	0.4	1.51
	School Bus	0.0	0.00	0.4	-3.09*	0.3	-2.63*
	Bike/Walk	4.1	7.20	4	0.32	4.7	-1.07
	Rail	0.0	0.00	0	0.00	0.0	0.00
	Other	0.1	0.6	0	0.65	0.2	-1.31
Home-other	Driver	69.4	67.6	62.3	11.81*	64.5	8.15*
	Passenger	25.8	26.9	30.9	-8.95*	27.8	-3.54*
	Public Bus	0.4	0.8	0.8	-4.04*	1.3	-7.66*
	School Bus	0.1	0.3	0.7	-7.02*	1.0	-9.09*
	Bike/Walk	4.1	4.2	5.2	-4.17*	5.2	-4.01*
	Rail	0.0	0.0	0	-2.10*	0.0	-0.94
	Other	0.1	0.1	0	3.32*	0.2	-0.32
Non home-work	Driver	83.9	85.9	83.7	0.20	83.6	0.40
	Passenger	9.7	11.2	10	-0.57	11.0	-2.22*
	Public Bus	0.6	0.0	1.2	-2.81*	0.8	-0.89
	School Bus	0.0	0.0	0.2	-2.79*	0.1	-2.46*
	Bike/Walk	5.6	2.6	4.8	1.74	4.2	3.13*
	Rail	0.0	0.0	0.1	-2.46*	0.1	-1.86
	Other	0.2	0.3	0.0	3.50*	0.2	0.77
Non home-other	Driver	68.0	70.6	63.7	4.98*	66.2	2.15*
	Passenger	25.8	21.5	29.6	-4.66*	26.6	-0.99
	Public Bus	0.4	1.0	0.9	-3.01*	1.3	-4.73*
	School Bus	1.3	1.8	0.6	4.15*	1.0	1.36
	Bike/Walk	3.9	4.2	5.1	-3.27*	4.7	-2.26*
	Rail	0.0	0.0	0	-1.20	0.0	0.00
	Other	0.5	1.0	0.1	5.48*	0.2	3.21*

Transit shares were significantly overestimated for other-work trips prior to updating. Passenger and transit shares exhibit significant differences after updating. The worsening of the passenger mode share after updating is related to the local sample mode share. Other-other mode shares show more auto driver trips and less passenger and bike/walk in the survey compared to the simulation without updating. Updating has led to a reduction in the significant differences but they still remain significantly different.

Mode share comparisons for Salt Lake are shown in Table 18. Auto driver shares were overestimated whereas passenger and bike/walk shares are underestimated by the simulation before updating. These differences are less pronounced after updating.

Home-school mode shares show statistically significant differences in all modes except for rail before updating. Updating the mode shares produced mixed results; while most improved, public bus showed a larger difference. Home-college mode shares simulated well and show no differences except for passenger and other shares. After updating none of the mode shares exhibit significant differences. Salt Lake appears to have less drive alone and transit trips and more passenger trips than the simulation before updating for home-shop trips. After updating, the same pattern was noticed with a reduction, however, in the magnitude of difference. Home-other trips were poorly simulated with driver shares being under-predicted and passenger shares being over-predicted. After updating, significant differences still persisted in these mode shares, however they were observed to be much closer to the survey values after updating. For other-work mode shares auto driver trips were significantly overpredicted and bike/walk shares underpredicted before updating. After updating, other share showed significant differences.

Table 18:Comparison of Mode Shares for Salt Lake

Trip purpose	Mode	Survey	Local Sample	Simulation without updating	Z-value	Simulation with updating	Z-value
Home - Work	Driver	82.9	81.3	90.4	-11.22*	86.2	-4.65*
	Passenger	9.8	9.8	6.5	6.26*	8	3.17*
	Public Bus	2.2	3	1.6	1.88	2.1	0.23
	School Bus	0.1	0.0	0.2	-0.79	0	1.16
							(Table 18 Continued)

	Bike/Walk	5.2	5	1.3	8.80*	3.5	1.80
	Rail	0.1	0.1	0.0	1.75	0	1.75
	Other	0.8	0.7	0.0	6.34*	0.2	4.90*
Home-School	Driver	7.00	6.1	4.1	4.62*	4.7	3.58*
	Passenger	33.10	30.1	40.3	-5.64*	35.3	-1.76
	Public Bus	0.50	0.2	1.5	-3.90*	4.6	-10.75*
	School Bus	24.50	25	47.4	-18.27*	33.7	-7.66*
	Bike/Walk	34.20	36.9	6.7	24.34*	21	10.89*
	Rail	0.00	0	0	0.00	0	0.00
	Other	0.60	1.8	0	3.15*	0.7	-1.17
Home-College	Driver	65.80	71.7	69.2	-1.39	66	-0.10
	Passenger	13.20	11.4	9	2.54*	14.7	-0.81
	Public Bus	4.10	4.2	4.4	-0.30	4.7	-0.60
	School Bus	0.80	1.2	1.7	-1.66	1.7	-1.66
	Bike/Walk	14.30	9.6	15.3	-0.58	11.2	1.73
	Rail	0.00	0	0	0.00	0.2	-1.18
	Other	1.80	1.8	0.3	2.67*	1.4	0.60
Home-Shop	Driver	68.50	67.1	73.0	-4.36*	70.8	-2.26*
	Passenger	26.0	26.1	22.7	3.39*	23.8	2.29*
	Public Bus	0.60	1	0.7	-0.69	0.7	-0.69
	School Bus	0.1	0	0.4	-3.51*	0.3	-2.44*
	Bike/Walk	4.3	5.7	3.1	3.16*	4.1	0.60
	Rail	0.1	0	0	1.44	0	1.44
	Other	0.4	0.1	0	3.71*	0.2	1.72
Home - Other	Driver	63.9	62.1	62.4	2.49*	63.5	0.58
	Passenger	26.1	27.2	31.1	-9.09*	28.8	-4.91*
	Public Bus	0.6	0.4	0.4	1.48	0.6	0.08
	School Bus	0.2	0.4	0.8	-7.36*	0.6	-5.24*
	Bike/Walk	8.5	9.2	5.1	10.38*	6.1	7.09*
	Rail	0	0	0	1.51	0	1.01
	Other	0.8	0.7	0	8.87*	0.4	4.36*
Other - Work	Driver	82.8	85.1	85.5	-3.28*	83.8	-1.14
	Passenger	9.5	7.9	9.4	0.15	9.7	-0.32
	Public Bus	0.6	0.2	0.7	-0.13	0.5	0.95
	School Bus	0.3	0.2	0.2	0.40	0.2	0.93
	Bike/Walk	5.5	5.9	4.1	2.86*	5.2	0.68
	Rail	0	0	0.1	-0.61	0.1	-1.04
	Other	1.3	0.8	0.1	6.62*	0.7	2.84*
Other - Other	Driver	64.1	64.4	64.2	-0.18	65	-1.19
	Passenger	28.5	28.9	29.4	-1.14	27.4	1.42
	Public Bus	0.7	0.4	0.4	1.70	0.5	1.15
	School Bus	1.1	1.3	0.8	2.07*	0.6	3.63*
	Bike/Walk	5	4.8	5.1	-0.32	6.2	-3.14*
	Rail	0.1	0	0	1.93	0	1.29
	Other	0.6	0.2	0.1	4.97*	0.3	2.94*

Subsequent to updating, only the “other” mode share showed a significant difference. This difference is not wholly unexpected because the survey conducted in Salt Lake did not treat rail as a separate mode. Instead it was combined with the other mode, whereas the simulation explicitly considers rail as a different mode. Therefore, significant differences are found in the rail and other mode shares due to the disparity in the definitions of mode. Other-other mode shares showed misestimation of transit and other shares prior to updating. After updating these differences persisted.

The results obtained after local adjustment of mode shares were mixed. While, some mode shares improved after updating, others got worse. These results suggest that the demographic characteristics alone cannot explain all the variation in mode shares. All the characteristics of the transportation system (parking facilities, cost of parking, transit coverage, etc.) and the spatial environment must be incorporated for accurate prediction of mode shares. It was observed that the local sample played a pivotal role in influencing the mode shares during the updating process. Some of the local sample mode shares departed from the survey values by a considerable margin and these in turn affected the updated mode shares adversely. Therefore it is necessary to draw a local sample that has observations in all categories and is also representative. Therefore experimenting with different schemes to draw the sample may be worthwhile.

Mode shares are also compared by the number of household vehicles. The number of households vehicles is an important classification variable for the simulation. Table 19 shows the mode share comparisons for Dallas-Fort Worth by the number of vehicles owned for the three trip purposes of home-work, home-nonwork and non-home based.

Table 19: Mode Share Comparisons by Number of Household Vehicles for Dallas-Fort Worth

Trip Purpose	Vehicles	Data Source	Mode of Travel (Percent)			
			POV	Transit	Bike/Walk	Other
Home-Work	0	Survey	32.5	56.0	10.5	1.0
		Simulation without updating	47.3*	37.1*	15.6	0.0
		Simulation with updating	35.6	55.6	8.8	0.0
	1	Survey	91.1	6.9	2.0	0.0
		(Table 19 Continued)				

		Simulation without updating	94.5*	2.5*	3.0	0.0
		Simulation with updating	92.6	4.6*	2.7	0.0
	2	Survey	97.7	1.1	1.2	0.0
		Simulation without updating	99.2*	0.4*	0.4*	0.0
		Simulation with updating	99.0*	0.6*	0.4*	0.0
	3+	Survey	98.4	0.7	0.9	0.0
		Simulation without updating	98.5	0.7	0.8	0.0
		Simulation with updating	98.2	1.4*	0.5	0.0
Home-Non work	0	Survey	34.3	27.3	37.6	0.7
		Simulation without updating	56.1*	21.5*	22.4*	0.0*
		Simulation with updating	35.9	32.5	31.6*	0.0*
	1	Survey	86.8	4.4	8.6	0.2
		Simulation without updating	87.8	6.2*	6.0*	0.0*
		Simulation with updating	88.1	5.1	6.5*	0.3
	2	Survey	91.1	3.4	5.4	0.1
		Simulation without updating	89.2*	6.7*	4.0*	0.1
		Simulation with updating	90.2*	4.7*	4.9	0.2
	3+	Survey	93.1	3.4	3.3	0.1
		Simulation without updating	89.1*	6.2*	4.5*	0.1
		Simulation with updating	89.5*	5.6*	4.8*	0.1
Non-Home Based	0	Survey	44.8	29.5	25.7	0.0
		Simulation without updating	62.4*	18.8*	18.3	0.5
		Simulation with updating	42.3	32.9	24.3	0.5
	1	Survey	93.7	1.5	4.5	0.2
		Simulation without updating	92.0*	1.3	6.6*	0.0*
		Simulation with updating	93.5	1.3	5.1	0.1
	2	Survey	94.2	0.9	4.6	0.3
		Simulation without updating	95.4*	0.7	3.8*	0.1*
		Simulation with updating	95.8*	0.5*	3.4*	0.3
	3+	Survey	94.7	0.5	4.0	0.7
		Simulation without updating	95.3	0.7	3.9	0.1*
		Simulation with updating	95.6	0.5	3.6	0.3*

Transit was the predominant choice for households with no vehicles for home-work trips in Dallas, while the simulation overpredicted POV and bike/walk shares and underestimated transit shares prior to updating. Updating helped to restore the correct proportions of mode shares in most of the cases. Significant differences were noticed for POV, transit and bike/walk modes for the 2-vehicle category for home-work trips. Again the worsening of the mode shares after updating was related to the local sample. All other mode shares simulated well. For home-nonwork trips, the simulation prior to updating estimated too many transit trips and too few bike/walk trips, while POV trips were well simulated for the lower vehicle ownership categories. Significant differences continued to be present for POV and transit mode shares for 2 and 3+vehicle categories. For non-home based trips transit and bike/walk mode shares are under-predicted whereas POV shares do not show any trend.

Table 20 shows the mode share comparisons by number of household vehicles for Salt Lake. The z-test of proportions is used to test for significant differences. Salt Lake appeared to have more POV trips and less transit trips compared to the simulation without updating for home-work trips in the zero vehicle category. Generally POV trips were overestimated except for the zero vehicle households and transit and bike/walk shares were underestimated. Other mode shares showed consistent problems owing to the disparity in the rail mode share.

For home-nonwork mode shares, a similar pattern was noticed in terms of over-prediction of POV and under-prediction of transit and bike/walk mode shares. Updating helped to bring the mode shares closer to the survey mode shares by reducing the difference but significant differences remained. Non-home based mode shares were well simulated with minor differences occurring in other and transit mode shares.

Table 20: Mode Share Comparisons by Number of Household Vehicles for Salt Lake

Trip Purpose	Vehicles	Data Source	Mode of Travel (Percent)			
			POV	Transit	Bike/Walk	Other
Home-Work	0	Survey	54.2	25.0	14.6	6.3
		Simulation without updating	41.4	45.7*	12.9	0.0*
		Simulation with updating	54.3	35.7	10.0	0.0*
	1	Survey	86.0	5.2	7.5	1.3
		Simulation without updating	94.5*	3.3*	2.1*	0.0*
		Simulation with updating	89.1*	2.9*	7.4	0.6
	2	Survey	94.6	1.1	3.6	0.6
		Simulation without updating	96.7*	0.6	1.3*	1.4*
		Simulation with updating	95.6	1.2	3.1	0.1
	3+	Survey	96.0	1.0	2.5	0.5
		Simulation without updating	98.2*	0.8	1.0*	0.0*
		Simulation with updating	96.9	1.7	1.5*	0.0*
Home-Non work	0	Survey	63.6	15.3	20.6	0.5
		Simulation without updating	58.1	19.8	22.1	0.0
		(Table 20 Continued)				

		Simulation with updating	67.1	16.7	15.6	0.0
	1	Survey	81.9	3.6	13.8	0.7
		Simulation without updating	88.5*	6.1*	5.3*	0.1*
		Simulation with updating	86.7*	5.3*	7.5*	0.5
	2	Survey	81.9	4.9	12.4	0.8
		Simulation without updating	88.3*	7.3*	4.3*	0.0*
		Simulation with updating	86.2*	5.7*	7.6*	0.5*
	3+	Survey	84.8	4.6	9.8	0.7
		Simulation without updating	86.6*	7.7*	5.6*	0.1*
		Simulation with updating	85.9	6.2*	7.6*	0.3*
Non-Home Based	0	Survey	61.1	19.0	19.9	0.0
		Simulation without updating	60.7	18.0	21.3	0.0
		Simulation with updating	67.2	15.6	17.2	0.0
	1	Survey	90.7	1.8	6.5	0.9
		Simulation without updating	92.5*	1.2	6.2	0.1*
		Simulation with updating	89.3	1.2	8.1	1.5
	2	Survey	93.3	1.0	4.8	0.9
		Simulation without updating	94.8*	0.8	4.3	0.1*
		Simulation with updating	94.0	0.5*	5.2	0.2*
	3+	Survey	94.1	1.2	4.1	0.6
		Simulation without updating	95.3*	0.9	3.7*	0.1*
		Simulation with updating	94.4	0.7	4.8	0.1*

4.3 Departure Time Comparisons

Departure times for the Dallas-Fort Worth region are compared in Table 21. The Kolmogorov Smirnov D-value is used to test whether the departure times from the survey, simulation without updating and the simulation with updating were significantly different from each other.

Table 21: Comparisons of Departure Times for Dallas – Fort Worth

Trip purpose	Time Period	Survey	Local Sample	Simulation w/o updating	D value	Simulation w/ updating	D – value
Home-Work	6 AM – 9 AM	36.7	37.4	36.5	0.0194*	37.9	0.0115
	9 AM – 4 PM	22.2	21.9	24		22	
	4 PM – 7 PM	27.2	27.4	24.5		26.8	
	7 PM – 6 AM	14.0	13.5	15		13.3	
Home-School	6 AM – 9 AM	51.6	51.7	52	0.0141	52.9	0.0128
	9 AM – 4 PM	42.7	41.3	42.5		39.9	
	4 PM – 7 PM	4.8	6.4	4.7		6.6	
	7 PM – 6 AM	0.9	0.6	0.8		0.5	
Home-College	6 AM – 9 AM	36.0	32.9	31.5	0.0635*	32.1	0.04
	9 AM – 4 PM	41.2	46.1	42.9		47.4	
	4 PM – 7 PM	11.8	14.5	16.5		13.6	
	7 PM – 6 AM	10.9	6.6	9.1		6.9	
(Table 21 Continued)							

Home-Shop	6 AM – 9 AM	4.2	5.1	5.8	0.0263*	5.2	0.0369*
	9 AM – 4 PM	44.1	42.5	46.3		41.2	
	4 PM – 7 PM	32.3	35.0	27.2		30.3	
	7 PM – 6 AM	19.5	17.4	20.7		23.2	
Home-Other	6 AM – 9 AM	17.2	15.8	12.1	0.0484*	13.6	0.036*
	9 AM – 4 PM	31.0	28.6	36.9		32.6	
	4 PM – 7 PM	28.9	29.6	28.2		38.7	
	7 PM – 6 AM	22.8	26.0	22.9		25	
Other-Work	6 AM – 9 AM	14.5	14.3	13.5	0.0148	13.4	0.0168
	9 AM – 4 PM	64.5	64.4	63.9		63.5	
	4 PM – 7 PM	18.2	17.7	18.5		19.3	
	7 PM – 6 AM	2.9	3.6	4.2		3.8	
Other-Other	6 AM – 9 AM	9.4	8.1	6.5	0.0287*	7.2	0.0238*
	9 AM – 4 PM	53.5	52.8	57		55.1	
	4 PM – 7 PM	22.9	23.1	20.8		21.1	
	7 PM – 6 AM	14.2	16.0	15.8		16.7	

For Dallas-Fort Worth all departure times except home-school and other-work show significant differences prior to updating. Trips in the 6 AM-9 AM category seem to have been underestimated although the differences are small. After updating, home-shop, home-other and other-other trips still showed significant differences. This could probably represent the local conditions in Dallas, where people shop and take care of other business at times that are different from the times predicted by the simulation prior to updating. While, updating has helped in reflecting the local conditions, it was unable to capture them fully.

Table 22 shows the comparison of departure times for Salt Lake. Home-school, home-shop and home-other departure times were found to be significantly different at the 95% confidence level. It appears that people in Salt Lake make shopping and other trips later in the day compared to the times predicted by the simulation. While the updating procedure picked up this local trend, it was unable to eliminate the significant differences.

Table 22: Comparisons of Departure Times for Salt Lake

Trip purpose	Period	Survey	Local Sample	Simulation w/o updating	D-value	Simulation w/ updating	D-value
Home-Work	6 AM – 9 AM	34.7	35.1	36.5	0.0102	35.7	0.011
	9 AM – 4 PM	25.7	25.8	24.4		25.3	
	4 PM – 7 PM	25.3	25.3	24.3		24.3	
	7 PM – 6 AM	14.4	13.9	14.8		14.7	
Home-School	6 AM – 9 AM	45.7	45.8	51.5	0.0695*	49.4	0.0373*
	9 AM – 4 PM	50.2	49.4	41.8		44.8	
	4 PM – 7 PM	3	3.3	6		4.7	
	7 PM – 6 AM	1.1	1.4	0.6		1	
Home-College	6 AM – 9 AM	27	24.1	32.2	0.0407	29.4	0.0344
	9 AM – 4 PM	41.7	41.6	42.3		42.8	
	4 PM – 7 PM	16.8	20.5	15.6		16.7	
	7 PM – 6 AM	14.5	13.9	9.8		11.1	
Home-Shop	6 AM – 9 AM	2.9	3.1	6.1	0.1046*	4.5	0.0828*
	9 AM – 4 PM	42.4	43.6	50.7		49	
	4 PM – 7 PM	33.3	32	25.3		27.8	
	7 PM – 6 AM	21.4	21.2	17.9		18.7	
Home-Other	6 AM – 9 AM	12.3	11.7	11.9	0.0588*	11.6	0.0245*
	9 AM – 4 PM	32.9	32.5	39		36.1	
	4 PM – 7 PM	29.5	32.1	26.8		29.3	
	7 PM – 6 AM	25.3	23.7	22.3		23	
Other-Work	6 AM – 9 AM	13.9	12.2	14.4	0.0133	13.9	0.0159
	9 AM – 4 PM	63.1	65.8	63.8		64.5	
	4 PM – 7 PM	19.8	18.8	17.1		17.7	
	7 PM – 6 AM	3.3	3.2	4.7		3.9	
Other-Other	6 AM – 9 AM	6	6.1	6.5	0.0103	6.4	0.0039
	9 AM – 4 PM	57.9	55.9	58.9		57.8	
	4 PM – 7 PM	22.4	25.3	19.5		21.9	
	7 PM – 6 AM	13.8	12.8	15.1		13.9	

*Significantly different at 95% confidence level.

Departure times have responded well to the local adjustments that have been carried out. In almost all cases, updating the departure times with those drawn from a local sample has helped to bring these values closer to the survey values.

4.4 Trip Length Comparisons

Trip lengths for Dallas-Fort Worth and Salt Lake are compared in Table 23. All the trip lengths are significantly different prior to updating for Dallas-Fort Worth. The trip lengths were consistently underestimated across all trip purposes. The simulation did not use any city size variable to predict trip lengths, therefore the results are not surprising. While updating clearly assisted in improving the trip lengths, all the trip lengths remained significantly different at the 95% confidence level.

The trip lengths for Salt Lake were consistently overestimated before updating. It appears that people in Salt Lake travel for shorter periods for all trip purposes compared to the trip lengths predicted by the simulation before updating. After updating, home-work, home-school, home-shop, home-other and other-other trip lengths remained significantly different but were observed to move closer to the survey values after updating.

Table 23: Comparisons of Trip Lengths for Dallas-Fort Worth and Salt Lake

Purpose	Dallas			Salt Lake		
	Survey	Sim w/o updating	Sim with updating	Survey	Sim w/o updating	Sim with updating
Home-work	29.29	19.17*	23.37*	18.70	19.38*	19.69*
Home-school	20.24	16.46*	19.00*	13.15	16.20*	15.08*
Home-college	24.18	19.09*	20.30*	16.31	17.92	16.99
Home-shop	14.52	11.46*	12.96*	10.77	11.91*	11.39*
Home-other	17.15	13.34*	14.72*	12.46	13.24*	12.95*
Other-work	19.80	14.13*	15.93*	14.10	14.18	14.02
Other-other	16.21	13.59*	15.04*	12.20	13.42*	13.19*
Total	20.05	14.59*	16.63*	13.33	14.47*	14.21*

4.4 Cumulative Effects of the Simulation with Updating

The simulation results presented in the previous section were obtained by changing one factor at a time in order to observe the effect of the updated distributions. For the simulation of updated mode shares, the NPTS distributions were used for the simulation of trip rates whereas the updated distributions were used for the simulation of mode shares. Similarly to observe the effect of updated departure time distributions, trip rates and mode shares were simulated using the respective NPTS distributions and departure times alone were simulated using the updated distributions. This simulation in parts was done in order to study the effects of updating on a particular trip attribute. However, the simulation with updating was also run, using all the updated distributions at a time in order to observe the cumulative effect. Trip rates remained unchanged when compared to the trip rates obtained after updating while running the simulation in parts, because these were the first trip attributes to be simulated. These trip rates have been presented in section 4.1 and are not reproduced here. Mode shares, departure times and trip lengths are expected to change compared to the values obtained from the simulation with updating, run in parts.

- **Mode Shares**

Dallas – Fort Worth

Table 24 presents the mode shares obtained from the simulation without updating, those obtained from the simulation with updating, with the simulation carried out in parts and those obtained from the simulation with updating, which was run cumulatively for Dallas-Fort Worth. Passenger shares were over-predicted whereas driver, public bus and bike/walk shares were under-predicted by the simulation after updating for home-work mode shares. Passenger and bike/walk shares were underpredicted and school bus shares were overpredicted by the cumulative simulation after updating. Home-college mode shares were well predicted with school bus share being the only share that showed a significant difference. The bike/walk share was overpredicted by the simulation after updating for home-shop trips. Mode shares for the home-other trips were poorly simulated with driver shares being underpredicted and passenger shares being overpredicted by the simulation after updating. School bus mode shares were overpredicted and bike/walk shares were underpredicted by the simulation after updating for other-work trips. Public bus shares and bike/walk shares were overpredicted and school bus shares were underpredicted by the simulation after updating for other-other trips.

It can be observed that using either the simulation with updating carried out in parts or the simulation with updating carried out cumulatively, the trends remained the same with some mode shares being over estimated and some being underestimated. Therefore using either of the two simulations should yield approximately similar results.

Table 24: Comparison of Mode Shares for Dallas-Fort Worth

Purpose	Mode	Survey	Sim w/o updating		Sim with updating		Cumulative sim with updating	
			Share	Z-value	Share	Z-value	Share	Z-value
Home-work	Driver	88.8	89.8	-2.03*	89.5	-1.42	88.2	1.02
	Passenger	5.7	6.6	-2.20*	6.0	-0.69	6.8	-2.68*
	Public Bus	3.9	1.8	7.28*	3.2	2.08*	3.4	1.40
	School Bus	0.0	0.2	-2.56*	0.1	-0.74	0.1	-2.23*
	Bike/Walk	1.60	1.6	0.04	1.2	1.78	1.4	0.83
	Rail	0.00	0	0.00	0.0	0.00	0	0.00
	Other	0.0	0	1.78	0.0	1.78	0	0.00
Home-school	Driver	5.0	4.4	0.99	4.8	0.37	4.7	0.44
	Passenger	49.2	37.6	7.90*	41.7	5.10*	41.9	4.90*
	Public Bus	3.6	1.9	3.50*	2.2	2.81*	3.3	0.53
	School Bus	22.2	48.3	-18.54*	36	-10.30*	33.9	-8.75*
	Bike/Walk	20.0	7.8	12.06*	15.3	4.14*	16.2	3.33*
	Rail	0.0	0	0.00	0.0	0.00	0	0.00
	Other	0.0	0	1.02	0.0	1.02	0	1.00
Home-college	Driver	69.3	75.3	-2.42*	71	-0.65	71.3	-0.78
	Passenger	16.2	10.3	3.14*	15.1	0.55	16.5	-0.15
	Public Bus	3.6	4.8	-1.10	4.5	-0.84	4.6	-0.96
	School Bus	3.6	0.9	3.22*	1.1	2.99*	1.3	2.75*
	Bike/Walk	7.3	8.3	-0.71	8.3	-0.71	6.2	0.82
	Rail	0.0	0	0.00	0.0	0.00	0	0.00
	Other	0.0	0.3	0.00	0.0	0.00	0.1	-0.98
Home-shop	Driver	77.5	74.0	3.30*	75.9	1.48	75.8	1.59
	Passenger	17.6	20.9	-3.36*	18.5	-0.92	17.6	-0.03
	Public Bus	0.7	0.7	-0.11	0.4	1.51	0.7	-0.01
	School Bus	0.0	0.4	-3.09*	0.3	-2.63*	0.1	-1.42
	Bike/Walk	4.1	4	0.32	4.7	-1.07	5.6	-2.62*
	Rail	0.0	0	0.00	0.0	0.00	0	0.00
	Other	0.1	0	0.65	0.2	-1.31	0.2	-1.48
Home-other	Driver	69.4	62.3	11.81*	64.5	8.15*	64.5	7.99*
	Passenger	25.8	30.9	-8.95*	27.8	-3.54*	28.2	-4.16*
	Public Bus	0.4	0.8	-4.04*	1.3	-7.66*	1.3	-7.02*
	School Bus	0.1	0.7	-7.02*	1.0	-9.09*	0.8	-8.20*

(Table 24 Continued)

	Bike/Walk	4.1	5.2	-4.17*	5.2	-4.01*	5	-3.27*
	Rail	0.0	0	-2.10*	0.0	-0.94	0	-1.95
	Other	0.1	0	3.32*	0.2	-0.32	0.2	0.01
Other-work	Driver	83.9	83.7	0.20	83.6	0.40	84.6	-1.05
	Passenger	9.7	10	-0.57	11.0	-2.22*	10.8	-1.80
	Public Bus	0.6	1.2	-2.81*	0.8	-0.89	0.8	-0.74
	School Bus	0.0	0.2	-2.79*	0.1	-2.46*	0.2	-2.75*
	Bike/Walk	5.6	4.8	1.74	4.2	3.13*	3.4	5.07*
	Rail	0.0	0.1	-2.46*	0.1	-1.86	0.1	-1.94
	Other	0.2	0.0	3.50*	0.2	0.77	0.1	1.47
Other-other	Driver	68.0	63.7	4.98*	66.2	2.15*	66.7	1.43
	Passenger	25.8	29.6	-4.66*	26.6	-0.99	26.3	-0.61
	Public Bus	0.4	0.9	-3.01*	1.3	-4.73*	1.3	-4.89*
	School Bus	1.3	0.6	4.15*	1.0	1.36	0.7	3.18*
	Bike/Walk	3.9	5.1	-3.27*	4.7	-2.26*	4.7	-2.25*
	Rail	0.00	0.00	-1.20	0.00	0.00	0.00	0.00
	Other	0.5	0.1	5.48*	0.2	3.21*	0.2	3.51*

Salt Lake

Mode share comparisons for Salt Lake are shown in Table 25. Auto driver shares were overpredicted and passenger shares were underpredicted by the cumulative simulation after updating. The other mode share was also poorly predicted because of the disparity in the definition of rail. For home-school trips, transit shares were overpredicted and bike/walk shares were grossly underpredicted by the cumulative simulation with updating. Home-college trips also showed a similar trend to home-school trips, with public bus shares being overpredicted and bike/walk shares being underpredicted by the simulation after updating. Driver shares were overpredicted and passenger and other mode shares were underpredicted for home-shop trips by the simulation after updating. Driver and school bus shares were overestimated and bike/walk and other shares were underestimated by the cumulative simulation after updating for home-other trips. However in most of the cases, it was observed that the mode shares obtained from the simulation with updating were much closer to the survey mode shares than those obtained from the simulation without updating. Other-work mode shares were well simulated with passenger shares being overestimated and other mode shares being underestimated by the cumulative simulation after updating. For other-other shares, school bus shares were overestimated and bike/walk and other shares were underestimated by the simulation after updating.

Table 25: Comparison of Mode Shares for Salt Lake

Purpose	Mode	Survey	Sim w/o updating		Sim with updating		Cumulative sim with updating	
			Share	Z-value	Share	Z-value	Share	Z-value
Home-work	Driver	82.9	90.4	-11.22*	86.2	-4.65*	86.1	-4.45*
	Passenger	9.8	6.5	6.26*	8	3.17*	8	3.26*
	Public Bus	2.2	1.6	1.88	2.1	0.23	2	0.56
	School Bus	0.1	0.2	-0.79	0	1.16	0.1	0.68
	Bike/Walk	5.2	1.3	8.80*	3.5	1.80	3.6	1.56
	Rail	0.1	0.0	1.75	0	1.75	0	1.72
	Other	0.8	0.0	6.34*	0.2	4.90*	0.3	3.35*
Home-school	Driver	7.00	4.1	4.62*	4.7	3.58*	6.1	1.46
	Passenger	33.10	40.3	-5.64*	35.3	-1.76	34.9	-1.48
	Public Bus	0.50	1.5	-3.90*	4.6	-10.75*	4.4	-10.61*
	School Bus	24.50	47.4	-18.27*	33.7	-7.66*	33.8	-8.02*
	Bike/Walk	34.20	6.7	24.34*	21	10.89*	20	12.35*
	Rail	0.00	0	0.00	0	0.00	0	0.00
	Other	0.60	0	3.15*	0.7	-1.17	0.8	-2.07*
Home-college	Driver	65.80	69.2	-1.39	66	-0.10	65.1	0.31
	Passenger	13.20	9	2.54*	14.7	-0.81	14.8	-0.96
	Public Bus	4.10	4.4	-0.30	4.7	-0.60	6.9	-2.57*
	School Bus	0.80	1.7	-1.66	1.7	-1.66	1.2	-0.83
	Bike/Walk	14.30	15.3	-0.58	11.2	1.73	10.8	2.18*
	Rail	0.00	0	0.00	0.2	-1.18	0	0.00
	Other	1.80	0.3	2.67*	1.4	0.60	1.2	1.06
Home-shop	Driver	68.50	73.0	-4.36*	70.8	-2.26*	71.6	-3.04*
	Passenger	26.0	22.7	3.39*	23.8	2.29*	22.6	3.52*
	Public Bus	0.60	0.7	-0.69	0.7	-0.69	0.9	-1.45
	School Bus	0.1	0.4	-3.51*	0.3	-2.44*	0.2	-1.81
	Bike/Walk	4.3	3.1	3.16*	4.1	0.60	4.5	-0.21
	Rail	0.1	0	1.44	0	1.44	0	1.45
	Other	0.4	0	3.71*	0.2	1.72	0.1	2.53*
Home-other	Driver	63.9	62.4	2.49*	63.5	0.58	66	-3.51*
	Passenger	26.1	31.1	-9.09*	28.8	-4.91*	26.9	-1.48
	Public Bus	0.6	0.4	1.48	0.6	0.08	0.5	0.83
	School Bus	0.2	0.8	-7.36*	0.6	-5.24*	0.5	-3.48*
	Bike/Walk	8.5	5.1	10.38*	6.1	7.09*	5.9	7.82*
	Rail	0	0	1.51	0	1.01	0.0	0.98
	Other	0.8	0	8.87*	0.4	4.36*	0.3	5.19*
Other-work	Driver	82.8	85.5	-3.28*	83.8	-1.14	81.9	1.04
	Passenger	9.5	9.4	0.15	9.7	-0.32	11.0	-2.25*
	Public Bus	0.6	0.7	-0.13	0.5	0.95	0.6	0.22
	School Bus	0.3	0.2	0.40	0.2	0.93	0.2	0.05

(Table 25 Continued)

	Bike/Walk	5.5	4.1	2.86*	5.2	0.68	5.5	0.04
	Rail	0	0.1	-0.61	0.1	-1.04	0	-0.56
	Other	1.3	0.1	6.62*	0.7	2.84*	0.7	2.70*
Other-other	Driver	64.1	64.2	-0.18	65	-1.19	64.5	-0.57
	Passenger	28.5	29.4	-1.14	27.4	1.42	28	0.61
	Public Bus	0.7	0.4	1.70	0.5	1.15	0.5	1.49
	School Bus	1.1	0.8	2.07*	0.6	3.63*	0.5	4.07*
	Bike/Walk	5	5.1	-0.32	6.2	-3.14*	6.1	-2.90*
	Rail	0.1	0	1.93	0	1.29	0	0.88
	Other	0.6	0.1	4.97*	0.3	2.94*	0.3	2.26*

Overall for both Dallas-Fort Worth and Salt Lake, the cumulative simulation after updating behaved very similarly to the simulation with updating done in parts.

- **Departure Times**

Dallas Fort Worth

Departure times for Dallas-Fort Worth were well simulated by the cumulative simulation after updating. Prior to updating, except for home-school and other-work all the departure times for the other trip purposes were significantly different from the survey departure times at the 95% confidence level. After cumulative simulation with updating, only home-other and other-other departure times were significantly different at the 95% confidence level.

Table 26: Comparison of Departure Times for Dallas-Fort Worth

Purpose	Departure Time	Survey	Sim without updating		Sim with updating		Cumulative sim with updating	
			%	D-value	%	D-Value	%	D-value
Home-work	6 AM – 9 AM	36.7	36.5	0.0194*	37.9	0.0115	37.8	0.0107
	9 AM – 4 PM	22.2	24		22		22.1	
	4 PM – 7 PM	27.2	24.5		26.8		26.9	
	7 PM – 6 AM	14.0	15		13.3		13.3	
Home-school	6 AM – 9 AM	51.6	52	0.0141	52.9	0.0128	52.0	0.0132
	9 AM – 4 PM	42.7	42.5		39.9		40.9	
	4 PM – 7 PM	4.8	4.7		6.6		6.5	
	7 PM – 6 AM	0.9	0.8		0.5		0.5	
Home-college	6 AM – 9 AM	36.0	31.5	0.0635*	32.1	0.04	33.3	0.0411
	9 AM – 4 PM	41.2	42.9		47.4		48.0	
	4 PM – 7 PM	11.8	16.5		13.6		11.8	
	7 PM – 6 AM	10.9	9.1		6.9		6.9	

(Table 26 Continued)

Home-shop	6 AM – 9 AM	4.2	5.8	0.0263*	5.2	0.0369*	5.4	0.0182
	9 AM – 4 PM	44.1	46.3		41.2		43.0	
	4 PM – 7 PM	32.3	27.2		30.3		30.3	
	7 PM – 6 AM	19.5	20.7		23.2		21.3	
Home-other	6 AM – 9 AM	17.2	12.1	0.0484*	13.6	0.036*	13.9	0.0332*
	9 AM – 4 PM	31.0	36.9		32.6		32.7	
	4 PM – 7 PM	28.9	28.2		38.7		28.2	
	7 PM – 6 AM	22.8	22.9		25		25.1	
Other-work	6 AM – 9 AM	14.5	13.5	0.0148	13.4	0.0168	13.2	0.012
	9 AM – 4 PM	64.5	63.9		63.5		64.8	
	4 PM – 7 PM	18.2	18.5		19.3		18.3	
	7 PM – 6 AM	2.9	4.2		3.8		3.7	
Other-other	6 AM – 9 AM	9.4	6.5	0.0287*	7.2	0.0238*	7.3	0.0245*
	9 AM – 4 PM	53.5	57		55.1		54.5	
	4 PM – 7 PM	22.9	20.8		21.1		21.5	
	7 PM – 6 AM	14.2	15.8		16.7		16.7	

The departure times obtained from the cumulative simulation after updating are better than the ones obtained from the simulation with updating done in parts as the number of significant differences after updating has reduced in the former

Salt Lake

The departure times obtained from the cumulative simulation after updating for Salt Lake are shown in Table 27. Before updating, home-school, home-shop and home-other departure times were found to be significantly different at the 95% confidence level. After updating, the departure times for these trip purposes still remained significantly different. However as noticed with the Dallas-Fort Worth departure times, those for Salt Lake obtained from the cumulative simulation after updating were much more improved than those obtained with the simulation with updating done in parts. Also, the number of significant differences obtained from cumulative simulation after updating were less than the ones obtained from the simulation with updating done in parts.

Table 27: Comparison of Departure Times for Salt Lake

Purpose	Departure Time	Survey	Sim without updating		Sim with updating		Cumulative sim with updating	
			%	D-value	%	D-Value	%	D-value
Home-work	6 AM – 9 AM	34.7	36.5	0.0102	35.7	0.0177	35.7	0.0104
	9 AM – 4 PM	25.7	24.4		25.3		25.1	
	4 PM – 7 PM	25.3	24.3		24.3		24.9	
	7 PM – 6 AM	14.4	14.8		14.7		14.3	
Home-school	6 AM – 9 AM	45.7	51.5	0.0695*	49.4	0.0586*	49.7	0.0397*
	9 AM – 4 PM	50.2	41.8		44.8		45.2	
	4 PM – 7 PM	3	6		4.7		4.2	
	7 PM – 6 AM	1.1	0.6		1		0.9	
Home-college	6 AM – 9 AM	27	32.2	0.0407	29.4	0.0581*	29.1	0.0433
	9 AM – 4 PM	41.7	42.3		42.8		44	
	4 PM – 7 PM	16.8	15.6		16.7		15	
	7 PM – 6 AM	14.5	9.8		11.1		12	
Home-shop	6 AM – 9 AM	2.9	6.1	0.1046*	4.5	0.1153*	4.4	0.0719*
	9 AM – 4 PM	42.4	50.7		49		48	
	4 PM – 7 PM	33.3	25.3		27.8		28.7	
	7 PM – 6 AM	21.4	17.9		18.7		18.8	
Home-other	6 AM – 9 AM	12.3	11.9	0.0588*	11.6	0.0567*	12	0.0314*
	9 AM – 4 PM	32.9	39		36.1		36.3	
	4 PM – 7 PM	29.5	26.8		29.3		29.6	
	7 PM – 6 AM	25.3	22.3		23		22.1	
Other-work	6 AM – 9 AM	13.9	14.4	0.0133	13.9	0.014	13.7	0.0144
	9 AM – 4 PM	63.1	63.8		64.5		64.7	
	4 PM – 7 PM	19.8	17.1		17.7		17.8	
	7 PM – 6 AM	3.3	4.7		3.9		3.8	
Other-other	6 AM – 9 AM	6	6.5	0.0103	6.4	0.016	5.8	0.0075
	9 AM – 4 PM	57.9	58.9		57.8		57.3	
	4 PM – 7 PM	22.4	19.5		21.9		23.2	
	7 PM – 6 AM	13.8	15.1		13.9		13.7	

- **Trip Lengths**

Dallas-Fort Worth

The trip lengths for Dallas-Fort Worth are shown in Table 28. The trip lengths obtained both before and after updating are underestimated across all trip purposes. However the trip lengths obtained after updating are much closer to the survey values than those obtained prior to updating. The trip lengths obtained from the cumulative simulation with updating are not very different from the ones obtained from the simulation with updating run in parts.

Table 28: Comparison of Trip Lengths for Dallas-Fort Worth

Purpose	Survey	Sim without updating	Sim with updating	Cumulative sim with updating
Home-work	29.29	19.17*	23.37*	23.92*
Home-school	20.24	16.46*	19.00*	17.24*
Home-college	24.18	19.09*	20.30*	20.49*
Home-shop	14.52	11.46*	12.96*	12.82*
Home-other	17.15	13.34*	14.72*	14.83
Other-work	19.80	14.13*	15.93*	16.33*
Other-other	16.21	13.59*	15.04*	14.91*
Total	20.05	14.59*	16.63*	16.89*

Salt Lake

The trip lengths for Salt Lake are shown in Table 29. The trip lengths for all purposes are overestimated by the simulation both before and after updating. All the trip lengths except for home-college and other-work show significant differences at the 95% confidence level after updating, with very little difference between the values obtained from the simulation run in parts and those obtained from the cumulative simulation with updating.

Table 29: Comparison of Trip Lengths for Salt Lake

Purpose	Survey	Sim without updating	Sim with updating	Cumulative sim with updating
Home-work	18.70	19.38*	19.69*	19.54*
Home-school	13.15	16.20*	15.08*	14.64*
Home-college	16.31	17.92	16.99	17.57
Home-shop	10.77	11.91*	11.39*	11.51*
Home-other	12.46	13.24*	12.95*	13.18*
Other-work	14.10	14.18	14.02	14.05
Other-other	12.20	13.42*	13.19*	13.14*
Total	13.33	14.47*	14.21*	14.22*

4.5 Summary

The results shown here suggest that updating either done in parts or cumulatively is capable of producing trip rates, mode shares, departure times and trip lengths that are closer to the survey values than those obtained without updating in most cases. . However, it is not able to improve the values to the point of no significant difference from the household interview surveys, especially when the difference prior to updating is large. Therefore updating in general has succeeded in moving the simulated values in the right direction and closer to the survey values. However, the advantages of updating cannot be completely estimated by either the presence or absence of statistically significant differences. The presence or absence of statistically significant differences is neither a necessary nor a sufficient condition to draw conclusions about the advantages of updating. The travel survey data produced by the simulation will be used in building models and population values and unless and until these values are compared with the values estimated from the data obtained from travel surveys, the merits of updating cannot be completely specified and the conclusions pertaining to the advantages of updating cannot be drawn.

5. CONCLUSIONS AND RECOMMENDATIONS

An alternative approach for generating a synthetic data set incorporating local characteristics is tested in this thesis. It utilizes data sets (NPTS and PUMS90) that are available freely and requires a small local sample of households for the process of updating. The advantage of this method is that it produces a data set that has a local element to it, at a fraction of the cost of conducting a travel survey. It will be able to capture the differences that may not be captured by demographic characteristics alone. The synthetic data obtained from the simulation after updating were closer to the survey values than those obtained without updating.

The results achieved in this thesis are encouraging and indicate that the updating procedure tested in this research if used in conjunction with the simulation, can provide small/medium MPOs with the capability of generating a synthetic travel data set for their regions that incorporates a local element into their estimation process. However, conclusions regarding the benefit of the updating procedure cannot be drawn without building models with the updated data and generating population values and comparing these values with those obtained from the survey data. The synthetic data produced here must be tested against borrowed models and national default rates, to check whether significant improvements are obtained.

Trip rates after updating were well simulated and were generally comparable to the survey data. The simulation had inherent problems while trying to simulate home-other and other-other trips. Therefore, these trip purposes showed more significant differences than the other trip purposes. Mode shares after updating were found to be less effectively replicated. The accurate prediction of mode shares requires that information pertaining to the transportation system and the spatial environment must be incorporated into the simulation procedure. Because this simulation is based on demographic characteristics alone, these differences are not wholly unexpected. Departure times after updating were observed to have less significant differences. Trip lengths were poorly simulated before updating because the simulation did not incorporate any city size variable in order to predict them. While they showed improvement after updating, because of the large differences they were not improved to the point of no significant differences.

The impact of the local sample was observed in the differences in simulation for Dallas-Fort Worth and Salt Lake data. It was observed that the significant differences after updating for Dallas-Fort Worth were fewer than for Salt Lake. The simulation prior to updating was able to predict the data for Dallas-Fort Worth more accurately than for Salt Lake.

Three factors affected the results obtained from this procedure. Firstly, the survey methodologies for the NPTS, the Dallas-Fort Worth and the Salt Lake surveys are all different from each other. This difference in methodologies was reflected in the difference in non-mobility rates that were seen in the Dallas-Fort Worth survey compared to the NPTS. Due to the difference, trip rates were affected especially in Dallas-Fort Worth.

Secondly, the choice of the update sample also played a pivotal role in determining the number of significant differences after updating. It was observed that in some situations where the local sample was not representative, updating caused the values to move further away from the population values, making them more significant. The update sample adopted in this research consisted of 525 households, which were drawn as a random stratified disproportionate sample. The procedure outlined here was tested in areas that had previously conducted household travel surveys. However most small/medium MPOs will not have the luxury of obtaining a local sample from a previously conducted travel survey. Past research has proved that increasing the sample size reduces the sampling error while increasing cost. Hence, a tradeoff between the sample size and cost is required to enable accurate replication of survey data. The sample size of 525 households, while improving the results in most cases, also led to worsening of results after updating in some cases. Since the objective here was to validate and test the updating procedure, tests for varying sample sizes were not performed. The updating procedure needs to be further tested with varying sample sizes and conclusions on optimum sample size for updating need to be drawn. Also, tests with varying sampling schemes need to be carried out.

Third, the updating procedure adopted used equal variances as weights for both the prior and the local sample distributions. While this weighting scheme improved the results to some extent, they were not improved to the point of no significant difference. Therefore more tests need to be performed using various weights in order to arrive at the optimum weighting scheme.

5.1 Suggestions for Future Work

The work done in this research put forward a method for updating a synthetic data set. The following recommendations are made for further research in this area.

1. This approach needs to be refined further in order to generate conclusive evidence that updating has advantages. Models built with the synthetic data need to be compared with those built from the survey and the statistics derived from these

models, namely person trips by trip purpose need to be compared in order to assess the utility of updating.

2. This approach must be tested for different sample sizes, bearing in mind that larger sample sizes will increase the cost, defying the purpose of this research. Conclusions about the optimum sample size need to be drawn.
3. Future work must assess the various options available for use of varying weights in the updating process. Tests giving more weight to the local sample distributions or the NPTS distributions should be made and their affect on the simulated data should be studied.
4. The validation of the results must be extended towards developing travel forecasts and comparing them to the forecasts obtained from borrowed models.

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APPENDIX: COMPARISON OF TRIP RATES

Tables A.1 through A.10 present the comparisons of trip rates for Dallas-Fort Worth and Salt Lake. Table A.1 shows the comparison of person trip rates per household for Dallas-Fort Worth.

Table A.1 Comparison of Trip Rates for Dallas-Fort Worth

Purpose	Survey	Local Sample	Simulation without updating			Simulation with Updating		
			Mean	Standard Deviation	z-score	Mean	Standard Deviation	z-score
Home -Work	1.73	1.74	1.84	1.74	-2.96*	1.82	1.74	-2.42*
Home-School	0.57	0.63	0.59	1.32	-0.68	0.57	1.29	0.00
Home-College	0.17	0.15	0.16	0.64	0.73	0.17	0.65	0.00
Home-Shop	0.63	0.69	1.19	1.65	-17.39*	0.94	1.49	-10.27*
Home-Other	2.91	2.95	3.28	3.67	-4.59*	3.04	3.56	-1.64
Other-Work	1.17	1.12	1.36	2.06	-4.42*	1.24	1.87	-1.72
Other-Other	1.29	1.18	1.79	2.81	-8.77*	1.44	2.5	-2.82*
Total	8.47	8.46	10.2	7.35	-10.96*	9.22	6.71	-4.98*

*Significantly different at the 95% confidence level

Table A.2 shows the person trip rates per household for Salt Lake. The z score is used to illustrate significant differences.

Table A.2 Comparison of trip rates for Salt Lake

Purpose	Survey	Local Sample	Simulation without Updating			Simulation with updating		
			Mean	Standard Deviation	z-score	Mean	Standard Deviation	z-score
Home -Work	1.66	1.61	1.69	1.74	-0.70	1.63	1.69	0.71
Home-School	1.2	1.26	0.74	1.66	9.03*	0.85	1.8	6.67*
Home-College	0.28	0.32	0.21	0.79	3.18*	0.27	0.86	0.44
Home-Shop	1.25	1.34	1.3	1.72	-1.12	1.33	1.79	-1.75
Home-Other	4.93	4.89	3.66	3.93	11.24*	3.58	3.51	12.45*
Other-Work	1.29	1.14	1.24	1.97	1.04	1.32	1.76	-0.66
Other-Other	2.67	2.61	1.99	2.99	8.31*	2.2	3.05	5.69*
Total	8.47	13.16	10.83	7.97	10.64*	11.17	7.38	9.44*

*Significantly different at the 95% confidence level

Comparison of person trip rates per household by household size are presented in Table A.3 for Dallas Fort-Worth. These trip rates are compared across seven trip purposes and across five household size categories. These trip rates are tested at the 95% confidence level.

Table A.3 Comparisons of Person Trip Rates per Household by Household Size for Dallas

Trip Purpose	Data Set	Household Size				
		1	2	3	4	5+
Home-Work	Survey	0.95	1.78	2.23	2.23	2.34
	Simulation without updating	0.99	1.88	2.39	2.34	2.56
	Simulation with updating	0.97	1.89	2.33	2.27	2.54
Home-School	Survey	0.00	0.09	0.61	1.57	2.86
	Simulation without updating	0.00	0.08	0.62	1.63	2.95
	Simulation with updating	0.00	0.07	0.57	1.58	2.88
Home-College	Survey	0.06	0.09	0.31	0.28	0.38
	Simulation without updating	0.09	0.13*	0.27	0.19*	0.28
	Simulation with updating	0.11*	0.14*	0.26	0.22	0.27
Home-Shop	Survey	0.35	0.73	0.73	0.69	0.85
	Simulation without updating	0.59*	1.16*	1.39*	1.71*	2.01*
	Simulation with updating	0.50*	0.98*	1.03*	1.33*	1.42*
Home-Other	Survey	1.08	2.40	3.38	5.07	6.70
	Simulation without updating	1.28*	2.55	3.92*	5.65*	7.79*
	Simulation with updating	1.15	2.38	3.55	5.44	7.14
Other-Work	Survey	0.72	1.07	1.54	1.68	1.46
	Simulation without updating	0.72	1.49*	1.59	1.81	1.69
	Simulation with updating	0.68	1.35*	1.47	1.64	1.52
Other-Other	Survey	0.62	1.18	1.46	1.92	2.64
	Simulation without updating	0.77*	1.46*	2.25*	2.76*	4.08*
	Simulation with updating	0.66*	1.20	1.73	2.39*	2.85
All Purposes	Survey	3.78	7.34	10.26	13.46	17.24
	Simulation without updating	4.55*	8.75*	12.42*	16.08*	21.36*
	Simulation with updating	4.07*	8.02*	10.94*	14.87*	18.63

*Significantly different at the 95% confidence level

Table A.4 shows the comparisons of person trip rates by household by household size for Salt Lake.

Table A.4 Comparisons of Person Trip Rates per Household by Household Size for Salt Lake

Trip Purpose	Data Set	Household Size				
		1	2	3	4	5+
Home-Work	Survey	0.73	1.55	1.98	2.29	2.52
	Simulation without updating	0.78	1.47	2.21*	2.74*	2.40
	Simulation with updating	0.78	1.45	2.05	2.59*	2.25*
Home-School	Survey	0.00	0.04	0.99	2.42	5.40
	Simulation without updating	0.00	0.08*	0.52*	1.46*	3.33*
	Simulation with updating	0.03*	0.12*	0.59*	1.62*	3.75*
Home-College	Survey	0.06	0.29	0.27	0.42	0.49
	Simulation without updating	0.08	0.18*	0.25	0.31	0.32*
	Simulation with updating	0.11*	0.25	0.33	0.40	0.42
Home-Shop	Survey	0.53	1.07	1.47	1.73	2.24
	Simulation without updating	0.59	1.27*	1.61	1.72*	1.80*
	Simulation with updating	0.53	1.28*	1.67	1.84*	1.90*
Home-Other	Survey	1.67	3.43	5.27	7.33	11.59
	Simulation without updating	1.36*	2.83*	3.63*	5.34*	8.07*
	Simulation with updating	1.48*	3.22	4.42*	5.77*	5.18*
Other-Work	Survey	0.67	1.16	1.62	1.94	1.72
	Simulation without updating	0.54	1.05*	1.66	1.83	1.96
	Simulation with updating	0.55	1.04*	1.49	1.64	1.80
Other-Other	Survey	1.05	2.11	2.97	3.91	5.35
	Simulation without updating	0.86*	1.60*	2.14*	2.82*	3.94*
	Simulation with updating	1.02	1.71*	2.46*	3.39	4.16*
All Purposes	Survey	4.7	9.66	14.57	20.03	29.31
	Simulation without updating	4.2*	8.48*	12.02*	16.22*	21.82*
	Simulation with updating	4.51	9.07*	13.00*	17.25*	19.47*

* Significant difference at the 95% confidence level

Table A.5 shows the comparison of person trip rates per household by workers per household for Dallas-Fort Worth.

Table A.5 Comparisons of Person Trip Rates per Household by Workers per Household for Dallas

Trip Purpose	Data Set	Workers per Household			
		0	1	2	3+
Home-Work	Survey	0.00	1.40	2.43	3.4
	Simulation without updating	0.00*	1.39	2.62*	4.34*
	Simulation with updating	0.00	1.35	2.62*	4.06*
Home-School	Survey	0.14	0.47	0.77	1.01
	Simulation without updating	0.13	0.51	0.79	0.98
	Simulation with updating	0.12	0.50	0.75	0.95
Home-College	Survey	0.08	0.13	0.16	0.63
	Simulation without updating	0.08	0.12	0.19	0.44
	Simulation with updating	0.09	0.14	0.2	0.45
Home-Shop	Survey	0.85	0.55	0.61	0.71
	Simulation without updating	1.31*	0.96*	1.32*	1.63*
	Simulation with updating	1.24*	0.75*	1.00*	1.14*
Home-Other	Survey	2.51	2.45	3.34	4.08
	Simulation without updating	2.68	2.74*	3.74*	5.45*
	Simulation with updating	2.30	2.55	3.53	5.09*
Other-Work	Survey	0.00	0.93	1.74	1.87
	Simulation without updating	0.00	1.01	2.1*	2.42*
	Simulation with updating	0.00	0.93	1.9*	2.12
Other-Other	Survey	1.18	1.16	1.42	1.58
	Simulation without updating	1.54*	1.51*	2.01*	2.88*
	Simulation with updating	1.13	1.29	1.58	2.27*
All Purposes	Survey	4.98	7.09	10.47	13.29
	Simulation without updating	5.74*	8.25*	12.76*	18.14*
	Simulation with updating	5.02	7.51*	11.59*	16.09*

*Significantly different at the 95% confidence level

Comparison of person trip rates per household by workers per household for Salt Lake are presented in Table A.6.

Table A.6 Comparisons of Person Trip Rates per Household by Workers per Household for Salt Lake

Trip Purpose	Data Set	Workers per Household			
		0	1	2	3+
Home-Work	Survey	0.00	1.39	2.31	3.77
	Simulation without updating	0.00	1.40	2.65*	4.09
	Simulation with updating	0.00	1.37	2.54*	3.62
Home-School	Survey	0.18	1.18	1.40	2.93
	Simulation without updating	0.16	0.73*	0.99*	1.57*
	Simulation with updating	0.20	0.83*	1.13*	1.78*
Home-College	Survey	0.11	0.23	0.35	0.67
	Simulation without updating	0.07	0.13*	0.26*	0.79
	Simulation with updating	0.09	0.18	0.34	0.96*
Home-Shop	Survey	1.03	1.17	1.28	2.05
	Simulation without updating	1.38*	1.06	1.38	1.74
	Simulation with updating	1.40*	1.07	1.43	1.84
Home-Other	Survey	3.28	4.43	5.35	9.36
	Simulation without updating	2.84*	3.37*	4.00*	6.03*
	Simulation with updating	3.06	3.13*	3.98*	5.48*
Other-Work	Survey	0.00	1.06	1.93	2.49
	Simulation without updating	0.00	1.03	2.01	2.63
	Simulation with updating	0.00	1.04	1.90	2.22
Other-Other	Survey	1.91	2.32	2.94	4.99
	Simulation without updating	1.58*	1.86*	2.20*	2.90*
	Simulation with updating	1.78	2.01*	2.43*	3.43*
All Purposes	Survey	6.75	11.77	15.56	26.25
	Simulation without updating	6.02*	9.58*	13.49*	19.75*
	Simulation with updating	6.59*	9.62*	13.74*	19.33*

*Significantly different at the 95% confidence level

Person trip rates by school age children per household are compared in Table A.7 for Dallas-Fort Worth.

Table A.7 Comparisons of Person Trip Rates per Household by School Age Children per Household for Dallas-Fort Worth

Trip Purpose	Data Set	School Age Children per Household			
		0	1	2	3+
Home-Work	Survey	1.61	2.08	1.98	2.00
	Simulation without updating	1.67	2.34*	2.10	2.50*
	Simulation with updating	1.65	2.31*	2.08	2.49*
Home-School	Survey	0.00	1.12	2.47	4.30
	Simulation without updating	0.00	1.35*	2.69	4.17
	Simulation with updating	0.00	1.23*	2.70*	4.06
Home-College	Survey	0.15	0.27	0.17	0.19
	Simulation without updating	0.16	0.17*	0.16	0.20
	Simulation with updating	0.17	0.18*	0.18	0.21
Home-Shop	Survey	0.59	0.65	0.74	0.91
	Simulation without updating	0.99*	1.47*	1.90*	2.21*
	Simulation with updating	0.80*	1.20*	1.38*	1.60*
Home-Other	Survey	2.00	3.95	6.11	7.59
	Simulation without updating	2.22*	4.84*	7.14*	8.76
	Simulation with updating	2.07	4.54*	6.45	8.14
Other-Work	Survey	1.02	1.60	1.63	1.18
	Simulation without updating	1.27*	1.62	1.58	1.53
	Simulation with updating	1.17*	1.46	1.44	1.38
Other-Other	Survey	0.96	1.69	2.63	2.41
	Simulation without updating	1.31*	2.42*	3.56*	4.54*
	Simulation with updating	1.06*	2.10*	2.60	3.40*
All Purposes	Survey	6.34	11.36	15.74	18.57
	Simulation without updating	7.63*	14.21*	19.12*	23.91*
	Simulation with updating	6.93*	13.01*	16.84	21.29*

*Significantly different at the 95% confidence level

Table A.8 compares the trip rates by school age children per household for Dallas-Fort Worth.

Table A.8 Comparisons of Person Trip Rates per Household by School Age Children per Household for Salt Lake

Trip Purpose	Data Set	School Age Children per Household			
		0	1	2	3+
Home-Work	Survey	1.43	2.02	2.17	2.23
	Simulation without updating	1.47	2.22	2.31	2.36
	Simulation with updating	1.42	2.12	2.19	2.21
Home-School	Survey	0.03	1.58	3.03	5.98
	Simulation without updating	0.00*	1.36*	2.75*	4.70*
	Simulation with updating	0.03	1.51	2.99	5.36*
Home-College	Survey	0.28	0.22	0.26	0.37
	Simulation without updating	0.21*	0.18	0.15	0.22
	Simulation with updating	0.28	0.27	0.18	0.27
Home-Shop	Survey	0.97	1.52	1.81	2.18
	Simulation without updating	1.10*	1.64	1.87	1.99
	Simulation with updating	1.12*	1.63	2.06	2.03
Home-Other	Survey	3.12	5.82	7.96	11.85
	Simulation without updating	2.52*	4.82*	6.96*	9.10*
	Simulation with updating	2.92*	4.92*	5.51*	5.60*
Other-Work	Survey	1.08	1.83	1.75	1.61
	Simulation without updating	1.04	1.67	1.93	1.76
	Simulation with updating	0.99	1.53	1.78	1.69
Other-Other	Survey	1.91	3.24	3.98	5.42
	Simulation without updating	1.47*	2.59*	3.28*	4.56
	Simulation with updating	1.68*	2.77	3.69	4.72
All Purposes	Survey	8.81	16.24	20.97	29.64
	Simulation without updating	7.78*	14.49*	19.25*	24.70*
	Simulation with updating	8.45*	14.74*	18.40*	21.87*

*Significantly different at the 95% confidence level

Table A.9 shows the comparison of person trip rates by vehicle per household for Dallas-Fort Worth.

Table A.9 Comparisons of Person Trip Rates per Household by Vehicles per Household for Dallas-Fort Worth

Trip Purpose	Data Set	Vehicles per Household			
		0	1	2	3+
Home-Work	Survey	1.01	1.16	1.94	2.47
	Simulation without updating	0.99	1.28*	2.06*	2.68*
	Simulation with updating	1.02	1.26	2.04	2.62
Home-School	Survey	0.57	0.34	0.65	0.78
	Simulation without updating	0.46	0.36	0.66	0.93
	Simulation with updating	0.41	0.36	0.63	0.89
Home-College	Survey	0.15	0.09	0.14	0.38
	Simulation without updating	0.22	0.13*	0.15	0.26*
	Simulation with updating	0.20	0.14*	0.16	0.29
Home-Shop	Survey	0.32	0.52	0.71	0.73
	Simulation without updating	0.88*	0.94*	1.29*	1.51*
	Simulation with updating	0.75*	0.78*	1.01*	1.13*
Home-Other	Survey	0.98	1.89	3.47	3.93
	Simulation without updating	2.33*	2.29*	3.67	4.59*
	Simulation with updating	2.10*	2.09	3.44	4.27
Other-Work	Survey	0.19	0.80	1.41	1.54
	Simulation without updating	0.72*	0.96*	1.58*	1.82*
	Simulation with updating	0.66*	0.90	1.44	1.62
Other-Other	Survey	0.31	0.96	1.50	1.66
	Simulation without updating	1.13*	1.36*	1.93*	2.54*
	Simulation with updating	0.83*	1.10	1.54	2.08*
All Purposes	Survey	3.55	5.76	9.82	11.49
	Simulation without updating	6.73*	7.31*	11.34*	14.34*
	Simulation with updating	5.97*	6.62*	10.26	12.91*

*Significantly different at the 95% confidence level

The comparisons of person trip rates per household by vehicles per household for Salt Lake are shown in Table A.10.

Table A.10 Comparisons of Person Trip Rates per Household by Vehicles per Household for Salt Lake

Trip Purpose	Data Set	Vehicles per Household			
		0	1	2	3+
Home-Work	Survey	0.71	1.12	1.71	2.41
	Simulation without updating	0.52	1.11	1.78	2.54
	Simulation with updating	0.56	1.10	1.71	2.37
Home-School	Survey	0.19	0.59	1.40	1.75*
	Simulation without updating	0.10	0.35*	0.84*	1.20*
	Simulation with updating	0.11	0.42*	0.95*	1.37
Home-College	Survey	0.15	0.28	0.26	0.38
	Simulation without updating	0.19	0.12*	0.19*	0.36
	Simulation with updating	0.26	0.16*	0.23	0.50
Home-Shop	Survey	0.68	0.94	1.30	1.65
	Simulation without updating	0.77	1.02	1.38	1.61
	Simulation with updating	0.76	1.04	1.41	1.66
Home-Other	Survey	1.93	3.45	5.34	6.52
	Simulation without updating	1.56	2.50*	4.09*	4.73*
	Simulation with updating	1.70	2.58*	3.98*	4.44*
Other-Work	Survey	0.40	0.85	1.43	1.71
	Simulation without updating	0.30	1.56	1.35	1.79
	Simulation with updating	0.30	1.79	1.29	1.63
Other-Other	Survey	1.20	1.98	2.85	3.46
	Simulation without updating	0.61*	1.42*	2.23*	2.52*
	Simulation with updating	0.78*	1.60*	2.44*	2.82*
All Purposes	Survey	5.27	9.20	14.29	17.86
	Simulation without updating	4.04*	7.33*	11.86*	14.75*
	Simulation with updating	4.47	7.70*	12.01*	14.78*

*Significantly different at the 95% confidence level

VITA

Sirisha Kothuri was born on June 25th, 1978 in Indore, India, to Ramanamurthy Kothuri and Usha Bharathi Kothuri. She graduated from St. Ann's high school in 1993 and St. Francis junior college in 1995. She received her Bachelor of Engineering in civil engineering in 1999 from M. J. College of Engineering and Technology, Osmania University, Hyderabad, India. She came to the United States in the fall of 1999 to pursue a master's degree in civil engineering, majoring in transportation engineering at Louisiana State University, Baton Rouge, Louisiana. She married Dr. Sridhar Govindaraju in December 2000. She is currently pursuing a career in transportation research at the Texas Transportation Institute in Austin, Texas. The degree of Master of Science in civil engineering will be conferred on Ms. Kothuri at the august 2002 commencement.