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An analysis of factors related to areawide highway traffic congestion

Elisabeth Anne Hahn

To the Graduate Council:

I am submitting herewith a thesis written by Elisabeth Anne Hahn entitled "An analysis of factors related to areawide highway traffic congestion." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Arun Chatterjee, Major Professor

We have read this thesis and recommend its acceptance:

Frederick J. Wegmann, Mary Sue Younger, Shih-Lung Shaw

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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An Analysis of Factors Related to Areawide Highway Traffic Congestion

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Elisabeth Anne Hahn
December 2000

DEDICATION

This thesis is dedicated to my parents,

George and Charlotte Hahn.

I am eternally grateful for their encouragement and support.

And a very special thanks to Melanie J White.

I couldn't have possible made it without her willingness to let me hog the computer

and her encouragement and laughter.

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I am very grateful to Dr. Arun Chatterjee for providing direction, for assisting me in accessing the needed resources, and for his encouragement and kindness throughout the process. Dr. Mary Sue Younger was very patient and helpful in guiding me through the regression analysis, and Dr. Shaw generously donated his time to review my findings.

Dr. Rich Margiotta graciously took the time to meet with me to discuss this project and supplied both HPMS data and congestion indices used to perform the regression analysis

Also, I would like to thank Deanna Flinchum and Dr. Stephen Richards at the Southeastern Transportation Center for providing the funding for me to pursue a Master of Science Degree in Civil Engineering with a focus on Transportation Engineering.

Dr Frederick Wegmann has provided enthusiastic support I have greatly appreciated his patience, guidance, and his sense of humor which made my experience as a graduate student enjoyable. He and the others acknowledged in this section are responsible for making this research effort a positive experience

ABSTRACT

Roadway expansion is a traditional strategy used to accommodate travel demand and reduce traffic congestion in urban areas. The potential negative effects of roadway expansion and mounting concerns over urban area congestion, however, have spurred research into the factors that control congestion.

The aim of this study is to investigate the relationship between traffic congestion, travel demand, and supply of roadways. To accomplish this goal, data for the top 138 urbanized areas (by population) were assembled for developing a least squares regression model. Travel Rate Index, a congestion measure developed by researchers at the Texas Transportation Institute, was selected as the response (dependent) variable. A variety of explanatory variables were used to address highway and transit supply and travel demand related factors.

The partial regression coefficients measured the effect of each explanatory (independent) variable on congestion (as measured by Travel Rate Index), holding all other independent variables constant. The results of the multiple regression analysis indicated a negative correlation between freeway lane miles and Combined Travel Rate Index. Additionally, a strong positive correlation was observed between Combined Travel Rate Index and population density and net land area, respectively. A positive correlation was observed between Combined Travel Rate Index and bus transit service revenue miles Principal arterial lane miles and rail transit revenue miles variables were not observed to be

significant for explaining traffic congestion and were removed entirely during the stepwise regression

The results indicated that the best predictors among the tested variables were freeway lane miles, population density, net land area, and bus revenue miles. When used together, these predictors accounted for approximately 61% of the total variation in the dependent variable, Combined Travel Rate Index. Overall, population and net land area accounted for the bulk of the variation in congestion level (Travel Rate Index).

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Chapter I. Introduction & Research Goal

Urban area traffic congestion is the result of the interaction of travel demand and transportation supply Highway travel demand is explained by a combination of socioeconomic and demographic characteristics such as population and population density, transit use, auto dependence etc Traditionally, increasing road capacity is considered to be an essential strategy for combating congestion, although a number of transportation demand and system management strategies are being applied as lower cost alternatives for alleviating congestion.

An anti-freeway sentiment was energized in some urban areas in the late 1960's and resulted in the cancellation of a few proposed freeway projects. Such a sentiment still exists, and there are many persons who blame highways for.

- the decline of environmental quality and resource preservation due to increased auto dependency and land development,
- reduced economic opportunity through disinvestments in the urban core,
- increased travel times, and as a result, increased cost of commerce,
- underutilization of alternative modes (e.g. transit) and loss of opportunity to develop more efficient alternatives, and
- loss of a sense of community.

Recently, the issue of induced travel demand has gained attention. Induced travel demand theory suggests that increasing roadway capacity of major arterial highways, as a means to solving urban area traffic congestion, is a short term solution and may actually serve to perpetuate the problem by inducing more travel and in turn bringing about urban sprawl This study does not address the issues involving induced travel

New research efforts to quantify networkwide congestion have resulted in the establishment of congestion measures with a broader range of applications than Highway Capacity Manual methods The new procedures can be used for the analysis of congestion along roadway sections, corridors, and within sub-areas and regional networks Furthermore, they allow for the comparison of facilities having different performance characteristics and are considered to be straightforward, consistent, and reliable (Schrank et al. 1999). These performance measures provide an alternative approach for investigating congestion as it relates to roadway supply and other factors.

Among the major highways, the most attention drawing facilities are freeways Traffic congestion on freeways as well as freeway expansion is often controversial. The goal of this research is to try to explain freeway traffic congestion in terms of the supply of different types of highways—freeways and non-freeways, transit supply, and in terms of travel demand related factors such as population density and land area. Traffic congestion on principal arterials is also examined.

Chapter II. Literature Review

Traffic congestion measures have been generated for a variety of reasons, including for input into air quality/energy models, assessment of traffic controls, prioritization of transportation improvement projects, identification of facility/system deficiencies, and development of policy guidelines These measures and related procedures vary in a number of ways: cost of data collection, level of complexity, and applicability (e g corridor vs areawide measures), etc (Levinson 1996).

In an article entitled *Alternative Methods for Measuring Congestion Levels,* Michael Meyer (1994) provides a summary of congestion measures generated from the mid 1950's up until the early 90's, some of which are still being applied today. These include:

- ratio of actual travel time to the optimum travel time on a roadway section,
- straight travel time to traverse a specific section of roadway,
- reduction of speed under high volume conditions,
- relationship of average overall speed to speed changes and frequency of speed changes per mile, and
- v/c ratios in excess of 0 77 for urban areas of population of more than 50,000

The above list does not include all traffic congestion measures used in different studies In most cases, the congestion measure is related to either speed or traffic density. An example of a traffic density measure is Vehicle Miles Traveled (VMT) per lane mile of roadways The studies that examined the relationships of traffic congestion with transportation supply and travel demand related factors were of special interest to this study. The scope and findings of several of these studies are presented in this chapter.

Beltways: Boon, Bane, or Blip? Factors Influencing Changes in Urbanized Area Traffic, 1990-1997

In a recent study, research was conducted to quantify the effect of beltways on sprawl and on traffic congestion (Hartgen 1999) Changes for the top 65 urbanized areas in size, population, population density, economic activity, transit service and use, roadway supply (for 7 urban road classes), and extent of beltway completion were evaluated using 1990, 1994, and 1997 data from various sources. A stepwise linear regression analysis was used for investigating the relationship between VMT to demographic, network, beltway and transit related statistics. Traffic density was used as a measure of congestion (VMT/lane-mile of road). Resulting elasticities were reviewed and the following key points were made:

- Growth in employment was concluded to be the primary factor in increasing traffic;
- Geographic area, population, and employment, in non- or partially belted urbanized areas, increased faster than belted areas;
- population density was positively correlated with traffic congestion;
- increases in geographic area were observed to alleviate traffic congestion by providing a larger road network; and
- transit service was found to play a minor role in lowering VMT on higher systems and was positively correlated with VMT on lower systems

Overall, beltway construction was not found to be a key cause of urban sprawl.

Beltway completion did not affect overall regional traffic growth rate. Changes in freeway lane mileage, however, were reported to have a modest effect.

Hours of Congestion as a Transportation Measure of Effectiveness Under Capacity Constrained Conditions

In another study, a performance measure referred to as hours of congestion was proposed for the purpose of screening preliminary transportation improvement alternatives (Dey 1998). Hours of congestion were estimated by comparing transportation supply and demand across a hypothetical screen-line for each hour of a day. Supply was measured as roadway capacity or a maximum theoretical person throughput, and the demand was obtained by employing the travel demand forecasting process. When demand was recorded to exceed capacity, the excess was stored in a queue until it could be processed. The time required for queue dissipation was tracked, and congested hours were computed as the time during which demand equaled or exceeded capacity (Dey 1998). This method was applied in a project in Washington, D C., called the Capital Beltway Major Investment Study. This study was performed to assist the Virginia DOT in prescreening alternatives to alleviating beltway traffic congestion on the 66-mile loop around D.C. known as I-495 Forecasted hours of congestion for year 2020 ranged between 18 and 22 hours for a no action alternative, whereas, other alternatives resulted in a substantially smaller estimate (e.g 6 to 8 hours of congestion)

Speed And Delay Prediction Models For Planning Applications

In a study by Margiotta et al. (1998) a simulation model was developed, called QSIM, to study the effects of queuing on speed estimation. As part of this study, a ratio of Average Annual Daily Traffic (AADT) to two way capacity was employed as a measure of congestion, and this ratio was incorporated into a queuing model to test the impact of uncongested and congested conditions on speed and on average delay over the course of a year. The conclusion of this study was that QSIM provides an improvement over traditional methods for speed estimation, which consider only the peak hour and tend to overestimate speeds Under congested conditions, QSIM was concluded to predict substantially more delay than traditional methods. According to the authors of this report, overestimation of speeds in congested or highly congested conditions could lead, in turn, to an underestimation of the extent of congestion, and, thus, an underestimation of the benefits of transportation improvements/control strategies (Margiotta et al 1998).

Highway Capacity and Areawide Congestion

In a paper entitled *Highway Capacity and Areawide Congestion* by Xuehao Chu (2000), the congestion measure, daily VMT/lane miles, was employed to investigate the relationship between highway capacity and congestion. Data for 391 urbanized areas in the U.S, which largely came from the Federal Highway Administration's (FHWA) Annual Highway Statistics Series, was used to perform the analysis. Additional information on minor arterials and collectors was obtained from other FHWA sources. Chu employed an economic model of vehicle travel in which the dependent variable was defined as the measure of congestion (daily VMT per lane miles), and the independent variables included personal income, fuel cost, user cost of travel by alternative modes, and lane miles. The result of this exploration was a negative elasticity of VMT to lane miles for freeways, principal arterials, minor arterials, and collectors That is, an increase in capacity of roadways resulted in a decrease in congestion. More specifically, Chu's models predicted an approximately 0 18%, 0 27%, and 0 37% reduction in congestion in response to a 1% increase to existing capacity of 1000 lane miles for principal arterials, minor arterials, and collectors, respectively For freeways, Chu's model predicted 0 03%, 0.07%, 0.08%, 0.09%, 0 12%, and 0 14% reduction in freeway congestion in response to a 1% increase to existing capacity of 50, 250, 500, 1000, 5000, 10,000 lane miles, respectively The higher functional system roadways displayed smaller reductions in congestion due to capacity expansion This, Chu suggested, may be due to a higher induced vehicle travel occurring on higher functional class highways.

Induced Traffic

A number of facility specific, as well as areawide studies have examined induced travel demand. These studies often involve the estimation of elasticities through a least squares regression procedure, where growth in demand is measured in VMT or some variation, and supply is measured by travel time savings or lane miles (Barr 1999). Overall, several of these studies have reported a positive correlation between VMT and capacity and/or a negative correlation between VMT and travel time. These findings have been interpreted, by some, as evidence that capacity improvements increase mobility and reduce the time and cost of travel. Although increased mobility is desirable, it is linked by many of the authors of such studies to a potential loss in the benefits of capacity expansion over time (Fulton et al 2000).

There are some doubts, however, that have been raised about the concept of induced travel demand For example, travel induced by capacity expansion may not necessarily occur on the expanded roadway segment. It may be more likely to emerge during the non-peak periods. It has also been suggested that any increase in travel occurring following capacity expansion might be traffic that has been diverted from lower systems rather than being an induced, newly created travel demand (Hartgen 1999) In fact, the travel might be shifting from other similar class roadways as well, as drivers become aware of a new facility that may better serve their needs (e.g. one that is closer to their origin or destination or lowers their travel time) Finally, some studies have found travel demand to increase on the expanded roadway but not to levels exceeding the new capacity, in the long term (e.g. within the design period).

Urban Mobility Study

Researchers at the Texas Transportation Institute (TTI) have developed a number of performance measures to describe the quality of transportation for approximately 68 urbanized areas within the United States (Schrank et al. 1999).

The roadway congestion index (RCI) is one of the measures derived by TTI. It employs traffic density, daily vehicle miles of travel per lane mile of roadway, to indirectly measure congestion. RCI assumes that congested facilities are ones that experience performance above a threshold of 13,000 and 5000 daily VMT per lane, for freeways and principal arterials, respectively. These levels correlate to a LOS D or worse. RCI is a weighted (by VMT) based on the proportion of travel on freeways versus principal arterials An undesirable level of congestion is one where RCI is greater or equal to 1 (Schrank et al 1998).

Researchers at TTI have defined of congestion to be

> ". travel time or delay in excess of that normally incurred under light or freeflow travel conditions." (Lomax et al 1997, page 20)

TTI considers one of its current primary performance measures of mobility, which is based on the above definition, to be their travel rate index (TRI) (Levinson 1996). TRI is a comparison of travel time during peak periods of the average day with travel time during free flow conditions. Travel rates are computed using speed estimates for freeways and principal arterials The delay described by TRI is recurring and is not associated with accident or incident delay TRI is an estimator of the additional time it takes to travel during peak periods due to congested conditions caused by high volumes of traffic (Schrank et al. 1999).

Researchers at TTI have arrived at a number of conclusions as a result of the analysis of the 68 urbanized areas using the TRI measure According to TTI, overall mobility in urban areas can be improved if additional roads are constructed at pace that equals the growth in traffic demand They further state, however, that few urban areas can sustain that level of roadway expansion. These may be either due to financial, political, or right of way or environmental constraints The conclusion is drawn that additional roadway capacity cannot be the only alternative method used to address urban mobility. TTI further looked at vehicle occupancy and demand management options. They determined that vehicle occupancy would have had to have gone from 1.25 to 1.29, on average, to accommodate the additional passenger miles of travel in 1997. Alternatives to capacity expansion (improved traffic signal coordination, incident management, flexible work hours, telecommuting, congestion pricing, ramp metering, HOV lanes etc.) could contribute to mobility but are generally employed on a corridor level or are difficult to measure on an areawide basis (Lomax et al. 1999).

Despite the lack of consensus, there continues to be a belief that no one single action can effectively control traffic congestion and enhance urban mobility. Instead a combination of measures (that include capacity improvements and demand management solutions) is the best approach.

Chapter III. Scope and Methodological Approach

The scope of this study encompasses the top 138 urbanized areas (by population) within the United States. The term, urbanized area, used in this report is based on the U.S. Census Bureau definition. These areas are presented in Table A-1 and are ranked by the 1997 population estimates. The data for this analysis is presented in Table B-1, and it includes the following variables:

- Population
- Net Land Area
- Freeway Travel Rate Index (TRI)
- Principal Arterial Travel Rate Index (TRI)
- Combined Travel Rate Index (TRI)
- Freeway Lane Miles
- Principal Arterial Lane Miles
- Bus Annual Revenue Miles
- Commuter Rail Annual Revenue Miles
- Light Rail Annual Revenue Miles
- Heavy Rail Annual Revenue Miles

The regression analysis methodology for this study consisted of several phases: collection and data generation; a descriptive/exploratory analysis which included an examination of relationships among variables (using frequency histograms, scatter plots, box plots and other statistical tools), fit of the model to the data using stepwise regression; review of partial regression coefficients, residuals and other outputs; an evaluation of results

The regression analysis included a TRI measure as the dependent variable and highway supply related variables and other urban area characteristics as independent variables.

Population and net land area were combined to compute population density, which also was used as a variable Observations for the previously listed variables were assembled for individual urbanized areas The data set includes 138 urbanized areas and 9 variables Three of the variables dealing with traffic congestion were treated as dependent variables, one at a time, while the others were selected as independent variables The purpose of the analysis is to determine statistically if the variation of each dependent variable among urban areas can be explained by the variations in one or more of the independent variables It should be pointed out that most of the independent variables were selected to represent the supply of transportation facilities and services. However, the demand related variables viz , population were also employed. An investigation of the distribution of variables (univariate analysis) was performed first, followed by an exploration of the relationship of each independent variable with the dependent variables The bivariate analysis was followed by a stepwise multiple regression process using the backwards elimination procedure. An explanation of the different variables and sources of data are provided in the following paragraphs

Travel Rate Index (TRI)

TRI values for 1997 were computed for the top 138 federal-aid urbanized areas following guidelines provided by TTI and were provided by Dr. Richard A. Margiotta, a Transportation Engineering consultant with Cambridge Systematics, Inc There are differences between Combined TRI values computed for this study by Dr. Margiotta and those provided by TTI due to certain modifications made by TTI to VMT, average speeds and other input data TTI provides a summary of adjustments made in Appendix B of the

1999 Annual Mobility Report (Schrank et al 1999) According to TTI, HPMS data are reviewed for consistency and reasonableness Based on this assessment, changes are made to the HPMS data by TTI before the performance measures are calculated. These adjusted data were not available for this research Instead, the unadjusted HPMS data were used.

Combined TRI is computed as a weighted average of travel rates and VMT on freeways and principal arterials The equation used for computing Combined TRI is as follows.

(Equation III-1)

Combined Travel Rate Index (TRI) =

$$\frac{\left[\dfrac{\text{Freeway Travel Rate}}{\text{Freeway Free flow Travel Rate}} \times \text{Freeway Peak Period VMT (50\% Daily Traffic)} + \dfrac{\text{Principal Arterial Travel Rate}}{\text{Principal Arterial Free flow Travel Rate}} \times \text{Principal Arterial Peak Period VMT (50\% Daily Traffic)}\right]}{\left[(\text{Freeway Peak Period VMT}) + (\text{Principal Arterial Peak Period VMT})\right]}$$

Freeway and Principal Arterial TRI values are computed separately and are simply the ratio of travel rate to freeflow travel rate

$$\text{Freeway TRI} = \frac{\text{Freeway Travel Rate}}{\text{Freeway Freeflow Travel Rate}}$$

(Equation III-2)

$$\text{Principal Arterial TRI} = \frac{\text{Principal Arterial Travel Rate}}{\text{Principal Arterial Freeflow Travel Rate}} \quad \text{(Equation III-3)}$$

The resulting unit for Travel Rate is minutes per mile It is computed by estimating the average speed using mathematical models, not measurements. Speed estimates for sample urban freeway and arterial segments were adjusted to reflect conditions on the entire roadway system using appropriate expansion factors based on the sample size of each class of roadway. The 1999 Urban Mobility Report provides the criteria used for estimating speed (Schrank et. Al 1999) AADT per lane is used to infer the average speed, and then average speed is converted to minutes per mile using the equation III-4.

$$\text{Travel Rate} = \frac{60}{\text{Avg. Speed (in miles per hour)}} \quad \text{(Equation III-4)}$$

The calculated travel rate from these procedures is meant to represent conditions in a 6-hour peak period: 3 hours in the morning and 3 hours in the afternoon and represents peak commuting times. Vehicle miles of travel and average speeds used to compute TRI are presented in Table C-1

This study, as does TTI's, draws its base data for computing TRI from the FHWA's Highway Performance Monitoring System (HPMS) HPMS is a federally administered information system The system was developed in 1978 and is updated annually with state-furnished data on the extent, condition, performance, use, and operating characteristics of the national highway system The data is used to assess highway system performance under FHWA's strategic planning process and for allocation of federal-aid highway funds under the Transportation Equity Act for the 21st Century (TEA-21) Additionally, HPMS serves as a resource for states, MPOs, local governments, and research institutions interested in assessing the condition, performance, and investment needs of roadways under study (FHWA 2000)

Lane Miles

Lane miles represent roadway supply. Freeway and arterial lane miles in each urban area were obtained from the HPMS database and are presented in B-1

Vehicle Revenue Miles

Vehicle revenue miles represent transit service supply and are defined by the distance traveled by transit vehicles when providing service to fare paying passengers. Vehicle revenue miles for bus and trolley, and for light, heavy, and commuter rail were obtained from the Federal Transit Administration's (FTA) 1997 National Transit Database (see Table B-1)

Chapter IV. Exploratory Data Analysis

Prior to the development of multiple regression models, a variety of exploratory analyses were performed to examine each variable individually and also their relationships with each other These univariate and bivariate analyses are presented in this chapter.

This study was performed using a statistical software package, JMP JMP is a product of SAS Initially, the data was fit to a linear model. Nonlinear models were also investigated (e g. fit polynomial-quadratic) A logarithmic transformation was ultimately chosen, however, to linearize the data

Univariate Analysis

A univariate analysis was performed to describe the data by generating sample frequency distributions for all variables, Y_1 through Y_3, and X_1 through X_7, individually The resulting histograms, especially for the independent variables, were strongly skewed to the right. Outlier box plots provided a quick summary of that data, indicating median, spread, and range. It was also noted that individual outliers (unusual or extreme observations falling above or below a range defined by 1 5•interquartile range) were present in outlier box plots generated for all the predictor variables Some outliers were observations having the highest populations among the urbanized areas in the study (e g. Los Angeles, CA, New York-Northeastern NJ, Chicago, IL.), while others were urbanized areas having lower than the average population The outlier box plots also reflected the skewed nature of data, as the interquartile range (box portion

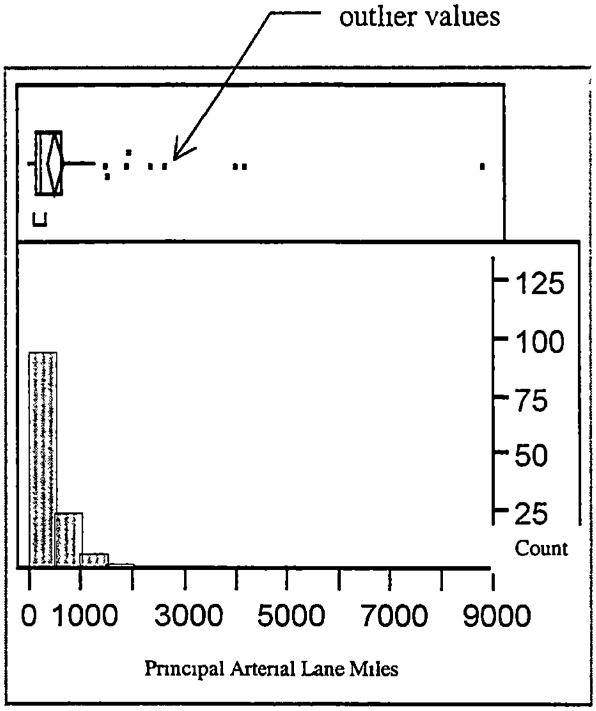

Figure IV-1: Frequency Histogram and Outlier Box Plot for Principal Arterial Lane Miles
Outliers from left to right include Philadelphia, Washington DC, Atlanta, Houston, Detroit, Tacoma, New York-Northeastern New Jersey, Chicago and Los Angeles

showing the middle half of the data, lower quartile to the upper quartile) was located to the far left, thus, indicating a one-sided data distribution. As an example, the outlier box plot and frequency histogram for principal arterial lane miles (X_4) are presented in Figure IV-1.

Bivariate Analysis

Because of the presence of the outliers and appearance of the distribution (skewed to the right) it was concluded that a logarithmic transformation should be attempted to reduce the resulting positive skewness by compressing the upper tail of the distribution The

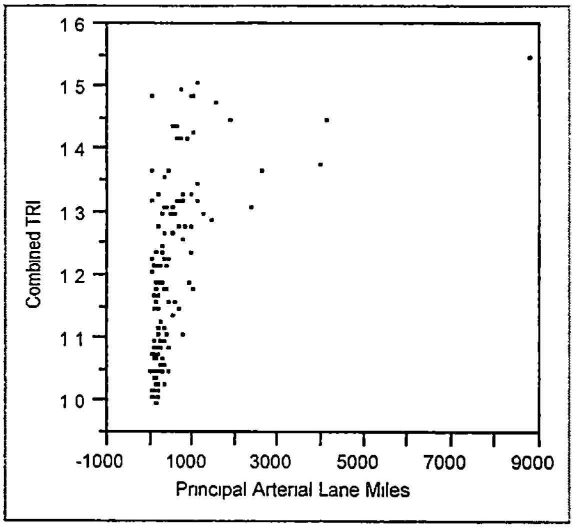

Figure IV-2: Combined TRI By Principal Arterial Lane Miles

need to rescale the data was confirmed when viewing the plots from the bivariate analyses, as scatterplots revealed no obvious relationships between the dependent-independent variable pairs, and observations were bunched in the lower range of the independent variable values A typical example of this phenomenon is exhibited as Figure IV-2.

Logarithmic transformation of the response and predictor variables had a noticeable impact on the data. The result of transforming the independent variables using the natural log (ln (X)) was a more symmetric distribution and more linear appearance of the data when plotted in a bivariate analysis

After the transformation of the variables was complete, each of the three response (dependent) variables ln (Y_1), ln (Y_2), and ln (Y_3) was paired with each of the predictor (independent) variables ln (X_1),.. ,ln (X_7) An example scatterplot, obtained from the fit Y by X platform in JMP, is presented in Figure IV-3

The scatterplots generated by the bivariate analysis revealed a few urbanized areas having relatively high residuals (differences between the observed value (Y_i) and the fitted (predicted) value $(\hat{Y}_i)$), namely Stamford, CT-NY and Lowell, MA-NH Also, the urbanized areas that were seen earlier in the outlier box plots obtained during the univariate analysis appeared in the bivariate plots as well (e.g. New York-Northeastern New Jersey in Figure IV-3). The latter observations, however, did not appear to be influential.

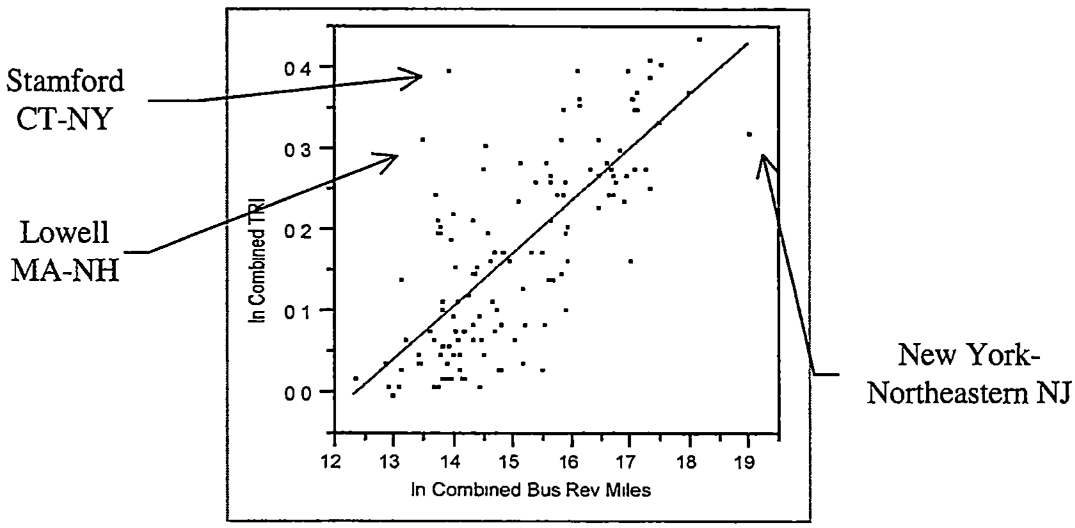

Figure IV-3: ln Combined TRI By ln Combined Bus Revenue Miles

Correlation Among Variables

A correlation analysis helped determine how closely pairs of variables were linearly related (see Table IV-1). All correlation coefficient values, denoted as r, ranged between 0 and 1, indicating a positive correlation between variables. Population (ln (X_1)) was found to be strongly correlated with net land area (ln (X_3)) (correlation coefficient, r = 0.93), freeway lane miles (ln (X_4)) (r = 0.91), principal arterial lane miles (ln (X_5)) (r = 0.81), and combined bus revenue miles (ln (X_6)) (r = 0.93), respectively. Net land area (ln (X_3)) was strongly correlated with freeway lane miles (ln (X_4)) (r = 0.91). Additionally, combined bus revenue miles (ln (X_6)) was observed to be correlated (although to a lesser extent) to net land area (ln (X_3)) (r = 0.84), freeway lane miles (ln (X_4)) (r = 0.86), and principal arterial lane miles (ln (X_5)) (r = 0.76). It was also noted that correlation between Combined TRI and freeway TRI was strong (r=0.95), whereas, the correlations between Combined TRI and Principal Arterial TRI, and that between Freeway TRI and Principal Arterial TRI were weaker (r = 0.69 and r = 0.50, respectively).

Although the relationship between population and other variables was closely linear ($r > 0.9$ in 3 out of 4 cases), the correlation coefficients between population density (ln (X_2)) and the other variables were relatively small (ranging between r = 0.26 and r = 0.60). Because of the strong positive correlation between population (ln (X_1)) and other variables, it was decided that population (ln (X_1)) would not be used as a predictor variable in the model.

Table IV-1: Simple Correlation Matrix[1]

Variable	ln Comb. TRI	ln Fwy TRI	ln of Princ. Art. TRI	ln Pop. Density	ln Net Land Area (Sq. Mi.)	ln Fwy Lane Miles	ln Princ. Art. Lane Miles	ln Comb. Bus Rev Miles	ln Pop. (1000's)
ln Comb. TRI	1.0000	0.9490	0.6938	0.5325	0.6643	0.6251	0.6177	0.7463	0.7556
ln Fwy TRI	0.9490	1.0000	0.4994	0.5401	0.6655	0.6665	0.6132	0.7609	0.7594
ln of Princ. Art. TRI	0.6938	0.4994	1.0000	0.3622	0.5125	0.4503	0.4267	0.5184	0.5643
ln Pop. Density	0.5325	0.5401	0.3622	1.0000	0.2577	0.4126	0.4268	0.6021	0.5968
ln Net Land Area (Sq. Mi.)	0.6643	0.6655	0.5125	0.2577	1.0000	0.9068	0.7755	0.8399	0.9291
ln Fwy Lane Miles	0.6251	0.6665	0.4503	0.4126	0.9068	1.0000	0.7055	0.8568	0.9110
ln Princ. Art. Lane Miles	0.6177	0.6132	0.4267	0.4268	0.7755	0.7055	1.0000	0.7580	0.8074
ln Comb. Bus Rev Miles	0.7463	0.7609	0.5184	0.6021	0.8399	0.8568	0.7580	1.0000	0.9279
ln Pop. (1000's)	0.7556	0.7594	0.5643	0.5968	0.9291	0.9110	0.8074	0.9279	1.0000

[1] Combined rail revenue miles was not included in the correlation of Y's analysis due to lack of a sufficient number of observations

However, although net land area (ln (X_3)) was highly correlated with freeway lane miles (ln (X_4)), these variables were included in the regression analysis The latter variable, it was assumed, would be eliminated in the stepwise regression if it was not needed The combined bus revenue mile variable (ln (X_6)) was also left in the model.

Sample Size

Of the original 138 urbanized areas selected for this study, there were 8 urbanized areas for which the FTA's National Transit Database did not contain transit profiles These omissions were due in part to reporting exemptions permitted by FTA For this reason the following areas were eliminated from the data set when the transit supply variables were retained in the model.

1. Birmingham, AL
2. Trenton, NJ-PA
3. Akron, OH
4. Ogden, UT
5. Atlantic City, NJ
6. Greenville, SC
7. Macon, GA
8. Fall River, MA-RI

Additionally, a review of the National Transit Database transit profiles revealed that only 25 urbanized areas used in this study contained rail revenue mile data. When combined rail revenue miles were included in the analysis, 113 rows of data were automatically omitted from the regression analysis. That is, only rows containing data for each variable type could be entered in the stepwise regression. To avoid a considerable reduction in sample size, combined rail revenue miles (ln (X_7)) was entered into the model as a 'dummy variable', thus, increasing the number of observations back to 130 and in turn improving the reliability and precision of the model To accomplish this, X_7 value was 'zero' (X_7=0), if commuter and/or light and/or heavy rail was absent in an urbanized area, and its value was 'one' (X_7=1) if commuter and/or light and/or heavy rail was present in an urbanized area

Chapter V. Multiple Regression Models

An equation of the form presented in Equation V-1 was tested for the regression model

$$\hat{Y}_i = a + b_1X_1 + \ldots + b_nX_n \qquad \text{(Equation V-1)}$$

$\hat{Y}$	predicted (fitted) Y
X	independent variable
a	Y-intercept
b	partial regression coefficients
i	positive integer 1 through n

The model variables were as follows

Dependent Variables

Y_1	Combined Travel Rate Index for freeways and non-freeway arterials
Y_2	Travel Rate Index for freeways only
Y_3	Travel Rate Index for non-freeway arterials only

Independent Variables

X_2	Population Density (persons/sq. mi)
X_3	Net Land Area (sq. mi.)
X_4	Freeway Lane Miles
X_5	Principal Arterial Lane Miles
X_6	Combined Bus Transit Service Revenue Miles (including bus and trolley bus revenue miles combined)
X_7	Combined Rail Transit Service Revenue Miles Indicator ('Dummy') Variable

Backward Elimination

The regression of the ln of Y_1, Y_2, and Y_3, respectively on the ln of $X_2 \ldots X_7$ was performed by applying the backward elimination procedure in JMP. The backward elimination process starts with the model containing all potential independent variables. The variable that is least significant is removed and the model is refitted This procedure is repeated until all the remaining variables have p values smaller than the probability to leave The backward elimination procedure is sometimes preferred over other methods (e.g. JMP's forward or mixed selection processes) It is more likely to allow for identification of a set of variables, which taken together, have considerable predictive capacity even though individually they may not Other regression methods might fail to identify such sets, as variables that do not predict well individually would never be entered into the model Because the backward elimination procedure begins with all the predictor variables entered into the model, joint predictive capabilities of the predictors can be evaluated (Dallal 2000).

The significance level for removal (also called the probability to leave) for the stepwise regression was specified as 0.05. This p-value was employed, because it is one that is typically used in transportation research.

Additionally, a statistic called variance inflation (VIF) was used to check for multicollinearity. VIF indicates, for each independent variable, how much larger the variance of the estimated coefficient is than it would be if the variable was uncorrelated with other independent variables. It is computed as $1/(1-r^2)$, where r^2 is obtained from the regression coefficient of that independent variable on all other independent variables VIF was computed in JMP and inspected after completion of the regression runs. A VIF value of 1 indicated that the variable is not involved in multicollinearity A value greater than 1 indicated that some degree of multicollinearity exists (Freund et al 1997). A VIF of 10 was used as the cutoff point. Independent variables having a VIF of 10 or greater were considered to display a high multicollinearity and were eliminated from the model (Garson 2000 and Neter et al 1996) The results of each of the three regressions, including parameter estimates (partial regression coefficients), standard error, t-test results, and 95% confidence intervals, are summarized in Table V-1. These models are referred to as 'initial models', because a second set of models were developed after eliminating a few outliers from the data. The initial models were eventually retained as the final models. Additionally, as explained in Chapter IV, because of the strong positive correlation between population (ln (X_1)) and other variables, population (X_1) was eliminated as a predictor variable from the model

Distribution of Residuals

Upon completion of the stepwise regression, frequency histograms, outlier box plots, and normal quantile plots were generated for the residuals (see Figures V-1 through V-3). The outlier box plots indicated the presence of unusual or extreme residuals Where outliers were identified in the outlier box plots, a secondary analysis was performed, whereby the stepwise regression procedure was repeated, this time without the outlying observations (note the results of this analysis are discussed in latter sections of this report). A review of the histograms of the residuals shows a fairly normal distribution. The normal quantile plots (quantile-quantile or q-q plots) were generated as an additional tool for visualizing the extent to which each is normally distributed. The normal quantile plots showed close to a diagonal straight line in each case, suggesting that the variables were distributed normally

Table V-1: Summary of Fit for Response Variables (Initial Models)

Y = ln Combined TRI, r^2 = 0.612							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-1 195457	0 135778	-8 80	< 0001	-1 464181	-0 926733	0
ln Pop Density	0 0926048	0 025568	3 62	0 0004	0 0420029	0 1432067	2 4462146
ln Net Land Area	0 0855926	0 022575	3 79	0 0002	0 0409127	0 1302725	8 9750719
ln Fwy Lane Mile	-0 044164	0 01743	-2 53	0 0125	-0 07866	-0 009669	7 1409856
ln Combined Bus Revenue Miles	0 0303697	0 013358	2 27	0 0247	0 0039331	0 0568064	7 5668956

Y= ln Freeway TRI, r^2 = 0.607							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-1 339427	0 152419	-8 79	< 0001	-1 641063	-1 037791	0
ln Pop Density	0 086377	0 03034	2 85	0 0052	0 0263345	0 1464195	2 3319333
ln Net Land Area	0 0481995	0 020573	2 34	0 0207	0 0074853	0 0889137	5 0459416
ln Combined Bus Revenue Miles	0 0388398	0 016043	2 42	0 0169	0 0070908	0 0705888	7 3893064

Y= ln Principal Arterial TRI, r^2 = 0.320							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-0 62956	0 138433	-4 55	< 0001	-0 903359	-0 35576	0
ln Pop Density	0 0729863	0.019268	3 79	0 0002	0 0348773	0 1110954	1 3182049
ln Net Land Area	0 081749	0 019232	4 25	< 0001	0 0437102	0 1197879	6 2779096
ln Fwy Lane Miles	-0 034783	0 017661	-1 97	0 0510	-0 069714	0 0001481	7 0331669

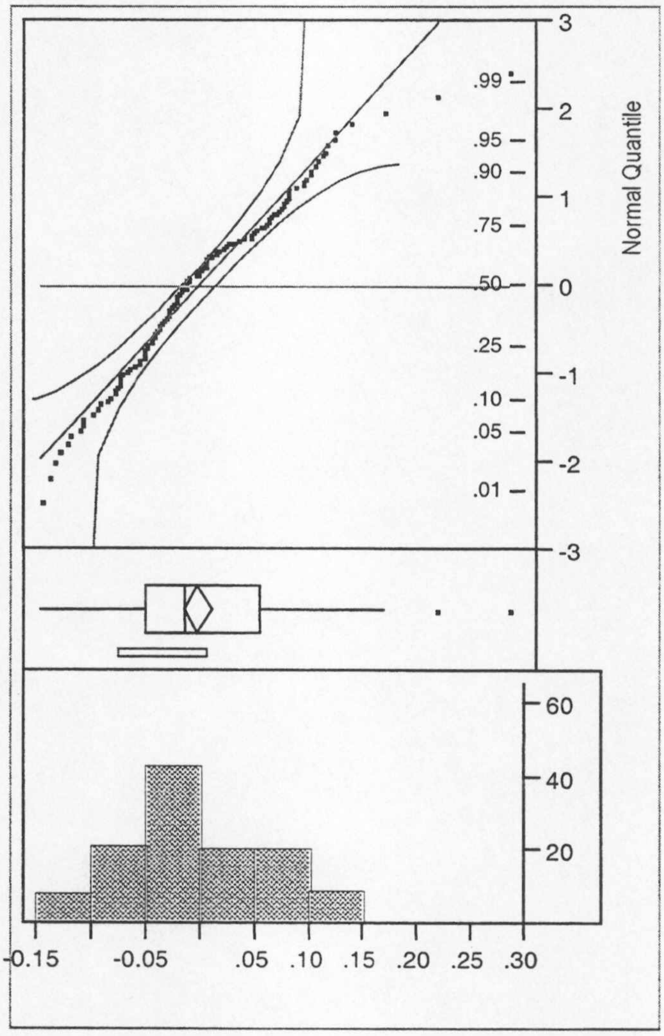

Figure V-1: Frequency Histogram, Outlier Box Plot, and Normal Quantile Plot For Residuals of Combined TRI

Note: The outliers shown in the outlier box plot are the residuals for Stamford, CT-NY and Lowell, MA-NH, from the least to the most extreme value (left to right).

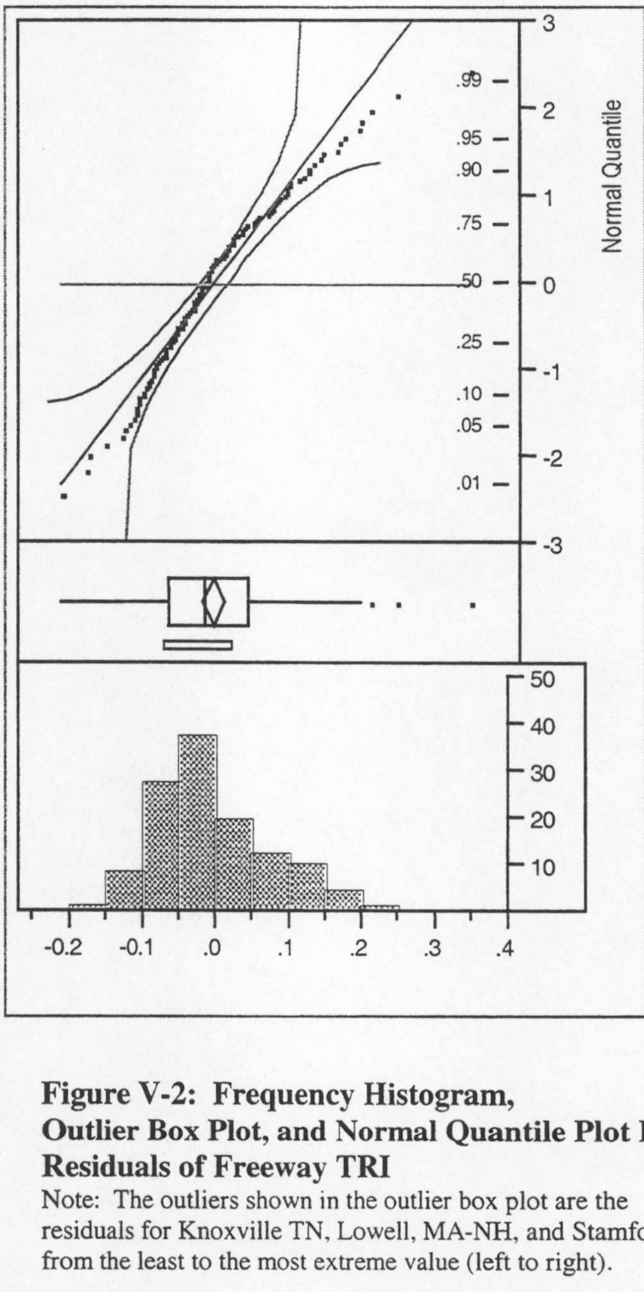

Figure V-2: Frequency Histogram, Outlier Box Plot, and Normal Quantile Plot For Residuals of Freeway TRI

Note: The outliers shown in the outlier box plot are the residuals for Knoxville TN, Lowell, MA-NH, and Stamford CT-NY, from the least to the most extreme value (left to right).

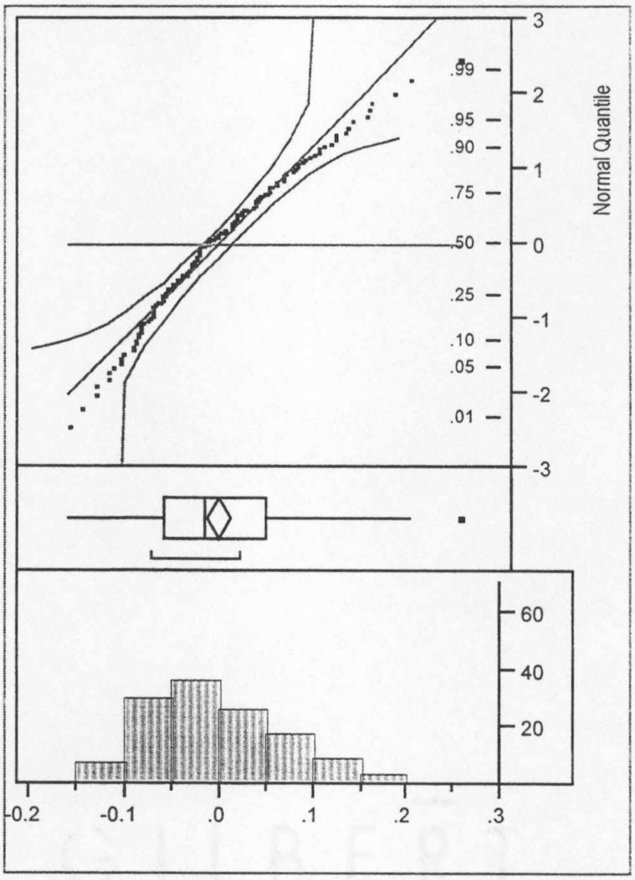

Figure V-3: Frequency Histogram, Outlier Box Plot, and Normal Quantile Plot For Residuals of Principal Arterial TRI

Note: The outlier shown in the outlier box plot is the residual for Evansville, IN-KY.

Regression Equations for Initial Models

The expressions for the estimated regression lines for each of the response variables are.

$$\ln(Y_1) = -1\ 195457+0\ 0926048\ln(X_2) + 0\ 0855926\ln(X_3) - 0\ 044164\ln(X_4) + \ .$$
$$..\ +0.0303697\ln(X_6) \qquad \text{(Equation V-2)}$$

$$\ln(Y_2) = -1\ 339527+0\ 086377\ln(X_2) + 0\ 0481995\ln(X_3) + 0.0388398\ln(X_6) \qquad \text{(Equation V-3)}$$

$$\ln(Y_3) = -0.62956+0\ 0729863\ln(X_2) + 0\ 081749\ln(X_3) - 0\ 034783\ln(X_4) \qquad \text{(Equation V-4)}$$

Y_1 Combined Travel Rate Index for freeways and non-freeway arterials
Y_2 Travel Rate Index for freeways only
Y_3 Travel Rate Index for non-freeway arterials only
X_2 Population Density (persons/sq. mi.)
X_3 Net Land Area (sq. mi)
X_4 Freeway Lane Miles
X_5 Principal Arterial Lane Miles
X_6 Combined Bus Transit Service Revenue Miles (including bus and trolley bus revenue miles combined)
X_7 Combined Rail Transit Service Revenue Miles Indicator Variable (including commuter, light, and heavy rail)

A summary of the predictor variables retained by the backwards elimination procedure are presented in Table V-2

Table V-2: Predictor Variables Retained By The Backwards Elimination Regression Procedure[1]

Predictor Variable		Combined TRI $r^2 = 0.612$	Freeway TRI $r^2 = 0.607$	Principal Arterial TRI $r^2 = 0.320$
ln population density	(X_2)	√	√	√
ln net land area	(X_3)	√	√	√
ln fwy lane mi	(X_4)	√		√
ln pa lane mi	(X_5)			
ln comb bus rev mi	(X_6)	√	√	
rail rev mi indicator variable	(X_7)			

[1]Note· a check mark (√) indicates which variables were retained, and a blank space indicates which variables were eliminated in the stepwise regression

Interpretation of Partial Regression Coefficients

The final set of equations indicates.

- a positive correlation between population density and Combined TRI, holding all other independent variables constant.
- a positive correlation between net land area and Combined TRI, holding all other independent variables constant.
- a positive correlation between combined bus transit service revenue miles and Combined TRI, holding all other independent variables constant
- a negative correlation between freeway lane miles and Combined TRI, holding all other independent variables constant.
- rail indicator and principal arterial lane miles variables can be removed entirely from all of the models

Additionally, as mentioned earlier, a strong correlation was observed between Combined TRI and Freeway TRI during the exploratory data analysis. Once the regression model results were inspected it became apparent why that was the case. As indicated by Equation III-1, VMT is used to compute the weighted average of Freeway and Principal Arterial TRI, which is referred to as Combined TRI by TTI. Inspection of the data inputted to compute Combined TRI (see Table B-1) shows freeway VMT on average outnumbering principal arterial VMT by a ratio of approximately 3.1 Thus Combined TRI is more heavily weighted by freeway VMT than by principal arterial VMT. Combined TRI as a result resembles Freeway TRI. The variables retained in the backward elimination procedure for Freeway and Principal Arterial TRI reflect the impact of the weighted average, they can be combined to yield the same variables retained for the Combined TRI model Once this was observed, a greater emphasis was placed for the remainder of this study on the model for Combined TRI This model, like the index, would adequately describe the combined results of the models for Freeway and Principal Arterial TRI.

Goodness of Fit

The standard error of the estimate ($S_{y\,x}$) was computed to measure the variability (degree of scatter) of the results (Lapin 1997). $S_{y\,x}$ provides a measure of the average amount that the predicted values of TRI are off from the observed values (see Equation V-5).

$$S_{y\,x} = \frac{\sum [Y_i - \hat{Y}(X_i)]^2}{n - p} \qquad \text{(Equation V-5)}$$

where
i = 1 through n
Y_i = observed TRI
$\hat{Y}(X_i)$ = predicted TRI
p = k+1
k = number of predictors

The standard error of the estimate was observed to be relatively low, ranging between 0.008 to 0.01 units

The coefficient of variation (CV) was estimated to give an indication of the relative scatter of the data with respect to the mean and is computed on a percent basis (see Equation V-6):

$$CV = \frac{S_{y\,x}}{\text{Mean } Y} * 100 \qquad \text{(Equation V-6)}$$

Table V-3: Standard Error and Coefficient of Variation

Response Variable	n	p	$S_{y \cdot x}$	CV (%)
Combined TRI (Y_1)	130	5	0 008302	0.695188
Freeway TRI (Y_2)	130	4	0.010215	0.861073
Principal Arterial TRI (Y_3)	138	4	0.008198	0.689376

The standard error of the estimate and coefficient of variation for the three models are presented in Table V-3

The predicted values using the regression equation for Combined TRI would miss actual TRI values by 0.008 units on the average, or approximately 0.7% with respect to the mean Also the predicted values using the equation for Freeway TRI would miss actual TRI values by 0 010 units or approximately 0.9 % with respect to the mean, and the predicted values using the equation for Principal Arterial TRI would miss actual TRI values by 0 008 units or approximately 0.7% with respect to the mean.

Residuals

After each stepwise regression the distribution of the residuals were computed (see Table D-1) and plotted. In each case outliers were identified. The outlier box plot for Combined TRI displayed outliers identified as Lowell (MA-NH) and Stamford (CT-NY). The outlier box plot for freeway TRI displayed outliers identified as Lowell (MA-NH), Stamford (CT-NY), and Knoxville (TN). The outlier box plot for principal arterial TRI displayed the outlier Evansville (IN-KY) (see Figures V-1 through V-3). Because outliers are unusual or extreme values they sometimes have the potential of exerting a large influence or leverage on the best-fit location of the regression line (Freund 1997). For this reason the regression models were generated a second time in JMP, but this time minus the extreme or unusual observations.

The results from this second analysis (see Table V-4) were inspected to see if excluding outliers would greatly impact the results of the regression analysis. The standard error and coefficient of variation were also recomputed for comparison with before conditions. Variables retained in the stepwise regression were compared, before and after conditions, to see how the model changed. Additionally, the characteristics of the influential observations (urbanized areas) were investigated to determine if evidence suggests that the permanent removal of outliers would be justified (see Tables V-4 through V-6). The results of the second regression analysis show an increase in the value of the coefficient of determination (e.g. from $r^2 = 0.612$ to $r^2 = 0.675$ for the Combined TRI model). Even so, the variables retained in the repeated stepwise regression were identical to those generated in the first analysis with outliers (see Tables V-1 and V-4). Also, negligible changes in standard error of the estimate and coefficient of variation were observed (e.g. from $S_{y\,x} = 0.008302$ to an $S_{y\,x} = 0.008497$ and CV = 0.695 to CV = 0.712 for the Combined TRI model). For the reasons stated, the outliers were retained and the initial models were used for the final analysis.

Table V-4: Summary of Fit for Response Variables After Removal of Outliers

Y = ln Combined TRI, r^2 = 0.675							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-1 162549	0 122967	-9 45	< 0001	-1 405957	-0 919142	0
ln Pop Density	0 0761047	0 023334	3 26	0 0014	0 0299154	0 1222941	2 4816764
ln Net Land Area	0 0852003	0 020437	4 17	< 0001	0 0447455	0 1256551	8 7800426
ln Fwy Lane Mile	-0 043222	0 015768	-2 74	0 0070	-0 074435	-0 01201	7 024091
ln Combined Bus Revenue Miles	0 0358926	0 012164	2 95	0 0038	0 011815	0 0599702	7 5487723
Y = ln Freeway TRI, r^2 = 0.683							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-1 339427	0 152419	-8 79	< 0001	-1 641063	-1 037791	0
ln Pop Density	0 086377	0 03034	2 85	0 0052	0 0263345	0 1464195	2 3319333
ln Net Land Area	0 0481995	0.020573	2 34	0 0207	0 0074853	0 0889137	5 0459416
ln Combined Bus Revenue Miles	0 0388398	0 016043	2.42	0 0169	0 0070908	0 0705888	7 3893064
Y = ln Principal Arterial TRI, r^2 = 0.354							
Term (X)	**Estimates**	**Std Error**	**t Ratio**	**Prob>|t|**	**Lower 95%**	**Upper 95%**	**VIF**
Intercept	-0 653269	0 133176	-4 91	< 0001	-0 916689	-0 389849	0
ln Pop Density	0.0744839	0 018517	4 02	< 0001	0 0378576	0 1111103	1 3170942
ln Net Land Area	0 0846252	0 018496	4 58	<.0001	0 0480397	0 1212106	6 2501449
ln Fwy Lane Miles	- 035719	0 01697	-2 10	0 0372	-0 069286	-0 002152	7 000456

Table V-5: Predictor Variables Retained By The Backwards Elimination Regression Procedure After Removal of Outliers[1]

Predictor Variable		Combined TRI $r^2 = 0.675$	Freeway TRI $r^2 = 0.683$	Principal Arterial TRI $r^2 = 0.354$
ln population density	(X_2)	√	√	√
ln net land area	(X_3)	√	√	√
ln fwy lane mi	(X_4)	√		√
ln pa lane mi	(X_5)			
ln comb bus rev mi	(X_6)	√	√	
rail rev mi indic var	(X_7)			

[1]Note: a check mark (√) indicates which variables were retained, and a blank space indicates which variables were eliminated in the stepwise regression

Table V-6: Standard Error and Coefficient of Variation After Removal of Outliers

Response Variable	n	P	$S_{y \cdot x}$	CV (%)
Combined TRI (Y_1)	128	5	0.008497	0 711532
Freeway TRI (Y_2)	127	4	0.010542	0 888616
Principal Arterial TRI (Y_3)	137	4	0.008274	0.6958

Chapter VI. Discussion of Factors

An explanation of the significance of each independent variable with regard to its relation with traffic congestion (TRI variables), as revealed by the regression analysis, is presented in the following sections The observed relationships are explained in some cases intuitively, also.

Freeway and Non-freeway Principal Arterial Lane Miles

The results of the stepwise regression analysis performed for this study indicate that a significant relationship exists between freeway lane miles and Combined TRI, which is a measure of traffic congestion. As mentioned earlier, a negative correlation between freeway lane miles and Combined TRI was observed in the multiple regression analysis. The variable for principal arterial lane miles, in contrast, was eliminated in the stepwise regression.

This inclusion of freeway lane miles in, and removal of principal arterial lane miles from the multiple regression model may be partially explained by the fundamental role that freeways and principal arterials play in urbanized areas. Non-freeway principal arterials carry major volumes of trips within the urbanized area, whereas, freeways provide an alternative conduit to principal arterials such that intra-city as well as intercity, and regional trips can occur on these facilities. Freeways are fully access-controlled facilities They have greater capacity, enable travel at higher speeds, and one lane of freeway can carry up to approximately 2 to 3 times the amount of traffic carried per hour by a typical non-freeway arterial lane with traffic signals and little driveway control. Most importantly, freeways act to decrease parallel arterial volumes (Coleman 1997) Freeways attract commuter traffic in large urban areas and traffic congestion commonly is associated with delay on freeways.

Non-freeway principal arterials form the backbone of the highway network in an urban area and serve intracity commuters. They also have a critical role of feeding traffic to/from freeways in many cases (Hartgen 1999) Although principal arterials were eliminated from the model, they are believed to have an impact on congestion levels during non-commuting times. If principal arterials lack the capacity, for example, to accommodate the demand originating from freeways, then congestion can become a problem at their interchanges with freeways.

The freeway lane mile variable was eliminated during the stepwise regression performed for Freeway TRI and was retained in the model for Principal Arterial TRI. Hartgen employed traffic density as the measure of congestion, and its units were in terms of VMT and VMT/lane (using 1990 and 1997 data). For his models the freeway lane mile variable was noticeably absent. However, when a percent change in VMT (%ΔVMT) was computed (between 1997 and 1990), and the regression was repeated, the model variables changed such that a number of variables formerly eliminated (freeway lane miles and other principal arterial miles among them) were now retained in the stepwise regression. A similar phenomenon was observed when the dependent variable was freeway VMT/lane. The elimination of freeway lane miles from the Freeway TRI model in the study presented in this report, like Hartgen's study, could be due to the use of single year of data Perhaps an expanded data set covering a 5-year or longer time span would yield a different model for Freeway TRI, one that includes freeway lane miles. For the Principal Arterial TRI model, the inclusion of the freeway lane mile variable in the model may be evidence of the role of the principal arterial as a feeder to freeways. In this case freeway lane mile expansion may play a greater role in easing lower-system traffic congestion.

Population Density

An inspection of the models revealed a positive correlation between population density and Combined TRI, holding all other independent variables constant Hartgen (1999) also observed a positive relationship between population density and traffic density (VMT/lane mile of roadway) and noted that this finding is consistent with the belief that an increase in urban density is accompanied by an increase in traffic congestion The results of the multiple regression analysis, similarly, suggest an increase in travel time during peak periods in higher density urban areas due to congested conditions caused by high volumes of traffic

Net Land Area

A positive correlation was observed to exist between net land area and Combined TRI, holding all other independent variables constant. Stated more simply, the urbanized areas having larger net land areas tend to have longer travel times during peak periods, relative to freeflow travel times. TRI values are higher in urbanized areas having larger net land area probably for a number of reasons sprawl may be more conducive to traffic congestion during commuting hours. Urban freeways are radially oriented in most cases, and each radial freeway can be likened to a stream or river within a watershed area This watershed area for a radial freeway is larger for urban areas with larger net land areas More traffic converges on radial freeways as an urban area grows causing more congestion Also, although urbanized areas having larger net land area might exhibit lower population densities, the congestion index for these urbanized areas may be exacerbated by the longer travel distances required by commuters during peak periods to get to the outskirts of town

<u>Bus Transit Service</u>

A positive correlation was observed to exist between combined bus transit service revenue miles and Combined TRI, holding all other independent variables constant. This finding seems to contradict what one might normally expect, as an increase in transit supply is usually considered as a strategy for the alleviation of traffic congestion The simple correlation matrix that was generated during the descriptive/exploratory portion of this study (see Table IV-1) showed combined bus revenue miles to be highly correlated with population ($r = 0.93$). The results of the simple correlation and the stepwise regression analysis suggest that bus transit service is strongly a function of population and may have acted as a surrogate for the urban area size. Furthermore the usage characteristics of bus transit service supply are a complex phenomena. The implications of bus transit supply and demand may require a more detailed analysis than an aggregate study such as this can provide.

Rail Transit Service

The rail transit revenue mile indicator variable was not found to be correlated with TRI measures as it was removed from all of the models during the stepwise regression. Although rail does have more of a potential for decreasing traffic congestion level on highways due to its characteristic riders, rail riderhip levels in most U.S. cities may just be too low to have an impact. Rail riders rarely represented more than 0 5% of the population on a daily basis or 0.05% of the population on an hourly basis according to Hartgen (1991). Although more recent data indicates an increase in rail transit demand, rail transit supply and demand at the present are still too limited to have a significant impact on highway traffic congestion. Additionally, the National Transit Database listed 25 of the 138 urbanized to have commuter, light or heavy rail revenue mile data. Although an indicator variable was employed in an attempt to overcome the fact that only a few urbanized areas offer passenger rail service, they may have been too small in number for the indicator variable to be retained/selected as being significant.

Chapter VII. General Findings and Recommendations

A detailed traffic engineering study can be performed to determine site-specific causes of congestion The purpose of this study, however, was not to perform a detailed site specific analysis, but to examine recurring networkwide traffic congestion in different cities to determine if the variation in the level of congestion can be explained by variations in the areawide values of travel demand and roadway supply related variables

Since the data for this networkwide study could not feasibly be collected first hand, it was necessary to turn to outside sources to perform this study. The data utilized by this study were obtained from other sources that are widely recognized. However, in most cases these other sources have developed their respective data based on mathematical models and/or statistical sampling procedures as a matter of practicality The travel rate index, which was used to represent traffic congestion levels, is computed using speed estimates generated using a mathematical model, which is developed and calibrated using observed data. Also, roadway supply related measures such as freeway lane miles were obtained from the HPMS database, which relies on a sampling procedure. Thus, a certain amount of error can be expected to be associated with the estimated values of these variables.

Recognizing the limitations of the data and of the analysis, the results must be interpreted in a general way. The findings of this study, as presented in Chapter VI, and in the subsequent paragraphs, therefore, are presented with the caution that they should not be taken too rigidly

As part of the bivariate regression analysis the correlation coefficient was not only computed to measure the degree of the linear relationship between the dependent and independent variables, but also to examine the relationship between pairs of the independent variables. The results are presented in the form of a simple correlation matrix (see Table IV-1). In general, the congestion measures were observed to be positively correlated with the travel demand related variables—population, net land area, and population density, as anticipated. However, the 'positive' correlation observed between the supply related variables such as freeway lane miles and principal arterial lane miles, respectively, with TRI appears to be counter-intuitive, since increased roadway supply may be expected to decrease traffic congestion, provided the demand level remains constant. Further examination of the simple correlation matrix showed the supply related variables to be have a strong positive correlation with the demand related variables, net land area and population, indicating that the larger urban areas have more lane-miles of highways. The multiple regression analysis, however, showed a distinction between the demand related and supply related variables with regard to their relationship with the TRI. The regression equations presented in Chapter V (Equations V-2 and V-4, in particular) indicate that when both demand and supply related variables are correlated with TRI, the partial regression coefficients associated with the demand variables are positive, and the partial regression coefficient associated with the supply variable (freeway lane miles) is negative. This is compatible with the notion that as an urban area grows in size traffic congestion also grows. Additionally, the negative correlation between freeway lane miles and congestion level, holding all else constant, substantiates the idea that this growth in congestion is offset somewhat by increasing the supply of freeway lane miles As discussed previously, this observation can be explained by the fundamental role that freeways play in urbanized areas (see Chapter VI, Discussion of Factors)

There are a few findings of this study that are somewhat unexpected and paradoxical. It was anticipated that the principal arterial lane mile variable would be significant and would have a negative correlation with the congestion measures, holding all other variables constant. The concept behind this expectation is that non-freeway principal arterials provide alternative routes for travel and serve to facilitate distribution of traffic uniformly over the entire roadway network, thus, preventing the concentration of traffic on freeways. The results of the regression analysis performed by this study, however, did not clearly substantiate this concept

Concluding Remarks and Recommendations

This study was performed without any direct financial support Although assistance was obtained from others in accessing data, and guidance was provided for the statistical analysis, many of the potential factors influencing traffic congestion (e.g. land use density and employment related characteristics) could not be included in the analysis with the limited resources and within the time allotted. Although the findings of this study are limited in scope and do not address all aspects of traffic congestion, this study provides a strong foundation for a more focused and detailed future analysis

It is important to note that the study detailed herein was performed with the primary goal of exploring the relationship between freeway traffic congestion and the supply of freeways and non-freeway arterials The models were based on the statistical analysis of the data for top urbanized areas (by population). Because the results are indicative of the more highly populated areas, extrapolation of the results to urbanized areas of smaller population would not be appropriate. This approach could be modified in future investigations by taking a random sample of study areas from the full population of 396 urbanized areas. A randomly selected sample would not only allow for data interpolation but also for inferences regarding the population.

A number of assumptions had to be made in building the regression model for this study. Variables had to be selected, and the regression procedure and significance level also had to be chosen. The stepwise regression control panel in JMP gives the user the option of entering or removing certain variables from the analysis prior to building a model In JMP, the user chooses among the backward elimination, forward selection, or the mixed selection options and must also choose a significance level/probability attributed to the regressor term. It became apparent during this study that results of the stepwise variable selection will differ depending on the choices made:

1. With regard to the stepwise variable selection process, no one method is necessarily considered to be better than another, however; some statisticians do offer suggestions for choosing a procedure for certain situations

2. When variables are highly correlated, the ones that appear in the model can change with the addition of only a few observations.

3. The process selects variables that are significant at a level specified by the user, referred to as the probability to enter or leave There appears to be a lack of consensus, unfortunately, on how to select an appropriate significance level. Again, the decision is left up to the user and often, for lack of guidance, researchers fall back on the use of default values commonly applied in their field

In the case of this study, for example, when the number of variables entered into the model was reduced, and/or when the significance was changed slightly, the combined rail revenue mile indicator variable or principal arterial lane mile variable, which were eliminated from the initial models) were in some cases retained. Obviously there is a diversity of options, which must be considered in conducting a study such as this.

As noted earlier, approximately 61% of the total variation in the dependent variable, Combined TRI, was accounted for by the predictors· freeway lane miles, population density, net land area, and combined bus revenue miles. This leaves 39% of the variation unexplained by the regression model Other socioeconomic or demographic factors that might be considered for inclusion in a future analysis to fill this void could be car ownership, vehicle occupancy, gas prices, income, employment growth, and/or land use density. An employment related factor might be especially worth adding into the model as it has been determined to be a key factor influencing the growth of traffic density (Hartgen 1999). Another factor that has been considered to be important with respect to traffic congestion is the spatial relationship of jobs and affordable housing (FTA 1993). Urban area land use density, if incorporated into the model, could possibly provide a tool for gauging land use impacts on congestion. Land use data, computed as proportion of total land area, for residential, commercial, mixed uses, etc , could be incorporated into the model to describe an urban area, especially for an aggregate model Residential land use density could be measured as the number of dwelling units per acre, and commercial land use could be measured as number of employees per acre or commercial space per acre Another potential factor, not often addressed relates to the system characteristics of the urban area transportation network Urbanized area transportation networks perhaps could be categorized having a grid system, radial system or an irregular pattern Also, another factor that might be considered is the presence or absence of beltways or toll roads

Some factors related to areawide congestion investigated in future studies might require the use of other statistical analysis approaches in addition to the classical regression method. That is, the use of other investigative tools might allow for the inclusion of other factors such as land use patterns, road system spacing, trip lengths, etc., that otherwise are not conducive to evaluation by regression analysis Additionally, although the regression analysis served to develop a statistical relation between the TRI and the predictor variables, the regression model does not imply the presence of a cause and effect relationship. Therefore, methods other than the classical regression method and/or the straightforward aggregate analysis such as the one presented in this study, may be required to augment this study to confirm the presence of a causal relationship between the predictor and response variables.

The interpretation of the coefficients of independent variables was hindered by the fact that the supply variables selected in this study are strongly a function of the size of the urbanized area. One possible way to overcome this problem of colinearity would be to compute percent changes in independent variables over time It is clear that a more focused study including other explanatory variables and multiple years of data is needed to more definitively ascertain the nature of the relationship of travel demand and the supply of roadways, respectively, with urban area traffic congestion.

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Appendices

Appendix A

Urbanized Areas Ranked by Population

Table A-1: Urbanized Areas Ranked by Population[1]

	Urbanized Area	Primary State	Pop (1000)
1	New York-Northeastern NJ	NY	16,335
2	Los Angeles	CA	12,327
3	Chicago-Northwestern IN	IL	7,980
4	Philadelphia (PA-NJ)	PA	4,542
5	San Francisco-Oakland	CA	3,970
6	Detroit	MI	3,852
7	Washington (DC-MD-VA)	DC	3,436
8	Boston	MA	2,890
9	San Diego	CA	2,621
10	Phoenix	AZ	2,410
11	Atlanta	GA	2,401
12	Minneapolis-St Paul	MN	2,290
13	Baltimore	MD	2,107
14	Miami-Hialeah	FL	2,047
15	St Louis (MO-IL)	MO	1,984
16	Seattle	WA	1,950
17	Houston	TX	1,840
18	Denver	CO	1,800
19	Pittsburgh	PA	1,768
20	Cleveland	OH	1,739
21	San Jose	CA	1,628
22	Portland-Vancouver (OR-WA)	OR	1,442
23	Portland	ME	1,442
24	Fort Lauderdale-Hollywood-Pompano Beach	FL	1,404
25	Riverside-San Bernardino	CA	1,368
26	Kansas City (MO-KS)	MO	1,357
27	Sacramento	CA	1,328
28	Milwaukee	WI	1,243
29	Cincinnati (OH-KY)	OH	1,223
30	New Orleans	LA	1,070
31	Buffalo-Niagara Falls	NY	1,070
32	San Antonio	TX	1,068
33	Orlando	FL	1,049
34	Oklahoma City	OK	1 027
35	West Palm Beach-Boca Raton-Delay Beach	FL	924
36	Indianapolis	IN	915
37	Columbus	OH	907
38	Providence-Pawtucket (RI-MA)	RI	900
39	Memphis (TN-AR-MS)	TN	895
40	Salt Lake City	UT	876
41	Jacksonville	FL	822
42	Louisville (KY-IN)	KY	799
43	Tulsa	OK	756
44	Honolulu	HI	694
45	Birmingham	AL	646
46	Tucson	AZ	629
47	Rochester	NY	617

[1]Urbanized areas are ranked by pop in descending order

Table A-1 Continued

	Urbanized Area	Primary State	Pop (1000)
48	Nashville	TN	613
49	Richmond	VA	611
50	Augusta (GA-SC)	GA	610
51	El Paso (TX-NM)	TX	607
52	Springfield (MA-CT)	MA	602
53	Hartford-Middletown	CT	593
54	Dayton	OH	592
55	Tacoma	WA	586
56	Charlotte	NC	572
57	Austin	TX	554
58	Omaha (NE-IA)	NE	544
59	Fresno	CA	537
60	Akron	OH	537
61	Grand Rapids	MI	495
62	Toledo (OH-MI)	OH	494
63	Wilmington (DE-NJ-MD-PA)	DE	490
64	Albany-Schenectady-Troy	NY	490
65	Albuquerque	NM	486
66	Allentown-Bethlehem-Easton (PA-NJ)	PA	457
67	Savannah	GA	452
68	Charleston	SC	427
69	Columbus (GA-AL)	GA	420
70	Bridgeport-Milford	CT	413
71	Chattanooga (TN-GA)	TN	384
72	Baton Rouge	LA	377
73	Bakersfield	CA	373
74	Youngstown-Warren	OH	373
75	Wichita	KS	364
76	Syracuse	NY	363
77	Worcester (MA-CT)	MA	355
78	Columbia	SC	355
79	Flint	MI	344
80	Trenton (NJ-PA)	NJ	340
81	Little Rock-North Little Rock	AK	340
82	Knoxville	TN	339
83	Mobile	AL	324
84	Spokane	WA	323
85	Harrisburg	PA	310
86	Macon	GA	305
87	Jackson	MS	304
88	Stockton	CA	299
89	Lawrence Haverhill (MA-NH)	MA	298
90	Corpus Christi	TX	297
91	Des Moines	IA	294
92	Ogden	UT	292
93	Lansing-East Lansing	MI	287
94	Pensacola	FL	285

Table A-1 Continued

	Urbanized Area	Primary State	Pop (1000)
95	Greenville	SC	268
96	Davenport-Rock Island-Moline (IA-IL)	IL	266
97	Shreveport	LA	263
98	Madison	WI	259
99	Ann Arbor	MI	258
100	Canton	OH	250
101	Fort Wayne	IN	248
102	Peoria	IL	246
103	South Bend-Mishawaka (IN-MI)	IN	240
104	Lexington-Fayette	KY	237
105	Lorain-Elyria	OH	234
106	Winston-Salem	NC	230
107	Lowell (MA-NH)	MA	221
108	Montgomery	AL	220
109	Greensboro	NC	217
110	Rockford	IL	212
111	Lubbock	TX	197
112	Reading	PA	194
113	Roanoke	VA	194
114	Stamford (CT-NY)	CT	193
115	Lincoln	NE	192
116	Brockton	MA	186
117	Erie	PA	186
118	Evansville (IN-KY)	IN	184
119	Waterbury	CT	183
120	Kalamazoo	MI	178
121	Atlantic City	NJ	177
122	Huntington-Ashland (WV-KY-OH)	WV	172
123	Amarillo	TX	169
124	Utica-Rome	NY	163
125	Fall River (MA-RI)	MA	157
126	Pueblo	CO	155
127	New Bedford	MA	147
128	Topeka	KS	141
129	Saginaw	MI	138
130	Cedar Rapids	IA	136
131	Springfield	IL	132
132	Binghamton	NY	127
133	Duluth (MN-WI)	MN	123
134	Beaumont	TX	115
135	Waterloo-Cedar Falls	IA	111
136	Waco	TX	107
137	Port Arthur	TX	61
138	Galveston	TX	59

Appendix B

Input Data for Regression Model

Table B-1· Input Data for Regression Model[1]

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq mi)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
1	Los Angeles	CA	12,327	2,231	1 66	1 35	1 55	6,927	8,778
2	Seattle	WA	1,950	844	1 61	1 18	1 51	1,261	1,129
3	San Francisco-Oakland	CA	3,970	1,203	1 52	1 2	1 5	2,936	702
4	Miami-Hialeah	FL	2,047	545	1 57	1 37	1 49	638	1,034
5	Fort Lauderdale-Hollywood-Pompano Beach	FL	1,404	489	1 56	1 38	1 49	654	986
6	Stamford (CT-NY)	CT	193	82	1 55	1 08	1 49	121	60
7	Washington (DC-MD-VA)	DC	3,436	999	1 51	1 41	1 48	2,326	1,545
8	Atlanta	GA	2,401	1,757	1 5	1 3	1 45	2,243	1,888
9	Chicago-Northwestern IN	IL	7,980	2,730	1 53	1 3	1 45	3,115	4,143
10	Riverside-San Bernardino	CA	1,368	514	1 49	1 17	1 44	901	524
11	Portland-Vancouver (OR-WA)	OR	1,442	685	1 49	1 27	1 44	746	638
12	Orlando	FL	1,049	667	1 4	1 45	1 43	755	1,028
13	San Diego	CA	2,621	733	1 45	1 3	1 42	1,968	849
14	West Palm Beach-Boca Raton-Delay Beach	FL	924	556	1 52	1 23	1 42	450	644
15	Boston	MA	2,890	1,138	1 43	1 34	1 42	1,505	741
16	Houston	TX	1,840	1,537	1 46	1 13	1 4	2,889	1,943
17	New York-Northeastern NJ	NY	16,335	3,962	1 36	1 43	1 38	7,716	3,967
18	Tacoma	WA	586	341	1 46	1 15	1 37	306	444
19	Phoenix	AZ	2,410	1,054	1 5	1 24	1 37	1,086	2,626
20	Lowell (MA-NH)	MA	221	116	1 37	1 27	1 37	165	35
21	Knoxville	TN	339	355	1 37	1 34	1 36	272	354
22	Baltimore	MD	2,107	712	1 38	1 26	1 35	1,534	1,100
23	Honolulu	HI	694	135	1 31	1 41	1 33	416	168
24	Albuquerque	NM	486	192	1 46	1 19	1 33	292	782
25	Indianapolis	IN	915	422	1 36	1 26	1 33	829	966
26	Milwaukee	WI	1,243	512	1 36	1 2	1 32	1,061	654
27	San Jose	CA	1,628	365	1 35	1 18	1 32	1,524	759
28	Austin	TX	554	314	1 36	1 22	1 32	658	628
29	Denver	CO	1,800	720	1 35	1 22	1 32	1,588	1,102

[1]Ranked by Combined TRI in descending order

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi)	Fwy TRI	Principal Art TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
30	Bridgeport-Milford	CT	413	178	1 32	1 24	1 32	293	63
31	Wilmington (DE-NJ-MD-PA)	DE	490	254	1 31	1 31	1 31	341	356
32	Cincinnati (OH-KY)	OH	1,223	630	1 32	1 23	1 31	1,132	530
33	Detroit	MI	3,852	1,304	1 33	1 26	1 31	2,978	2,358
34	Minneapolis-St Paul	MN	2,290	1,192	1 31	1 3	1 31	1,672	386
35	Louisville (KY-IN)	KY	799	384	1 3	1 29	1 3	705	471
36	St Louis (MO-IL)	MO	1,984	1,057	1 31	1 23	1 3	2,240	1,273
37	Jacksonville	FL	822	727	1 25	1 38	1 3	659	588
38	Charlotte	NC	572	299	1 28	1 33	1 3	486	308
39	Philadelphia (PA-NJ)	PA	4,542	1,350	1 23	1 43	1 29	2,000	1,465
40	Tucson	AZ	629	312	1 18	1 33	1 28	183	660
41	San Antonio	TX	1,068	485	1 32	1 19	1 28	1,048	816
42	Salt Lake City	UT	876	353	1 28	1 3	1 28	535	197
43	Fort Wayne	IN	248	93	1 09	1 41	1 28	105	212
44	Sacramento	CA	1,328	383	1 28	1 27	1 28	718	986
45	Nashville	TN	613	571	1 26	1 29	1 27	729	514
46	Cleveland	OH	1,739	838	1 28	1 15	1 27	1,516	331
47	New Orleans	LA	1,070	355	1 31	1 2	1 26	451	786
48	Pensacola	FL	285	337	1	1 37	1 25	96	265
49	Greensboro	NC	217	163	1 26	1 15	1 24	274	154
50	Memphis (TN-AR-MS)	TN	895	409	1 32	1 15	1 24	469	973
51	Chattanooga (TN-GA)	TN	384	360	1 26	1 19	1 24	320	274
52	Waterbury	CT	183	89	1 24	1 07	1 23	108	28
53	Birmingham	AL	646	608	1 2	1 33	1 23	655	418
54	Providence-Pawtucket (RI-MA)	RI	900	515	1 25	1 12	1 23	721	316
55	Evansville (IN-KY)	IN	184	123	1	1 46	1 22	172	122
56	Columbus	OH	907	476	1 22	1 23	1 22	871	368
57	Grand Rapids	MI	495	318	1 11	1 45	1 22	437	262
58	Canton	OH	250	160	1 22	1 21	1 22	198	81

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq mi)	Fwy TRI	Principal Art TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
59	Lawrence Haverhill (MA-NH)	MA	298	205	1 21	1 24	1 21	322	56
60	Rochester	NY	617	335	1 2	1 16	1 19	492	127
61	Richmond	VA	611	406	1 18	1 23	1 19	664	303
62	Tulsa	OK	756	394	1 19	1 19	1 19	566	246
63	Oklahoma City	OK	1,027	711	1 22	1 11	1 19	746	935
64	Fresno	CA	537	168	1 13	1 24	1 18	231	369
65	Pittsburgh	PA	1,768	1,112	1 13	1 27	1 18	1,288	1,024
66	Ann Arbor	MI	258	159	1 18	1 16	1 18	266	147
67	Dayton	OH	592	369	1 16	1 23	1 18	681	321
68	Allentown-Bethlehem-Easton (PA-NJ)	PA	457	187	1 13	1 34	1 17	310	109
69	Trenton (NJ-PA)	NJ	340	192	1 13	1 27	1 17	296	208
70	Harrisburg	PA	310	207	1 16	1 28	1 17	442	100
71	Akron	OH	537	356	1 18	1 08	1 16	507	166
72	Baton Rouge	LA	377	274	1 21	1 08	1 16	265	450
73	Charleston	SC	427	251	1 12	1 22	1 16	384	561
74	Odgen	UT	292	188	1 14	1 22	1 16	244	126
75	Kansas City (MO-KS)	MO	1,357	1,034	1 16	1 14	1 16	1,790	733
76	Atlantic City	NJ	177	89	1 08	1 3	1 15	136	118
77	El Paso (TX-NM)	TX	607	227	1 22	1 06	1 15	361	656
78	Montgomery	AL	220	202	1 05	1 28	1 15	135	199
79	Hartford-Middletown	CT	593	366	1 15	1 15	1 15	634	188
80	Omaha (NE-IA)	NE	544	221	1 06	1 23	1 14	428	533
81	South Bend-Mishawaka (IN-MI)	IN	240	147	1	1 23	1 13	179	220
82	Lexington-Fayette	KY	237	286	1 01	1 34	1 12	241	168
83	Lincoln	NE	192	81	1	1 16	1 12	52	214
84	Savannah	GA	452	420	1	1 21	1 12	159	337
85	Stockton	CA	299	90	1 13	1 09	1 11	194	210
86	Augusta (GA-SC)	GA	610	371	1 13	1 1	1 11	199	405
87	Bakersfield	CA	373	176	1 13	1 1	1 11	146	361

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi.)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
88	Buffalo-Niagara Falls	NY	1,070	564	1.14	1.06	1.11	647	796
89	Kalamazoo	MI	178	123	1.05	1.18	1.11	150	174
90	Greenville	SC	268	148	1.13	1.07	1.1	148	321
91	Reading	PA	194	81	1.08	1.12	1.1	105	105
92	Lansing-East Lansing	MI	287	157	1.03	1.2	1.1	307	233
93	Des Moines	IA	294	176	1.09	1.09	1.09	481	107
94	Spokane	WA	323	164	1.1	1.08	1.09	145	442
95	Madison	WI	259	98	1.07	1.15	1.09	264	170
96	Corpus Christi	TX	297	164	1.09	1.06	1.09	335	237
97	Roanoke	VA	194	103	1	1.21	1.08	135	170
98	Brockton	MA	186	132	1.09	1	1.08	90	41
99	Little Rock-North Little Rock	AK	340	199	1.08	1.07	1.08	452	180
100	Portland	ME	120	93	1.07	1.08	1.08	113	81
101	Mobile	AL	324	327	1.02	1.16	1.07	285	292
102	Worcester (MA-CT)	MA	355	263	1.06	1.17	1.07	403	117
103	Toledo (OH-MI)	OH	494	255	1.07	1.11	1.07	614	149
104	Columbus (GA-AL)	GA	420	319	1	1.15	1.07	215	284
105	Beaumont	TX	115	104	1.08	1.04	1.07	144	127
106	Columbia	SC	355	199	1.05	1.12	1.07	373	300
107	Jackson	MS	304	221	1.07	1.06	1.06	425	331
108	Rockford	IL	212	133	1	1.11	1.06	144	233
109	Amarillo	TX	169	97	1.03	1.09	1.05	201	248
110	Youngstown-Warren	OH	373	193	1	1.23	1.05	302	108
111	Lubbock	TX	197	143	1	1.08	1.05	253	432
112	Shreveport	LA	263	320	1.01	1.12	1.05	290	280
113	Winston-Salem	NC	230	177	1.05	1.17	1.05	302	46
114	Erie	PA	186	83	1	1.06	1.05	33	147
115	Lorain-Elyria	OH	234	232	1.05	1.01	1.04	309	108
116	Syracuse	NY	363	233	1.04	1.08	1.04	498	104

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
117	Saginaw	MI	138	78	1	1 09	1 04	115	166
118	Springfield	IL	132	77	1	1 1	1 04	169	109
119	Huntington-Ashland (WV-KY-OH)	WV	172	104	1	1 09	1 04	177	151
120	Macon	GA	305	194	1	1 11	1 03	161	134
121	Peoria	IL	246	151	1	1 11	1 03	254	141
122	Albany-Schenectady-Troy	NY	490	365	1 02	1 13	1 03	674	184
123	Galveston	TX	59	35	1	1 04	1 03	26	140
124	Flint	MI	344	237	1 01	1 06	1 03	343	330
125	Davenport-Rock Island-Moline (IA-IL)	IL	266	163	1 01	1 09	1 03	305	130
126	Wichita	KS	364	176	1 01	1 07	1 02	468	206
127	Springfield (MA-CT)	MA	602	422	1 02	1 06	1 02	391	117
128	Port Arthur	TX	61	89	1	1 04	1 02	112	180
129	Binghamton	NY	127	163	1	1 18	1 02	227	24
130	Utica-Rome	NY	163	206	1	1 07	1 02	307	98
131	New Bedford	MA	147	67	1	1 09	1 02	103	32
132	Pueblo	CO	155	75	1 02	1	1 01	184	44
133	Topeka	KS	141	85	1	1 03	1 01	158	182
134	Cedar Rapids	IA	136	135	1	1 03	1 01	217	110
135	Fall River (MA-RI)	MA	157	116	1	1 13	1 01	183	29
136	Waco	TX	107	154	1	1 02	1 01	202	143
137	Duluth (MN-WI)	MN	123	151	1	1 02	1 01	135	107
138	Waterloo-Cedar Falls	IA	111	113	1	1	1	91	155

Table B-1 Continued

	Urbanized Area	Annual Bus Revenue Miles	Annual Commuter Rail Revenue Miles	Annual Heavy Rail Revenue Miles	Annual Light Rail Revenue Miles	Annual Trolley Bus Revenue Miles	Annual Cable Car Revenue Miles	Combined Bus Revenue Miles	Combined Annual Rail Revenue Miles
1	Los Angeles	78,125,347		1,737,052	4,435,637			78,125,347	6,172,689
2	Seattle	30,808,531				3,255,845		34,064,376	
3	San Francisco-Oakland	33,675,570		48,523,158	3,739,458	7,104,652	520,170	40,780,222	52,262,616
4	Miami-Hialeah	23,851,395		5,739,132				23,851,395	5,739,132
5	Fort Lauderdale-Hollywood-Pompano Beach	9,801,046	2,491,975					9,801,046	2,491,975
6	Stamford (CT-NY)	1,110,420						1,110,420	
7	Washington (DC-MD-VA)	33,742,569		37,983,733				33,742,569	37,983,733
8	Atlanta	26,638,139		27,101,411				26,638,139	27,101,411
9	Chicago-Northwestern IN	64,932,579		50,686,527				64,932,579	50,686,527
10	Riverside-San Bernardino	10,226,933	33,161,988					10,226,933	33,161,988
11	Portland-Vancouver (OR-WA)	25,130,420			1,578,582			25,130,420	1,578,582
12	Orlando	10,011,284						10,011,284	
13	San Diego	25,996,863			5,059,054			25,996,863	5,059,054
14	West Palm Beach-Boca Raton-Delay Beach	7,538,885	792,525					7,538,885	792,525
15	Boston	27,119,123	17,044,374	22,933,914	5,434,464			27,119,123	45,412,752
16	Houston	39,103,629						39,103,629	
17	New York-Northeastern NJ	178,203,925	143,516,311	316,927,984	656,192			178,203,925	461,100,487
18	Tacoma	7,433,599						7,433,599	
19	Phoenix	14,068,196						14,068,196	
20	Lowell (MA-NH)	709,381						709,381	
21	Knoxville	2,054,647						2,054,647	
22	Baltimore	20,001,053	4,558,279	4,231,002	2,296,035			20,001,053	11,085,316
23	Honolulu	16,204,111						16,204,111	
24	Albuquerque	3,718,446						3,718,446	
25	Indianapolis	5,761,575						5,761,575	
26	Milwaukee	26,134,889						26,134,889	
27	San Jose	17,763,387			1,887,996			17,763,387	1,887,996
28	Austin	12,004,032						12,004,032	
29	Denver	31,246,619			648,291			31,246,619	648,291

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi.)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
30	Bridgeport-Milford	CT	413	178	1 32	1 24	1 32	293	63
31	Wilmington (DE-NJ-MD-PA)	DE	490	254	1 31	1 31	1 31	341	356
32	Cincinnati (OH-KY)	OH	1,223	630	1 32	1 23	1 31	1,132	530
33	Detroit	MI	3,852	1,304	1 33	1 26	1 31	2,978	2,358
34	Minneapolis-St Paul	MN	2,290	1,192	1 31	1 3	1 31	1,672	386
35	Louisville (KY-IN)	KY	799	384	1 3	1 29	1 3	705	471
36	St Louis (MO-IL)	MO	1,984	1,057	1 31	1 23	1 3	2,240	1,273
37	Jacksonville	FL	822	727	1 25	1 38	1 3	659	588
38	Charlotte	NC	572	299	1 28	1 33	1 3	486	308
39	Philadelphia (PA-NJ)	PA	4,542	1,350	1 23	1 43	1 29	2,000	1,465
40	Tucson	AZ	629	312	1 18	1 33	1 28	183	660
41	San Antonio	TX	1,068	485	1 32	1 19	1 28	1,048	816
42	Salt Lake City	UT	876	353	1 28	1 3	1 28	535	197
43	Fort Wayne	IN	248	93	1 09	1 41	1 28	105	212
44	Sacramento	CA	1,328	383	1 28	1 27	1 28	718	986
45	Nashville	TN	613	571	1 26	1 29	1 27	729	514
46	Cleveland	OH	1,739	838	1 28	1 15	1 27	1,516	331
47	New Orleans	LA	1,070	355	1 31	1 2	1 26	451	786
48	Pensacola	FL	285	337	1	1 37	1 25	96	265
49	Greensboro	NC	217	163	1 26	1 15	1 24	274	154
50	Memphis (TN-AR-MS)	TN	895	409	1 32	1 15	1 24	469	973
51	Chattanooga (TN-GA)	TN	384	360	1 26	1 19	1 24	320	274
52	Waterbury	CT	183	89	1 24	1 07	1 23	108	28
53	Birmingham	AL	646	608	1 2	1 33	1 23	655	418
54	Providence-Pawtucket (RI-MA)	RI	900	515	1 25	1 12	1 23	721	316
55	Evansville (IN-KY)	IN	184	123	1	1 46	1 22	172	122
56	Columbus	OH	907	476	1 22	1 23	1 22	871	368
57	Grand Rapids	MI	495	318	1 11	1 45	1 22	437	262
58	Canton	OH	250	160	1 22	1 21	1 22	198	81

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi.)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
59	Lawrence Haverhill (MA-NH)	MA	298	205	1 21	1 24	1 21	322	56
60	Rochester	NY	617	335	1 2	1 16	1 19	492	127
61	Richmond	VA	611	406	1 18	1 23	1 19	664	303
62	Tulsa	OK	756	394	1 19	1 19	1 19	566	246
63	Oklahoma City	OK	1,027	711	1 22	1 11	1 19	746	935
64	Fresno	CA	537	168	1 13	1 24	1 18	231	369
65	Pittsburgh	PA	1,768	1,112	1 13	1 27	1 18	1,288	1,024
66	Ann Arbor	MI	258	159	1 18	1 16	1 18	266	147
67	Dayton	OH	592	369	1 16	1 23	1 18	681	321
68	Allentown-Bethlehem-Easton (PA-NJ)	PA	457	187	1 13	1 34	1 17	310	109
69	Trenton (NJ-PA)	NJ	340	192	1 13	1 27	1 17	296	208
70	Harrisburg	PA	310	207	1 16	1 28	1 17	442	100
71	Akron	OH	537	356	1 18	1 08	1 16	507	166
72	Baton Rouge	LA	377	274	1 21	1 08	1 16	265	450
73	Charleston	SC	427	251	1 12	1 22	1 16	384	561
74	Odgen	UT	292	188	1 14	1 22	1 16	244	126
75	Kansas City (MO-KS)	MO	1,357	1,034	1 16	1 14	1 16	1,790	733
76	Atlantic City	NJ	177	89	1 08	1 3	1 15	136	118
77	El Paso (TX-NM)	TX	607	227	1 22	1 06	1 15	361	656
78	Montgomery	AL	220	202	1 05	1 28	1 15	135	199
79	Hartford-Middletown	CT	593	366	1 15	1 15	1 15	634	188
80	Omaha (NE-IA)	NE	544	221	1 06	1 23	1 14	428	533
81	South Bend-Mishawaka (IN-MI)	IN	240	147	1	1 23	1 13	179	220
82	Lexington-Fayette	KY	237	286	1 01	1 34	1 12	241	168
83	Lincoln	NE	192	81	1	1 16	1 12	52	214
84	Savannah	GA	452	420	1	1 21	1 12	159	337
85	Stockton	CA	299	90	1 13	1 09	1 11	194	210
86	Augusta (GA-SC)	GA	610	371	1 13	1 1	1 11	199	405
87	Bakersfield	CA	373	176	1 13	1 1	1 11	146	361

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi.)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
88	Buffalo-Niagara Falls	NY	1,070	564	1 14	1 06	1 11	647	796
89	Kalamazoo	MI	178	123	1 05	1 18	1 11	150	174
90	Greenville	SC	268	148	1 13	1 07	1 1	148	321
91	Reading	PA	194	81	1 08	1 12	1 1	105	105
92	Lansing-East Lansing	MI	287	157	1 03	1 2	1 1	307	233
93	Des Moines	IA	294	176	1 09	1 09	1 09	481	107
94	Spokane	WA	323	164	1 1	1 08	1 09	145	442
95	Madison	WI	259	98	1 07	1 15	1 09	264	170
96	Corpus Christi	TX	297	164	1 09	1 06	1 09	335	237
97	Roanoke	VA	194	103	1	1 21	1 08	135	170
98	Brockton	MA	186	132	1 09	1	1 08	90	41
99	Little Rock-North Little Rock	AK	340	199	1 08	1 07	1 08	452	180
100	Portland	ME	120	93	1 07	1 08	1 08	113	81
101	Mobile	AL	324	327	1 02	1 16	1 07	285	292
102	Worcester (MA-CT)	MA	355	263	1 06	1 17	1 07	403	117
103	Toledo (OH-MI)	OH	494	255	1 07	1 11	1 07	614	149
104	Columbus (GA-AL)	GA	420	319	1	1 15	1 07	215	284
105	Beaumont	TX	115	104	1 08	1 04	1 07	144	127
106	Columbia	SC	355	199	1 05	1 12	1 07	373	300
107	Jackson	MS	304	221	1 07	1 06	1 06	425	331
108	Rockford	IL	212	133	1	1 11	1 06	144	233
109	Amarillo	TX	169	97	1 03	1 09	1 05	201	248
110	Youngstown-Warren	OH	373	193	1	1 23	1 05	302	108
111	Lubbock	TX	197	143	1	1 08	1 05	253	432
112	Shreveport	LA	263	320	1 01	1 12	1 05	290	280
113	Winston-Salem	NC	230	177	1 05	1 17	1 05	302	46
114	Erie	PA	186	83	1	1 06	1 05	33	147
115	Lorain-Elyria	OH	234	232	1 05	1 01	1 04	309	108
116	Syracuse	NY	363	233	1 04	1 08	1 04	498	104

Table B-1 Continued

	Urbanized Area	Primary State	Population (1000's)	Net Land Area (sq. mi.)	Fwy TRI	Principal Art. TRI	Combined TRI	Fwy Lane Miles	Principal Arterial Lane Miles
117	Saginaw	MI	138	78	1	1 09	1 04	115	166
118	Springfield	IL	132	77	1	1 1	1 04	169	109
119	Huntington-Ashland (WV-KY-OH)	WV	172	104	1	1 09	1 04	177	151
120	Macon	GA	305	194	1	1 11	1 03	161	134
121	Peoria	IL	246	151	1	1 11	1 03	254	141
122	Albany-Schenectady-Troy	NY	490	365	1 02	1 13	1 03	674	184
123	Galveston	TX	59	35	1	1 04	1 03	26	140
124	Flint	MI	344	237	1 01	1 06	1 03	343	330
125	Davenport-Rock Island-Moline (IA-IL)	IL	266	163	1 01	1 09	1 03	305	130
126	Wichita	KS	364	176	1 01	1 07	1 02	468	206
127	Springfield (MA-CT)	MA	602	422	1 02	1 06	1 02	391	117
128	Port Arthur	TX	61	89	1	1 04	1 02	112	180
129	Binghamton	NY	127	163	1	1 18	1 02	227	24
130	Utica-Rome	NY	163	206	1	1 07	1 02	307	98
131	New Bedford	MA	147	67	1	1 09	1 02	103	32
132	Pueblo	CO	155	75	1 02	1	1 01	184	44
133	Topeka	KS	141	85	1	1 03	1 01	158	182
134	Cedar Rapids	IA	136	135	1	1 03	1 01	217	110
135	Fall River (MA-RI)	MA	157	116	1	1 13	1 01	183	29
136	Waco	TX	107	154	1	1 02	1 01	202	143
137	Duluth (MN-WI)	MN	123	151	1	1 02	1 01	135	107
138	Waterloo-Cedar Falls	IA	111	113	1	1	1	91	155

Appendix C

Input Data for Computing TRI

Table C-1: Input Data for Computing TRI

Urbanized Area	Speed	Artl. Speed	Fwy VMT (Millions)	Artl VMT (Millions)
Los Angeles	36 2	26 1	23,238	11,907
Seattle	37 4	29 7	4,138	1,159
San Francisco-Oakland	39 4	29 2	8,623	569
Miami-Hialeah	38 3	25 5	2,133	1,426
Fort Lauderdale-Hollywood-Pompano Beach	38 4	25 4	1,899	1,359
Stamford (CT-NY)	38 8	32 4	407	61
Washington (DC-MD-VA)	39 8	24 9	6,653	2,192
Atlanta	40 1	27	7,107	2,153
Chicago-Northwestern IN	39 3	27 1	9,213	5,022
Riverside-San Bernardino	40 2	30	2,731	518
Portland-Vancouver (OR-WA)	40 2	27 6	2,261	771
Orlando	42 8	24 1	1,449	1,626
San Diego	41 5	26 9	5,436	1,023
West Palm Beach-Boca Raton-Delay Beach	39 4	28 6	1,287	712
Boston	41 9	26 2	4,492	976
Houston	41	31	7,055	1,669
New York-Northeastern NJ	44	24 6	18,353	5,994
Tacoma	41 1	30 6	951	380
Phoenix	40 1	28 2	2,800	2,801
Lowell (MA-NH)	43 7	27 7	445	37
Knoxville	43 7	26 2	750	433
Baltimore	43 6	27 8	3,898	1,174
Honolulu	45 6	25	1,056	241
Albuquerque	41 1	29 6	773	752
Indianapolis	44 1	27 8	2,234	1,164
Milwaukee	44	29 1	1,912	626
San Jose	44 3	29 8	3,677	818
Austin	44 1	28 9	1,576	675
Denver	44 4	28 8	3,548	1,187
Bridgeport-Milford	45 4	28 3	762	70
Wilmington (DE-NJ-MD-PA)	45 6	26 9	846	447
Cincinnati (OH-KY)	45 3	28 6	2,816	483
Detroit	45 3	27 9	7,093	2,521
Minneapolis-St Paul	45 9	27 1	4,415	496
Louisville (KY-IN)	46	27 1	1,776	547
St Louis (MO-IL)	45 7	28 4	4,901	1,283
Jacksonville	47 8	25 3	1,574	756
Charlotte	46 7	26 4	1,150	387

Table C-1 Continued

Urbanized Area	Speed	Artl Speed	Fwy VMT (Millions)	Artl VMT (Millions)
Philadelphia (PA-NJ)	48 9	24 6	4,426	2,116
Tucson	50 9	26 4	342	846
San Antonio	45 6	29 6	2,476	759
Salt Lake City	46 9	27	1,275	253
Fort Wayne	55 2	24 9	189	284
Sacramento	47	27 5	1,952	1,214
Nashville	47 5	27 2	1,769	660
Cleveland	47	30 6	3,305	324
New Orleans	45 9	29 2	1,073	814
Pensacola	60	25 6	161	344
Greensboro	47 5	30 4	539	126
Memphis (TN-AR-MS)	45 5	30 6	1,092	961
Chattanooga (TN-GA)	47 8	29 6	697	286
Waterbury	48 2	32 8	253	16
Birmingham	50 2	26 3	1,468	539
Providence-Pawtucket (RI-MA)	47 8	31 4	1,398	282
Evansville (IN-KY)	60	24 1	193	186
Columbus	49 2	28 5	2,060	391
Grand Rapids	54 1	24 2	742	349
Canton	49 2	29	315	50
Lawrence Haverhill (MA-NH)	49 6	28 4	710	62
Rochester	50	30 3	952	130
Richmond	50 7	28 5	1,369	327
Tulsa	50 6	29 5	1,074	248
Oklahoma City	49	31 7	1,612	761
Fresno	53 1	28 3	434	400
Pittsburgh	53 1	27 7	2,021	1,176
Ann Arbor	50 8	30 3	596	147
Dayton	51 8	28 6	1,154	369
Allentown-Bethlehem-Easton (PA-NJ)	53 1	26 2	568	154
Trenton (NJ-PA)	53 2	27 6	568	240
Harrisburg	51 9	27 4	850	124
Akron	51	32 4	974	141
Baton Rouge	49 6	32 4	535	326
Charleston	53 8	28 7	783	584
Ogden (UT)	52 4	28 7	486	137
Kansas City (MO-KS)	51 7	30 8	3,200	668
Atlantic City	55 7	26 9	282	137

Table C-1 Continued

Urbanized Area	Speed	Artl Speed	Fwy VMT (Millions)	Artl VMT (Millions)
El Paso (TX-NM)	49.2	33.1	694	530
Montgomery	57.1	27.5	268	213
Hartford-Middletown	52.2	30.6	1,382	168
Omaha (NE-IA)	56.4	28.5	675	520
South Bend-Mishawaka (IN-MI)	60	28.6	188	261
Lexington-Fayette	59.4	26.1	458	232
Lincoln	60	30.3	58	210
Savannah	60	29	249	312
Stockton	53.2	32.3	445	195
Augusta (GA-SC)	53.2	31.9	322	348
Bakersfield	53.2	32	279	297
Buffalo-Niagara Falls	52.4	33.1	1,024	650
Kalamazoo	57.3	29.6	207	180
Greenville	52.9	32.8	279	303
Reading	55.3	31.4	162	113
Lansing-East Lansing	58	29.3	389	232
Des Moines	54.9	32.1	601	57
Spokane	54.5	32.3	252	374
Madison	56	30.6	412	147
Corpus Christi	55	33	546	145
Roanoke	60	29	272	174
Brockton	55.1	35	193	25
Little Rock-North Little Rock	55.6	32.9	879	142
Portland (ME)	55.9	32.4	159	76
Mobile	58.8	30.1	475	277
Worcester (MA-CT)	56.7	30.1	755	118
Toledo (OH-MI)	56.3	31.7	925	131
Columbus (GA-AL)	60	30.6	224	204
Beaumont	55.6	33.7	310	105
Columbia	57.3	31.3	679	287
Jackson	56.3	33	714	238
Rockford	60	31.7	176	209
Amarillo	58.2	32.3	246	154
Youngstown-Warren	60	28.5	358	103
Lubbock	60	32.5	190	334
Shreveport	59.3	31.4	424	245
Winston-Salem	57.2	30	538	37
Erie	60	33	50	137

Table C-1 Continued

Urbanized Area	Speed	Artl Speed	Fwy VMT (Millions)	Artl VMT (Millions)
Lorain-Elyria	57 1	34 8	457	79
Syracuse	57 7	32 6	644	61
Saginaw	60	32 2	143	131
Springfield	60	31 8	184	102
Huntington-Ashland (WV-KY-OH)	60	32 2	206	137
Macon	60	31 6	273	126
Peoria	60	31 7	314	127
Albany-Schenectady-Troy	59 1	31	1,068	159
Galveston	60	33 6	46	94
Flint	59 4	33 1	557	274
Davenport-Rock Island-Moline (IA-IL)	59 5	32 2	300	80
Wichita	59 2	32 9	588	159
Springfield (MA-CT)	59	33 1	715	87
Port Arthur	60	33 8	133	109
Binghamton	60	29 7	273	29
Utica-Rome	60	32 8	240	69
New Bedford	60	32 2	152	31
Pueblo	59 1	35	171	31
Topeka	60	34 2	172	137
Cedar Rapids (IA)	60	34 1	185	77
Fall River (MA-RI)	60	31 2	287	20
Waco	60	34 2	289	102
Duluth (MN-WI)	60	34 4	146	68
Waterloo-Cedar Falls	60	35	65	57

Appendix D

JMP Output

Appendix D-1:
Observed and Predicted TRI and Residuals

	Urbanized Area	Combined TRI	Freeway TRI	Principal Arterial TRI	Predicted Combined TRI	Predicted Freeway TRI	Predicted Principal Arterial TRI	Residuals for Combined TRI	Residuals for Freeway TRI	Residuals for Principal Arterial TRI
1	Los Angeles	1.55	1.66	1.35	1.53	1.62	1.38	0.014	0.024	-0.022
2	Seattle	1.51	1.61	1.18	1.36	1.39	1.27	0.102	0.148	-0.073
3	San Francisco-Oakland	1.50	1.52	1.20	1.41	1.47	1.30	0.064	0.036	-0.082
4	Miami-Hialeah	1.49	1.57	1.37	1.40	1.40	1.30	0.062	0.116	0.053
5	Fort Lauderdale-Hollywood-Pompano Beach	1.49	1.56	1.38	1.32	1.31	1.26	0.124	0.173	0.090
6	Stamford (CT-NY)	1.49	1.55	1.08	1.12	1.09	1.14	0.287	0.354	-0.054
7	Washington (DC-MD-VA)	1.48	1.51	1.41	1.40	1.45	1.30	0.058	0.042	0.084
8	Atlanta	1.45	1.50	1.30	1.34	1.36	1.27	0.080	0.097	0.023
9	Chicago-Northwestern IN	1.45	1.53	1.30	1.51	1.54	1.38	-0.040	-0.005	-0.058
10	Riverside-San Bernardino	1.44	1.49	1.17	1.30	1.31	1.25	0.106	0.129	-0.063
11	Portland-Vancouver (OR-WA)	1.44	1.49	1.27	1.35	1.35	1.26	0.067	0.101	0.006
12	Orlando	1.43	1.40	1.45	1.27	1.27	1.23	0.118	0.101	0.163
13	San Diego	1.42	1.45	1.30	1.36	1.42	1.28	0.040	0.023	0.019
14	West Palm Beach-Boca Raton-Delay Beach	1.42	1.52	1.23	1.28	1.25	1.24	0.107	0.198	-0.009
15	Boston	1.42	1.43	1.34	1.39	1.41	1.30	0.021	0.016	0.029
16	Houston	1.40	1.46	1.13	1.31	1.36	1.23	0.069	0.073	-0.088
17	New York-Northeastern NJ	1.38	1.36	1.43	1.59	1.68	1.41	-0.144	-0.209	0.014
18	Tacoma	1.37	1.46	1.15	1.25	1.22	1.21	0.094	0.179	-0.052
19	Phoenix	1.37	1.50	1.24	1.36	1.35	1.30	0.007	0.102	-0.046
20	Lowell (MA-NH)	1.37	1.37	1.27	1.10	1.07	1.14	0.220	0.250	0.106
21	Knoxville	1.36	1.37	1.34	1.15	1.11	1.17	0.171	0.214	0.136
22	Baltimore	1.35	1.38	1.26	1.34	1.38	1.27	0.007	0.002	-0.004
23	Honolulu	1.33	1.31	1.41	1.29	1.32	1.20	0.032	-0.010	0.158
24	Albuquerque	1.33	1.46	1.19	1.21	1.20	1.19	0.096	0.200	-0.001
25	Indianapolis	1.33	1.36	1.26	1.23	1.25	1.21	0.076	0.087	0.040
26	Milwaukee	1.32	1.36	1.20	1.31	1.35	1.23	0.006	0.010	-0.025
27	San Jose	1.32	1.35	1.18	1.31	1.38	1.24	0.007	-0.019	-0.046
28	Austin	1.32	1.36	1.22	1.22	1.24	1.17	0.080	0.091	0.039

Appendix D-1 Continued

	Urbanized Area	Combined TRI	Freeway TRI	Principal Arterial TRI	Predicted Combined TRI	Predicted Freeway TRI	Predicted Principal Arterial TRI	Residuals for Combined TRI	Residuals for Freeway TRI	Residuals for Principal Arterial TRI
29	Denver	1.32	1.35	1.22	1.34	1.38	1.25	-0.013	-0.024	-0.024
30	Bridgeport-Milford	1.32	1.32	1.24	1.17	1.15	1.18	0.123	0.135	0.053
31	Wilmington (DE-NJ-MD-PA)	1.31	1.31	1.31	1.22	1.21	1.19	0.074	0.083	0.098
32	Cincinnati (OH-KY)	1.31	1.32	1.23	1.28	1.30	1.23	0.024	0.014	0.002
33	Detroit	1.31	1.33	1.26	1.37	1.41	1.30	-0.042	-0.060	-0.031
34	Minneapolis-St Paul	1.31	1.31	1.30	1.35	1.37	1.28	-0.028	-0.043	0.019
35	Louisville (KY-IN)	1.30	1.30	1.29	1.24	1.25	1.20	0.048	0.038	0.068
36	St Louis (MO-IL)	1.30	1.31	1.23	1.31	1.35	1.25	-0.004	-0.028	-0.014
37	Jacksonville	1.30	1.25	1.38	1.23	1.21	1.22	0.055	0.030	0.126
38	Charlotte	1.30	1.28	1.33	1.20	1.20	1.19	0.076	0.061	0.112
39	Philadelphia (PA-NJ)	1.29	1.23	1.43	1.44	1.47	1.33	-0.110	-0.176	0.070
40	Tucson	1.28	1.18	1.33	1.28	1.23	1.24	-0.002	-0.040	0.071
41	San Antonio	1.28	1.32	1.19	1.28	1.31	1.22	0.000	0.005	-0.022
42	Salt Lake City	1.28	1.28	1.30	1.30	1.30	1.22	-0.012	-0.018	0.060
43	Fort Wayne	1.28	1.09	1.41	1.14	1.10	1.17	0.113	-0.006	0.189
44	Sacramento	1.28	1.28	1.27	1.30	1.31	1.25	-0.012	-0.019	0.016
45	Nashville	1.27	1.26	1.29	1.17	1.17	1.18	0.078	0.076	0.085
46	Cleveland	1.27	1.28	1.15	1.32	1.35	1.25	-0.038	-0.054	-0.084
47	New Orleans	1.26	1.31	1.20	1.32	1.32	1.25	-0.048	-0.005	-0.040
48	Pensacola	1.25	1.00	1.37	1.16	1.07	1.20	0.073	-0.067	0.135
49	Greensboro	1.24	1.26	1.15	1.08	1.06	1.12	0.139	0.170	0.023
50	Memphis (TN-AR-MS)	1.24	1.32	1.15	1.26	1.25	1.23	-0.019	0.056	-0.070
51	Chattanooga (TN-GA)	1.24	1.26	1.19	1.14	1.11	1.17	0.081	0.129	0.014
52	Waterbury	1.23	1.24	1.07	1.11	1.07	1.14	0.101	0.145	-0.064
53	Birmingham	1.23	1.20	1.33			1.19			0.108
54	Providence-Pawtucket (RI-MA)	1.23	1.25	1.12	1.25	1.25	1.22	-0.016	-0.001	-0.084
55	Evansville (IN-KY)	1.22	1.00	1.46	1.09	1.06	1.13	0.116	-0.057	0.260
56	Columbus	1.22	1.22	1.23	1.24	1.25	1.21	-0.016	-0.028	0.017
57	Grand Rapids	1.22	1.11	1.45	1.16	1.15	1.18	0.046	-0.035	0.205
58	Canton	1.22	1.22	1.21	1.11	1.08	1.15	0.094	0.124	0.052
59	Lawrence Haverhill (MA-NH)	1.21	1.21	1.24	1.11	1.09	1.15	0.087	0.102	0.079
60	Rochester	1.19	1.20	1.16	1.21	1.21	1.20	-0.021	-0.009	-0.030

Appendix D-1 Continued

	Urbanized Area	Combined TRI	Freeway TRI	Principal Arterial TRI	Predicted Combined TRI	Predicted Freeway TRI	Predicted Principal Arterial TRI	Residuals for Combined TRI	Residuals for Freeway TRI	Residuals for Principal Arterial TRI
61	Richmond	1.19	1.18	1.23	1.19	1.19	1.18	0.001	-0.010	0.038
62	Tulsa	1.19	1.19	1.19	1.20	1.19	1.21	-0.012	-0.003	-0.016
63	Oklahoma City	1.19	1.22	1.11	1.21	1.19	1.23	-0.020	0.023	-0.104
64	Fresno	1.18	1.13	1.24	1.23	1.20	1.21	-0.038	-0.062	0.026
65	Pittsburgh	1.18	1.13	1.27	1.33	1.34	1.26	-0.122	-0.173	0.006
66	Ann Arbor	1.18	1.18	1.16	1.13	1.12	1.14	0.046	0.055	0.018
67	Dayton	1.18	1.16	1.23	1.21	1.22	1.18	-0.023	-0.052	0.042
68	Allentown-Bethlehem-Easton (PA-NJ)	1.17	1.13	1.34	1.17	1.16	1.18	-0.002	-0.024	0.125
69	Trenton (NJ-PA)	1.17	1.13	1.27			1.16			0.091
70	Harrisburg	1.17	1.16	1.28	1.10	1.10	1.14	0.062	0.055	0.119
71	Akron	1.16	1.18	1.08			1.18			-0.091
72	Baton Rouge	1.16	1.21	1.08	1.15	1.12	1.18	0.005	0.078	-0.086
73	Charleston	1.16	1.12	1.22	1.15	1.13	1.17	0.011	-0.011	0.041
74	Ogden (UT)	1.16	1.14	1.22			1.15			0.055
75	Kansas City (MO-KS)	1.16	1.16	1.14	1.24	1.26	1.22	-0.064	-0.080	-0.070
76	Atlantic City	1.15	1.08	1.30			1.13			0.142
77	El Paso (TX-NM)	1.15	1.22	1.06	1.24	1.23	1.20	-0.073	-0.010	-0.127
78	Montgomery	1.15	1.05	1.28	1.09	1.03	1.16	0.052	0.019	0.103
79	Hartford-Middletown	1.15	1.15	1.15	1.20	1.21	1.18	-0.045	-0.052	-0.028
80	Omaha (NE-IA)	1.14	1.06	1.23	1.20	1.20	1.19	-0.051	-0.125	0.036
81	South Bend-Mishawaka (IN-MI)	1.13	1.00	1.23	1.13	1.10	1.15	0.002	-0.093	0.069
82	Lexington-Fayette	1.12	1.01	1.34	1.09	1.05	1.14	0.025	-0.040	0.160
83	Lincoln	1.12	1.00	1.16	1.17	1.09	1.17	-0.040	-0.090	-0.011
84	Savannah	1.12	1.00	1.21	1.21	1.13	1.22	-0.076	-0.124	-0.007
85	Stockton	1.11	1.13	1.09	1.17	1.16	1.16	-0.051	0.028	-0.061
86	Augusta (GA-SC)	1.11	1.13	1.10	1.20	1.13	1.23	-0.078	0.001	-0.115
87	Bakersfield	1.11	1.13	1.10	1.20	1.15	1.20	-0.079	-0.021	-0.083
88	Buffalo-Niagara Falls	1.11	1.14	1.06	1.27	1.26	1.24	-0.138	-0.103	-0.156
89	Kalamazoo	1.11	1.05	1.18	1.09	1.06	1.13	0.016	-0.009	0.045
90	Greenville	1.10	1.13	1.07			1.16			-0.085
91	Reading	1.10	1.08	1.12	1.13	1.09	1.15	-0.025	-0.011	-0.022
92	Lansing-East Lansing	1.10	1.03	1.20	1.13	1.12	1.14	-0.023	-0.084	0.050
93	Des Moines	1.09	1.09	1.09	1.10	1.11	1.13	-0.010	-0.021	-0.034
94	Spokane	1.09	1.10	1.08	1.21	1.18	1.18	-0.108	-0.068	-0.091

Appendix D-1 Continued

	Urbanized Area	Combined TRI	Freeway TRI	Principal Arterial TRI	Predicted Combined TRI	Predicted Freeway TRI	Predicted Principal Arterial TRI	Residuals for Combined TRI	Residuals for Freeway TRI	Residuals for Principal Arterial TRI
95	Madison	1.09	1.07	1.15	1.15	1.16	1.13	-0.056	-0.085	0.013
96	Corpus Christi	1.09	1.09	1.06	1.14	1.14	1.14	-0.042	-0.043	-0.074
97	Roanoke	1.08	1.00	1.21	1.11	1.08	1.14	-0.032	-0.080	0.062
98	Brockton	1.08	1.09	1.00	1.13	1.07	1.15	-0.048	0.014	-0.142
99	Little Rock-North Little Rock	1.08	1.08	1.07	1.13	1.14	1.14	-0.045	-0.051	-0.066
100	Portland (ME)	1.08	1.07	1.08	1.06	1.02	1.10	0.018	0.043	-0.022
101	Mobile	1.07	1.02	1.16	1.12	1.08	1.16	-0.048	-0.061	-0.002
102	Worcester (MA-CT)	1.07	1.06	1.17	1.13	1.12	1.15	-0.055	-0.055	0.014
103	Toledo (OH-MI)	1.07	1.07	1.11	1.16	1.18	1.16	-0.084	-0.096	-0.048
104	Columbus (GA-AL)	1.07	1.00	1.15	1.15	1.09	1.20	-0.073	-0.089	-0.039
105	Beaumont	1.07	1.08	1.04	1.03	1.00	1.09	0.036	0.075	-0.050
106	Columbia	1.07	1.05	1.12	1.13	1.12	1.15	-0.056	-0.069	-0.030
107	Jackson	1.06	1.07	1.06	1.09	1.08	1.14	-0.029	-0.013	-0.070
108	Rockford	1.06	1.00	1.11	1.11	1.08	1.15	-0.050	-0.073	-0.031
109	Amarillo	1.05	1.03	1.09	1.06	1.05	1.11	-0.012	-0.017	-0.018
110	Youngstown-Warren	1.05	1.00	1.23	1.13	1.11	1.17	-0.073	-0.103	0.053
111	Lubbock	1.05	1.00	1.08	1.08	1.07	1.12	-0.031	-0.068	-0.034
112	Shreveport	1.05	1.01	1.12	1.12	1.08	1.14	-0.060	-0.071	-0.021
113	Winston-Salem	1.05	1.05	1.17	1.09	1.08	1.13	-0.038	-0.028	0.039
114	Erie	1.05	1.00	1.06	1.18	1.09	1.19	-0.119	-0.083	-0.115
115	Lorain-Elyria	1.04	1.05	1.01	1.05	1.02	1.13	-0.009	0.029	-0.111
116	Syracuse	1.04	1.04	1.08	1.15	1.16	1.15	-0.098	-0.107	-0.060
117	Saginaw	1.04	1.00	1.09	1.07	1.04	1.11	-0.028	-0.037	-0.021
118	Springfield	1.04	1.00	1.10	1.06	1.05	1.09	-0.021	-0.052	0.005
119	Huntington-Ashland (WV-KY-OH)	1.04	1.00	1.09	1.07	1.05	1.12	-0.028	-0.046	-0.025
120	Macon	1.03	1.00	1.11			1.18			-0.057
121	Peoria	1.03	1.00	1.11	1.11	1.09	1.14	-0.073	-0.089	-0.023
122	Albany-Schenectady-Troy	1.03	1.02	1.13	1.17	1.18	1.16	-0.129	-0.148	-0.030
123	Galveston	1.03	1.00	1.04	1.05	0.98	1.09	-0.022	0.017	-0.051
124	Flint	1.03	1.01	1.06	1.15	1.14	1.16	-0.108	-0.117	-0.087
125	Davenport-Rock Island-Moline (IA-IL)	1.03	1.01	1.09	1.13	1.12	1.14	-0.091	-0.108	-0.042
126	Wichita	1.02	1.01	1.07	1.12	1.13	1.15	-0.093	-0.110	-0.069

Appendix D-1 Continued

	Urbanized Area	Combined TRI	Freeway TRI	Principal Arterial TRI	Predicted Combined TRI	Predicted Freeway TRI	Predicted Principal Arterial TRI	Residuals for Combined TRI	Residuals for Freeway TRI	Residuals for Principal Arterial TRI
127	Springfield (MA-CT)	1 02	1 02	1 06	1 16	1 12	1 21	-0 132	-0 098	-0 129
128	Port Arthur	1 02	1 00	1 04	0 96	0 92	1 05	0 060	0 079	-0 011
129	Binghamton	1 02	1 00	1 18	1 04	1 02	1 09	-0 022	-0 023	0 081
130	Utica-Rome	1 02	1 00	1 07	1 05	1 03	1 10	-0 026	-0 031	-0 026
131	New Bedford	1 02	1 00	1 09	1 11	1 08	1 12	-0 082	-0 077	-0 028
132	Pueblo	1 01	1 02	1 00	1 04	1 03	1 10	-0 032	-0 009	-0 099
133	Topeka	1 01	1 00	1 03	1 06	1 05	1 10	-0 052	-0 045	-0 069
134	Cedar Rapids (IA)	1 01	1 00	1 03	1 05	1 03	1 09	-0 035	-0 028	-0 059
135	Fall River (MA-RI)	1 01	1 00	1 13			1 11			0 018
136	Waco	1 01	1 00	1 02	1 00	0 98	1 08	0 006	0 024	-0 055
137	Duluth (MN-WI)	1 01	1 00	1 02	1 08	1 04	1 10	-0 066	-0 042	-0 079
138	Waterloo-Cedar Fall:	1 00	1 00	1 00	1 04	0 99	1 11	-0 042	0 012	-0 103

Appendix E

List Of Symbols And Abbreviations

Table E-1: List Of Symbols And Abbreviations

CV	coefficient of variation
DOT	Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HPMS	Highway Performance Management System
LOS	level of service
MPO	Metropolitan Planning Organization
PA	Principal Arterial
rev	Revenue
Sq mi	square mile
$S_{y x}$	standard error of the estimate
TTI	Texas Transportation Institute
TRI	travel rate index
UT	The University of Tennessee, Knoxville
var	variable
VIF	variance inflation factor
VMT	vehicle miles of travel

Vita

Elisabeth Hahn is originally from Columbus, Ohio She received a Bachelor of Science in Civil Engineering from the University of Tennessee in November of 1992 and has written this thesis to fulfill the requirements for obtaining a Masters of Science in Civil Engineering.

Elisabeth has 6 years of experience working as a Civil Engineer on environmental engineering projects for Stone and Webster, and Bechtel Corporation in Tennessee She has been involved in several projects while doing her graduate study at UT, some of which are listed below:

- Travel demand forecasting model development for two small cities in Tennessee
- Transit benefits study
- FHWA freight planning website renovation

Elisabeth has been active as an officer of UT's student chapter of the Institute of Transportation Engineers She was president of the chapter during 1999-2000. She enjoys travel in other countries, surfing, and backpacking.