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UPDATING PROCEDURES TO ESTIMATE AND FORECAST VEHICLE-MILES TRAVELED

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TECHNICAL *Summary*

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Updating Procedures To Estimate And Forecast Vehicle-Miles Traveled

Introduction

VMT estimates have been required by various legislation for planning purposes, highway fund allocation, and environmental monitoring, among other uses. The Transportation Equity Act for the 21st Century (TEA-21) allocates apportionment funds under various programs, such as the National Highway System (NHS), the Interstate Maintenance Program (IMP), and the Surface Transportation Program (STP), based on the ratio of the total VMT traveled on a state's public roads to the total nationwide VMT traveled on the same functional classes of roads.

The Federal Highway Administration (FHWA) and the Environmental Protection Agency (EPA) recommend the use of ground count-based programs for the estimation of vehicle-miles traveled. The Highway Performance Monitoring System (HPMS), which is being used by State DOTs, is a program developed by the FHWA for the monitoring of the nation's highway infrastructure. INDOT is not able to achieve its target 3-year periodic count program on all public roads in the state and is uncomfortable with statewide VMT estimates generated by this program.

The objective of this study was to generate simple and effective alternative VMT estimation procedures to augment or supplement current ground count-based methods.

Findings

The methods adopted in this study are based on driving characteristics of licensed drivers and households in Indiana for the estimation of total annual personal travel VMT. The annual VMT generated by buses and trucks, which represents commercial vehicles, is estimated from fuel tax records.

The statewide personal travel VMTs calculated for the year 2000 were lower than INDOT's estimates by about five percent. The statewide personal travel VMT calculated from the household-based model was lower than the INDOT estimate by 26 percent because of the exclusion of non-household vehicles. The commercial vehicle VMT exceeded INDOT's estimate for the year 2000 by 36 percent.

Because of the exclusion of non-household vehicles from the household-based method, the licensed driver-based VMT estimation method is recommended for the calculation of total annual personal travel VMT. The total statewide VMT obtained from this study is about 0.3 percent higher than INDOT's estimate for the year 2000. Because of the low difference between the VMT estimates obtained by INDOT and this study, there is no reason to revise INDOT's current method of VMT estimation, however, the negative impact of trucks on the highway pavement and the environment may require a review of the vehicle classification program to better estimate the volume of trucks on Indiana public roads.

Implementation

Three separate procedures are developed in this study for the estimation of personal travel and commercial vehicle VMT:

- a licensed driver-based method
- household-based methods
- a method based on fuel tax reports

The Nationwide Personal Transportation Survey (NPTS) is the data source for the first two methods. The third method produces an estimate of VMT by commercial vehicles, namely, all buses and trucks. Neither data source (NPTS or fuel tax reports) permits the estimation of VMT by highway functional class.

Because the household-based method's data source does not include non-household vehicle trips, the licensed driver-based method is recommended for the estimation of the personal travel component of the total statewide VMT. The licensed driver-based model was programmed into a Microsoft Excel spreadsheet, called LIC_VMT. The user's manual for LIC_VMT can be found in Chapter 7 of this report.

Because certain trucks are excluded from the fuel tax reports, the commercial vehicle VMT calculated in this study represents the lower bound of the statewide VMT generated by all buses and trucks. The data for the calculation of annual commercial vehicle VMT were obtained from the Motor Carrier Services Division of the Indiana Department of Revenue. INDOT can contact the Motor Carrier Services Division at (317) 615-7203 for the annual IFTA (International Fuel Tax Agreement) and MCFT (Motor Carrier Fuel Tax) reports. These reports are described in Section 3.6 of the report. The annual statewide commercial vehicle activity data can be estimated directly from these reports, as described in Sections 4.5 and 5.4 of this study's final report.

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16. Abstract

Procedures developed for the estimation of Vehicle-Miles of Travel (VMT) have been fraught with problems of inaccuracy. Emphasis on environmental issues (air quality), as mandated by current regulations (CAAA, ISTEA-91, and TEA 21), requires State DOTs to accurately estimate travel on their highway infrastructure. The Federal Highway Administration (FHWA) has developed, and subsequently modified, the Highway Performance Monitoring System (HPMS) to assist in data collection and reporting. INDOT currently estimates VMT by a method that closely follows the HPMS method. Roads that are not on the state highway system (minor collectors, urban collectors and local) are not represented in the estimation procedure, thus INDOT is uncomfortable with the accuracy of the statewide VMT estimates reported to the FHWA.

Cross-classification models are being developed, based on licensed driver and household travel characteristics, with data from the Nationwide Personal Transportation Survey (NPTS). These models are intended to address the problems of sampling bias associated with current VMT estimation procedures because they are independent of highway functional class. Variables adopted in these models include average annual miles driven per licensed driver, by sex and age cohort, and average annual household VMT based on selected demographic and socioeconomic characteristics.

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Three separate procedures are developed in this study for the estimation of personal travel and commercial vehicle VMT. The Nationwide Personal Transportation Survey (NPTS) is the secondary data source for two of the methods -- the licensed driver-based method and the household-based methods. The third method is based on fuel tax reports for the estimation of commercial vehicle VMT. The commercial vehicle VMT represents all buses and trucks. Neither data source permits the estimation of VMT by highway functional class.

The licensed driver-based model requires the number of licensed drivers by sex and age cohort registered in Indiana. The Indiana Bureau of Motor Vehicles or the *Highway Statistics* series are alternative sources of this information. However, the licensed driver data obtained from either of these sources must be treated with caution.

The household-based model requires the population of households by area type (at the census tract level) and any of the following demographic characteristics: *household size*, *household income*, and *household vehicle count*. The U. S. Census Bureau is probably the only source of such information. Because this information may only be available after the decennial census, this method may not be reliable for intermediate periods.

In view of the constraints associated with the data sources used in this study, the following recommendations are provided:

- The commercial vehicle VMT calculated in this study represents the lower bound of the statewide VMT generated by all buses and trucks. This lower bound estimate exceeded INDOT's estimate for the year 1999 by 45 percent, and exceeded the estimate for the year 2000 by 36 percent. The Interstate Maintenance Program (IMP) and National Highway System (NHS) under the TEA-21 require commercial vehicle contributions to the total annual statewide VMT for the distribution of the apportionment funds. Therefore, the vehicle classification equipment should be tested and calibrated to ensure the accuracy of data obtained from count programs. The vehicle detection and classification algorithms of the vehicle classification equipment should also be continuously calibrated. The Indiana Department of Revenue receives quarterly fuel tax reports from all jurisdictions containing the total miles driven on Indiana public roads by all IFTA and MCFT licensed vehicles. These reports can serve as a benchmark for the control of data obtained from ground count methods.

- The licensed driver-based method is recommended for the estimation of the personal travel component of the total statewide VMT because of the exclusion of non-household vehicle trips from the household-based method.
- The VMT estimate for the year 2000 obtained in this study is about 0.3 percent higher than the INDOT estimate. The low difference between the total VMT estimates obtained in this study and INDOT's current procedure does not warrant a change in INDOT's VMT estimation method. However, the negative impact of truck traffic on the highway pavement and the environment may require a re-evaluation of the vehicle classification program to better estimate the truck volume on Indiana public roads.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The estimation of statewide vehicle-miles traveled (VMT) has been required for planning purposes, accident analysis, highway fund allocation, trend extrapolation, and estimation of vehicle emissions. The Transportation Equity Act for the 21st century (TEA-21) 1998, the Intermodal Surface Transportation Efficiency Act of 1991(ISTEA), and the Clean Air Act Amendments (CAAA) of 1990 mandated at states Departments of Transportation to accurately estimate the amount of travel on highways under their jurisdiction. These estimates of travel are required for the monitoring of current environmental regulations. Thirty-five percent of the highway apportionment funds received by each state depend on the total vehicle-miles traveled on lanes of principal arterials (excluding the Interstate system) as a percent of the total VMT on principal arterials in all states. The accuracy of statewide VMT estimates reported to the Highway Performance Monitoring (HPMS) is therefore very important.

1.2 VMT Requirements Under the Various Legislations

The Clean Air Act Amendments (CAAA) of 1990 were geared towards controlling and reducing vehicle emissions to tolerable levels. The Environmental Protection Agency (EPA) and United States Department of Transportation (USDOT) were required to report triennially on the efficiency of federal, state, and local air quality programs implemented under the CAAA. Regions in which levels of a criteria air pollutant did not meet the health-based primary standard (national ambient air quality standard, or NAAQS) for the pollutant are designated nonattainment areas, and are expected to submit programs (State Implementation Plans) geared towards improving their air quality within a stipulated period. Vehicle inspection and maintenance (I/M) programs were instituted under the CAAA to control vehicle emissions. States with very poor air quality ratings were to develop programs aimed at discouraging automobile use. The EPA therefore required states DOTs to accurately estimate, forecast and track VMT as an indicator of air quality standards. The EPA recommended the use of the HPMS as a statewide VMT estimation tool.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA-91) governs the Federal Government's expenditure on transportation projects, and also controls the state and local governments' spending of Federal transportation-related funds. ISTEA created a new initiative called the Congestion Mitigation and Air Quality Improvement program (CMAQ). This initiative is aimed at controlling the growth in vehicle travel. States were tasked to implement programs and projects aimed at improving other modes of transportation, so as to reduce highway VMT.

The Transportation Equity Act for the 21st Century (TEA-21) allocates thirty-five percent of the apportionment funds, under the National Highway System (NHS), based on total VMT traveled on the principal arterial system of a state's highway system as a ratio of the total nationwide VMT on the same classes of roads. Though the use of this fund is very strictly controlled, the accurate estimation of statewide VMT is necessary, if a state is to get its fair share of the Federal funds. TEA-21 also requires a biennial report to congress on the progress in improving intermodal connectors. One-third of the funds for the Interstate Maintenance Program (IMP), which provides funds for resurfacing, restoring, rehabilitating and reconstructing of the Interstate system, depend on the ratio of Interstate highway travel in that state to the total nationwide Interstate highway travel. The Surface Transportation Program (STP) provides flexible funding that may be used for projects on any Federal-aid highway, including the NHS, bridge projects, transit capital projects, and intracity and intercity bus terminals and facilities. A portion of funds reserved for rural areas may be spent on rural minor collectors. Forty percent of funds a state receives under the STP are based on the ratio of total Federal-Aid Highway (FAH)

VMT to total nationwide FAH VMT. Accurate estimation of VMT is therefore very important.

1.3 Background of Research

States maintain traffic monitoring programs for planning purposes, estimation and tracking of VMT, establishing trends and conducting engineering analysis (Mohammed 1997). VMT is a primary indicator of the amount of travel and is also required under current legislation. VMT is an aggregation of trips made in a study area. Ten 2-mile vehicle trips contribute 20 vehicle-miles to the total area wide VMT. However, two 10-mile vehicle trips also contribute 20 vehicle-miles to the total VMT. VMT is therefore a function of both the number of trips made, and the lengths of these trips. VMT is usually reported as the total amount of travel in a day (Daily Vehicle-Miles Traveled) or the total amount of travel in a year (Annual Vehicle-Miles traveled).

Most state DOTs estimate VMT by ground count methods. However, the local road network, which usually forms a majority of the total state road mileage, is biased in the data collection sampling process. The EPA does not enforce the use of any particular method in the estimation of travel on local roads. Most state DOTs are also reluctant to develop comprehensive programs for traffic data collection on local roads because they do not form a part of the state highway system. VMT estimates by current methods do not accurately represent or exhibit expected trends. Because of limited resources, INDOT is not able to achieve its target 3-year periodic count program on all public roads in the state. A dependable method is therefore required to provide statewide estimates of travel to improve the equity and efficiency in the allocation of funds and also improve the confidence placed in the estimates and applications that depend on the estimates.

1.4 Purpose and Scope of Research

This study aims at developing VMT estimates from a variety of existing data sources to augment current estimation methods used by INDOT. Current VMT estimation methods will be reviewed to identify potential problems and shortcomings associated with these methods. The potential of these methods to satisfy requirements under the CAAA, ISTEA-91 and TEA-21 legislation will be assessed.

A primary purpose of this study is to develop unbiased statewide estimates of VMT. Methods developed for the estimation of VMT will be intended to supplement current estimation methods, to improve the accuracy of statewide VMT estimates, and to provide independent estimates of VMT as statewide control totals for planning purposes. The methods developed in this study should be simple, robust, cost-effective, easy to implement and update, and provide the necessary information without requiring extensive training. The estimates generated from this study should conform to Federal requirements. This study will be geared towards developing VMT estimation methods that would not require any additional resources to validate and implement. The models developed in this study would be ideally presented in spreadsheet programs that require minimum input variables. The models developed in this study would be designed to utilize secondary data sources.

It is, however, pertinent to mention that the VMT estimation models developed in this study might produce erroneous estimates when transferred to other states and regions. The 1995 Nationwide Personal Transportation Survey (NPTS) was the secondary data source utilized in the development of the VMT estimation models in this study. Data pertinent to travel in Indiana were extracted from the nationwide database. The method can, however, be transferred to any geographic region for the development of a VMT estimation model.

1.5 Implementation Benefits

The methods developed in this study are intended to provide independent sources of VMT for comparison with estimates obtained from other sources. The VMT estimates obtained from this study should provide statewide control totals for travel demand models and travel simulation. The methods are also intended to serve as a basis for fair and equitable disbursements of allocated funds.

This clustering technique of VMT estimation by household demographic characteristics and area type can provide VMT estimates at different levels, say, regional, county, and township, because the model is based on household travel characteristics and the number of households within the defined clusters is the only variable for the estimation of VMT. The models developed in this study can also provide an opportunity to forecast or track VMT as required by the Clean Air Act Amendments.

1.6 Report Organization

The results of this study are presented in six chapters. Chapter 1 provides an introduction to this study. It discusses the background, purpose, and scope. The intended implementation benefits of the study are also discussed. Chapter 2 presents a literature review of the existing VMT estimation methods developed by federal and state agencies, and other researchers. Chapter 3 discusses the data compilation procedures adopted for the development of two separate statewide VMT estimation models. The assumptions supporting the models developed in this study are also discussed in this chapter. The estimation of relevant parameters from the 1995 NPTS, like the average annual miles driven per licensed driver by sex and age cohort and the estimation of average annual household VMT by area type and certain selected demographic characteristics, are discussed. Chapter 4 discusses the development of the models. Statistical comparative tests required for the effective manipulation of the 1995 NPTS data are discussed. Chapter 5 presents the results, model calibration and validation. Chapter 6 discusses potential VMT estimation tools that could not be utilized in this study due to limited financial resources, or current technological limitations associated with the method. Chapter 7 presents the manual for the use of the licensed driver-based VMT estimation program. Chapter 8 presents the conclusions and findings of the study.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter assesses methods currently used for the estimation of Vehicle Miles of Travel (VMT). The Highway Performance Monitoring System (HPMS) is the federally recommended data collection and reporting process that happens to be the method adopted by the Indiana Department of Transportation (INDOT) for VMT estimation. The HPMS and VMT estimation methods developed by other researchers will be also reviewed.

The HPMS and many other VMT estimation methods focus entirely, or significantly, on roads under state jurisdiction. However, very little literature is available on VMT or traffic volume estimation for local and county roads that usually form a major percentage of the road network in a state.

2.2 Review of the HPMS with Emphasis on VMT Estimation Procedures

The Highway Performance Monitoring System (HPMS) is a program developed by the Federal Highway Administration (FHWA) for the monitoring of the Nation's highway infrastructure. The HPMS was introduced in 1978, and has been continuously modified over the years (1987, 1988, 1989, 1990, 1993, 1996 and 1999) to capture the changing foci of regulations and legislation. The HPMS was structured to perform the following functions (FHWA 1998):

- Serve as a data source for the biennial Condition and Performance Report to Congress,

- Provide a database of performance indicators for strategic planning and program assessment,
- Serve as a basis for the highway program fund apportionment, and
- Ensure air-quality conformity, with regards to current legislative mandates: CAAA, ISTEA, TEA-21 etc.

The HPMS is an inventory of the condition, performance, use and operating characteristics of the nation's road infrastructure. State Highway Agencies (SHAs) are required to submit to the FHWA annual reports on their respective highway systems (FHWA 1999a).

The data collection process is undertaken by the SHAs in collaboration with local governments and Metropolitan Planning Organizations (MPOs). The highway parameters of interest include the system length, performance and operating characteristics, and pavement condition. Data collection methods and techniques are proposed by the FHWA, but the SHAs develop their own methods of traffic estimation on local and rural minor collector functional classes. Strict data collection procedures have not been developed for local and rural minor collector systems on the National Highway System (NHS) within the HPMS. However, the increasing mileage of these classes of roads and their overall percentage, by length, within the NHS, warrants the upgrading of traffic data collection programs to include these classes. The SHAs report HPMS data covering a period of a calendar year ending December 31 to the FHWA by completing an HPMS submittal software package. The latest version of the HPMS software (version 3) was released in April 2000.

Emphasis on environmental issues (air quality), as mandated by current regulations (CAAA, ISTEA-91, TEA-21), has triggered a shift in focus from highway pavement management to the monitoring of highway travel (Kumapley 1994; FHWA 1998). The Environmental Protection Agency (EPA) requires the estimation of travel within non-attainment areas by HPMS-stipulated procedures. The HPMS data, particularly the sections on length, lane miles and travel data, serve as a criterion for the apportionment of Federal-aid highway funds and the monitoring of travel trends and performance characteristics. Planning and performance management procedures are also based on the HPMS database. Thus the importance of data accuracy cannot be overstated.

2.2.1 HPMS Data Classifications Systems

All statewide highway data reported to the HPMS are with respect to two major classification systems: area type and road functional system.

2.2.1.1 Area Type Classification Systems

The FHWA classifies all highway facilities by the area type of the facility, which is set by the population of the area within which the facility is located. The two main classes are rural and urban. Rural roads (HPMS Code 1) are defined as roads located in areas with a population of less than 5,000. Urban roads are further classified as follows:

- Small urban roads (HPMS Code 2) are roads located in areas with a population of between 5,000 and 50,000,
- Small urbanized roads are located in areas with a population of between 50,000 and 200,000 (HPMS Code 3). Indiana has 13 small urbanized areas.
- Large urbanized roads in areas with a population of over 200,000 (HPMS Code 4). The state of Indiana has 5 large urbanized areas.

These classifications are independent of the level of economic development of the area. Thus an urban area with a population of 5,000 or less is considered rural.

2.2.1.2 Road Functional Classification System

The FHWA road functional classes for which HPMS data should be reported are given below for both rural and urban areas:

Rural Functional System:

- Principal Arterials
    - Interstate - HPMS Code 1

    - Other Principal Arterials - HPMS Code 2
  - Minor Arterials - HPMS Code 6
  - Collector
    - Major Collector - HPMS Code 7
    - Minor Collector - HPMS Code 8
  - Local - HPMS Code 9

Urban Functional System:

- Principal Arterials
  - Interstate - HPMS Code 11
  - Other Freeways and Expressways - HPMS Code 12
  - Other Principal Arterials - HPMS Code 14
- Minor Arterials - HPMS Code 16
- Collector - HPMS Code 17
- Local - HPMS Code 19

2.2.2 HPMS Data Reporting Requirements

The data reported under the HPMS is based on a stratified sampling procedure, generating Universe data, Standard sample data, and Donut Area sample data for rural and urban areas (FHWA 1999a).

2.2.2.1 Universe Area Data Reporting Requirements

The universe data contains records of traffic and facilities on existing and proposed public roads for the Principal Arterial System (PAS), and on other existing NHS road functional classes. The data is classified by functional class and area type, and also by jurisdiction. The state of Indiana currently has 4,373 universe sections. Data types under this classification are:

Section data – data from a continuous and homogenous length of roadway, and

Grouped data – data from aggregated sections of non-NHS roads (not necessarily contiguous) with similar characteristics.

2.2.2.2 Standard Sample Data Reporting Requirements

The standard sample data contains records of statistically selected segments of major functional classes, excluding the rural minor collector, rural local and urban local functional classes. The selected samples must be representative of the PAS, on and off the state highway system, and are selected from the domain of the universe sample. Data on the standard sample is used for performance measurement, investment requirements modeling in support of Condition and Performance Reports to Congress, and many other analyses (FHWA 1999a). The state of Indiana has about 2,373 standard sample sections.

2.2.2.3 Donut Area Data Reporting Requirements

The donut area contains the records of a combination of existing standard samples and supplementary samples from a nonattainment area. The supplementary sample usually consists of sections in the rural minor arterial, small urban minor arterial, small urban collector and rural major collector functional classes. These roads are usually within the EPA designated NAAQS (National Ambient Air Quality Standards) nonattainment areas. The donut area samples are located outside of any urbanized area, but within the nonattainment area boundary. The purpose of the donut area sample is to enhance statistical confidence (to a 90-10 confidence level) of the records.

The Donut area records are currently reported primarily to develop travel estimates in NAAQS nonattainment areas under EPA requirements (FHWA 1999a) for transportation-related emissions estimation. Indiana has 123 NAAQS donut sections.

2.2.3 Sampling Procedures

The sampling process for the collection of data on the statewide system for the HPMS is discussed below. The data reported to the HPMS are collected from sampled sections of the state's road infrastructure.

2.2.3.1 Precision Levels of Sample Size

Precision levels are statistically set confidence levels for the traffic data collection process. The predetermined precision level influences the estimation of sample sizes for the various functional classes of road. These precision levels are based on the "importance" of the road. With a higher Federal interest in the PAS, the sample sizes of these classes are based on a higher precision level of 90-5, while the precision requirements for the minor arterial and collector (excluding the minor collector) functional classes are set at 90-10, and 80-10, respectively. The meaning of these precision requirements, say 90-10, is that out of every 100 traffic measurements, 90 are expected to fall within 10 percent of the actual value. These limits of precision levels are, however, not stringent. States with a high number of urbanized areas (usually 3 or more) use a lower precision level to decrease the number of samples generated.

2.2.3.2 Sample Selection

The sample selection process of the HPMS is directed at satisfying the different data needs of the rural and urban area types. Roads on the state highway system within the rural, urban and small-urbanized areas (excluding the rural minor collector system) are sampled on a statewide basis, stratified only by functional class. Sample sections of these functional classes of roads are generated from the total mileage within the state. However, sample sections from roads within large urbanized areas, and nonattainment areas are generated from their total mileage within that area type. The sampling process described pertains to areas not designated as nonattainment areas.

The sample sizes (and road sections), once determined, are rarely revised, because the costs of reinventorying and updating the data elements may be onerous for the SHAs. The use of fixed sample sizes and sections over time, however, lowers the reliability of the data. Because travel patterns change occasionally, the ability of the samples to capture the changing trends in travel patterns may not be effective. The FHWA recommends a 3-year periodic review of a state's sample adequacy.

The sample design is based on the grouping of a random selection, from within the universe sample, of road sections within predetermined AADT strata for the HPMS data classification system of roads. The predetermined AADT classes were based on the 1976 National Highway Inventory and Performance Study (NHIPS). The SHAs are allowed to create their own AADT strata to adequately represent traffic conditions in their jurisdictions, but these state-specific AADT classes must be reported to the FHWA.

The sample selection process begins with the delineation of the sample universe from which the standard samples would be generated. The various arterial and collector system roads, broken into homogenous sections not exceeding 10 miles in length for rural sections and 5 miles for urban, are then assigned to the various AADT strata. The standard sample results are extrapolated to the universe level by use of expansion factors, which for each functional class is the ratio of the length of road within that class in the standard sample to the universe sample (for each AADT stratum). The number of standard samples (the sample size) for each stratum is determined by using an FHWA-developed statistical equation based on the standard normal statistic (for the required confidence level), the AADT coefficient of variation, desired precision rate and universe sample size. A minimum standard sample size of 3 is required for each AADT stratum. The data collection process on all selected samples should be repeated on a recommended 3-year cycle.

2.2.4 Traffic Monitoring and Data Collection Procedures

The collection of accurate and adequate count-based traffic data is a primary activity of the HPMS process. The count program, covering all interstates, principal arterial, other NHS, and HPMS sample sections, should be executed in a 3-year cycle. This includes counts made by MPOs and cities on behalf of the SHAs. The count program should, however, cover all public roads in the state highway network (for all functional classes) over a 6-year cycle (FHWA 1999a, Appendix F).

The traffic data of interest includes traffic counts, vehicle classification counts, and truck weight data. The data collection program adopts a sequential or nesting format, as shown in Fig 2.1, to avoid duplication of the process.

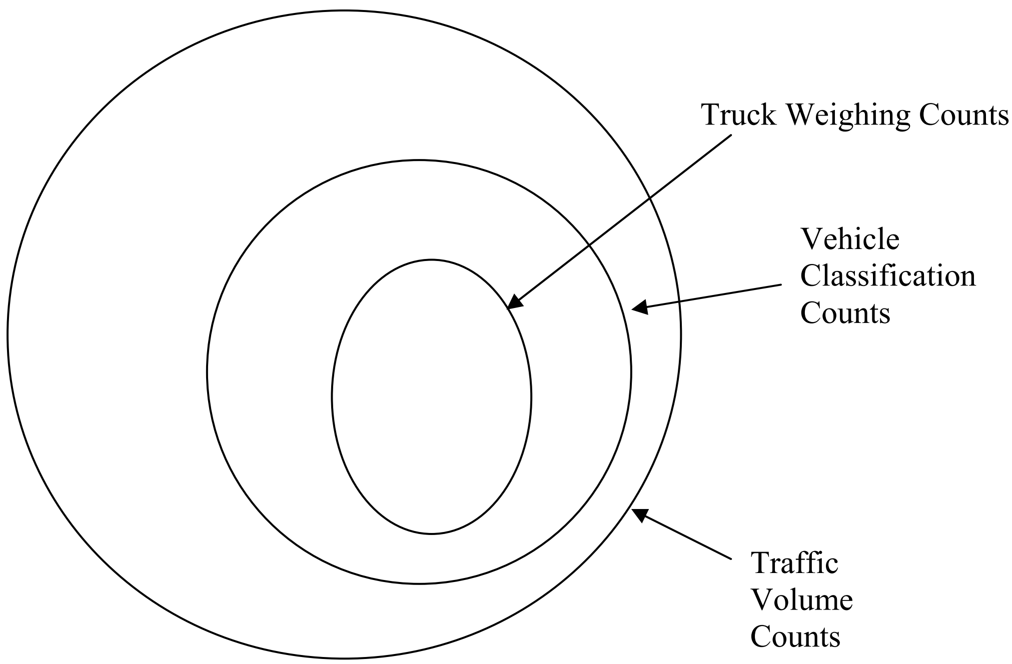


Figure 2.1 Nested format of the traffic data collection process

Fig 2.1 shows that truck weighing count programs are a subset of vehicle classification count programs, which are also a subset of traffic volume count programs. This nesting procedure implies that sites selected for truck weighing automatically should collect all data types, and sites selected for vehicle classification should also collect volume count data.

2.2.4.1 Estimation of Annual Average Daily Traffic (AADT)

The estimation of AADT is based on three types of count procedures (FHWA 2001):

- Continuous counts (year-round) using automatic traffic recorders (ATRs)
- HPMS coverage counts, which are short period counts performed on the HPMS-generated standard sample sections and adjusted by factors derived from the continuous counts, and
- Special needs studies, which are dependent on state data requirements.

Random variation in traffic volumes has been accounted for in present estimation procedures, thus atypical variation due to holidays, etc., should be avoided during the traffic counting process.

The continuous count program is primarily, but not exclusively, for the establishment of seasonal adjustment factors. These adjustment factors facilitate the expansion of short-term standard sample counts to universe samples. Continuous ATR count data is also reported monthly to the FHWA for the preparation of the Traffic Volume Trends report. The number of ATR locations usually depends on the predetermined precision level established for the functional class. The FHWA recommends the use of equations 3-3 through 3-5 in Chapter 3 of the Traffic Monitoring Guide (TMG) for the estimation of the continuous ATR locations (FHWA 2001, pg. 33-3 – 33-4). However, a minimum of 5 to 8 ATR locations per class has been found to satisfy the desired target precision levels for functional classes not exhibiting excessive variability in traffic patterns (FHWA 2001).

Data from the continuous count programs are periodically reviewed to assess the suitability of ATR groupings for roads with similar variability in traffic patterns. The adjustment factors, developed for each group of ATR locations, are derived from the ratio of average estimates of the annual average daily traffic (AADT) to the monthly average daily traffic (MADT) for the group. Adjustment factors are also generated for each ATR location. The expansion of the short-term counts is done by identifying the correct group of ATRs (not necessarily the closest) and multiplying the short-term count by the appropriate factor.

The HPMS coverage count program addresses the system-wide traffic data collection needs through random sampling to ensure fair geographic representation of all public roads. The TMG recommends a minimum 48-hour monitoring period for traffic volume and vehicle classification counts under the coverage count program, with a 3-year cycle for HPMS submittal and a 6-year cycle for the entire coverage count program. Arguments abound, however, as to the trade-offs between longer monitoring periods with longer cycles and shorter monitoring periods with shorter cycles. The objectives and resources of the count program should address trade-offs between the two monitoring programs.

The precision requirement for the Interstate System far exceeds that of the other functional classes. This is because of the huge financial investments in, and the importance of, the Interstate System from a national perspective. The resulting sample size for the Interstate System is usually larger than that of any other functional class.

The recommended count program for the HPMS standard sample suggests the counting of a percentage of the total sample (say 33 percent, randomly selected for a 3-year cycle) for each year of the cycle, and the traffic volume data for sections not counted within that year are expanded by using growth factors developed from ATRs or short duration counts (FHWA 2001).

The AADT estimation procedure for the standard samples entails averaging two separate 24-hour period counts (reduced from a 48-hour count) that have been adjusted. A short duration traffic volume count data will require some adjustments for the estimation of Annual Average Daily Traffic (AADT) to correct for temporal biases, equipment type, and a growth factor to account for a non-counting year (FHWA 2001). The equation for the estimation of AADT is:

$$\text{AADT}_{hi} = 0.5\sum\left(Vol_{hi} \times M_h \times D_h \times A_h \times G_h\right) \tag{2.1}$$

where

AADT_{hi} - Average annual daily traffic at location i of functional class h

Vol_{hi} - 24-hour axle volume at location i of functional class h

M_h - applicable monthly factor for functional class h

D_h - applicable day-of-week factor for functional class h

A_h - applicable axle-correction factor for functional class h, and

G_h - applicable growth factor for functional class h

The daily vehicle distance traveled (DVDT) is estimated from the HPMS standard samples by multiplying the computed AADT, for each section, by the section length to obtain section-specific DVDT. DVDT estimates for sections within a stratum are aggregated to represent DVDT for the entire stratum. To obtain system-wide DVDT, the estimates of stratum DVDT are multiplied by HPMS stratum expansion factors and summed up.

The equation for the estimation of the HPMS stratum expansion factors is

$$EF_i = \frac{TRM_i}{TSRM_i} \tag{2.2}$$

where

EF_i represents the expansion factor for functional class i

TRM_i represents the total statewide road mileage for functional class i

$TSRM_i$ represents the total sampled road mileage for functional class i

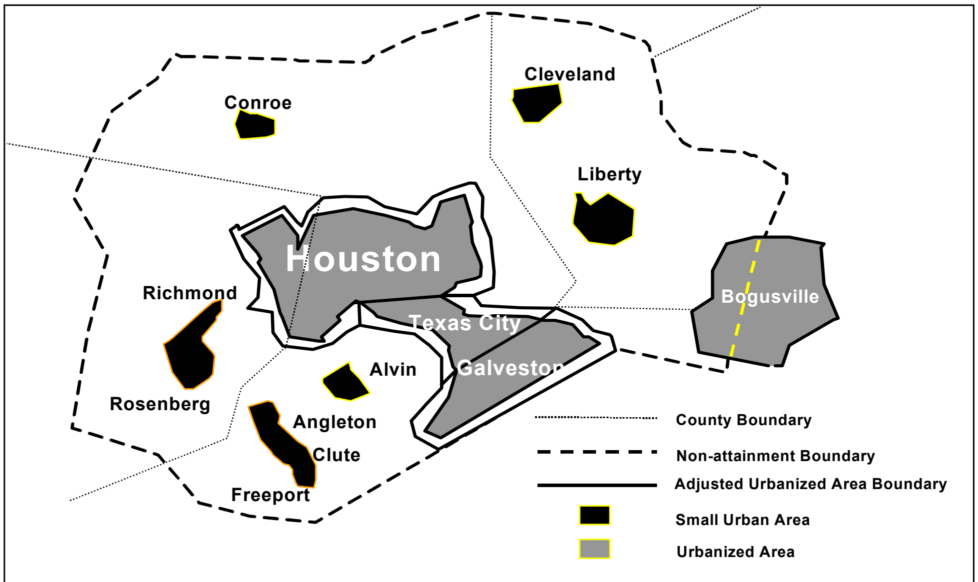
If the total statewide length of roads within a functional class, say rural collectors (RC), is X miles, and the total length of sampled sections is Y miles, then the expansion factor (EF) for this rural collector functional class is X/Y, and estimates of sampled rural collector DVDT will be multiplied by X/Y to obtain statewide estimates for the rural collector functional class. Subsequently, the DVDT estimates are summed over all strata to represent the estimate of travel within the HPMS universe. The DVDT can be multiplied by 365 to represent annualized estimates. DVDT estimates for any category of sample, say rural roads, can be made by multiplying the universe estimate by the percentage representing that category within the HPMS universe. DVDT estimates could be alternatively determined, independent of AADT, by directly expanding the 48-hour counts for axle-correction or growth and multiplying by the section length and appropriate factors.

The Special Needs Program attempts to fill in the voids, spatially and temporally, created by statistical sampling and also to address state-specific needs. Special Needs volume counts could be undertaken for project-level pavement rehabilitation design, signal timing improvements, or for a research study. This undertaking is at the prerogative of the SHA or whichever authority requires the data.

2.2.5 Nonattainment Area Travel Data Requirements

The Environmental Protection Agency (EPA) recommends the estimation of travel within air quality nonattainment areas by HPMS procedures. Modules dependent on HPMS-generated VMT estimates have been developed to estimate vehicle emissions within these areas. The donut area of the nonattainment area is defined as the area outside of the FHWA-approved adjusted urbanized area, but within the nonattainment area, classified as rural or small urban.

Travel estimation programs on the rural minor and collector systems of these areas are again not covered within the HPMS and are thus left to the local agency to develop. Travel within urbanized areas that are split by nonattainment boundaries can also not be estimated by HPMS procedures. Figure 2.2 shows an illustration of a NAAQS nonattainment area for "Houston", obtained from the 1999 HPMS. Data collection efforts for nonattainment areas cannot cross political boundaries, thus air quality travel data for the "Bogusville" urban area shown in Fig 2.2 must be collected outside of the HPMS. The nonattainment area codes of rural and small urban areas are taken as that of the primary urbanized area. The following smaller urban and rural areas in Figure 2.2 – Alvin, Angleton, Cleveland, Clute, Conroe, Freeport, Galveston, Liberty, Richmond, Rosenberg, and Texas City, will adopt the nonattainment code, '015 of Houston for all air-quality data collection efforts. Bogusville is assigned a nonattainment area code of '000' because data collection must be done outside of the HPMS, as explained earlier.



Urbanized Area Code	Non-attainment Area Code	Location
015	015	Houston Urbanized Area
137	015	Galveston Urbanized Area
250	015	Texas City Urbanized Area
000	015	All Small Urban Areas
000	015	All Rural Area
999	000	Bogusville

Figure 2.2 Illustration of Houston NAAQS nonattainment area

2.2.5.1 Donut Area Sampling Procedures and Data Collection

The donut universe represents all public roads belonging to the following functional classes within the demarcated donut area boundary: rural minor arterial, rural major collector, small urban minor arterial and small urban collector. These roads are stratified into two classes: donut minor arterial and donut collector, and five volume classes. The donut area sample consists of the existing HPMS standard sample within the boundary and any supplementary samples, if the current number of HPMS standard sample sections is inadequate. The donut area is stratified into 10 classes defined by two functional classes (minor arterial and collector) and five AADT classes. The homogenous road sections within the boundary are then placed in their appropriate AADT and functional class stratum. Travel within the donut area is estimated at a 90-10 precision level. The generation of the sampling procedure is similar to that described for nondesignated areas. The travel estimates within the nonattainment area are generated from AADT expanded counts within the boundary.

2.2.6 Potential Shortcomings of HPMS VMT Estimation Procedures

Sampling procedure determines the accuracy of the traffic characteristics generated. The stratification of samples by AADT depends on the accuracy of the previous AADT estimates pertaining to the functional classes. Interstate estimates of AADT might very much represent ground-truth data, however, the other, less monitored, functional classes might have a lower accuracy. The level of accuracy from this sampling procedure is questionable.

Local road travel estimates, though much lower than travel on other functional classes, are not represented in the HPMS process. The actual travel on these roads has long been assumed to be within the range of 10 percent - 15 percent of all travel. The accuracy of this assumption, considering the high proportion of local roads, by length, within the state road network, and changing economic patterns and land-use, is doubtful.

2.3 Demographic Survey Based VMT Estimation Methods

In the last half century, demographic surveys have been conducted at nationwide, regional, metropolitan, and local levels to obtain critical information required for effective transportation planning and policymaking. Examples of these surveys are the Nationwide Personal Transportation Survey (NPTS), American Travel Survey (ATS), Residential Transportation Energy Consumption Survey (RTECS), Vehicle Inventory and Use Survey (VIUS), and many others. Results from such surveys have been used extensively for modeling travel behavior and enhancing travel prediction methods (Griffiths et al. 2000). Travel-related surveys, like the NPTS and ATS, have been used extensively for modeling national, regional and local VMT, based on household travel characteristics (Reuscher et al. 2001; Kuzmyak 1981) and on licensed driver characteristics (Greene 1984; Kumapley 1994).

VMT estimation models based on demographic and socioeconomic characteristics usually require extensive data, including:

- Population, employment and land use data,
- Personal and household characteristics, such as:
    - Income
    - Household composition and vehicle ownership
    - Licensed driver status
- Personal and household travel characteristics as determined from household travel surveys, such as:
    - Average annual miles driven per licensed driver by sex and age cohorts
    - Average annual household VMT by area type
    - Household and personal trip making behavior

These models assume a constant driving pattern over a period, say five to six years, and require only the annual change in licensed drivers or household population for the estimation and forecasting of VMT. Estimates of average annual miles driven per licensed driver or household are either collected by asking the respondents to guess the amount of travel they do, or to extrapolate the difference between two odometer readings of a vehicle taken over a period. Regional (or other) VMT is then calculated by multiplying this estimate of average annual mileage per household unit (or licensed driver) by the population of households (or licensed drivers).

2.3.1 Improvements in Personal / Household Travel Survey Data Collection Methods

Traditionally, most travel surveys have relied on personal telephone interviews of respondents. This form of data collection relies on the respondent's recollection of past activities, and also result in situational response, where the composure or mood of the respondent affects the quality of the response (Wermuth et al. 2001). The accuracy of the survey data is thus questionable (Greene 1984; Kuzmyak 1981; Wermuth et al. 2001).
Global Positioning Systems (GPS), Personal Digital Assistants (PDAs), and cellular phones (by the Global System for Mobile Communication (GSM) technology) are

increasingly being adopted as travel or movement data collection methods (Murakami et al. 1997; Battelle 1997; Wermuth 2001).

The Lexington, Kentucky pilot study (Battelle 1997) documents the versatility of GPS units as travel data collection media. Combination of GPS and GIS (Geographic Information Systems) facilitates the tracking of vehicle routes by highway functional class, thus VMT estimates could easily be generated by road functional class for policy formulation and also reporting of travel data to the HPMS. It was found, as expected, that GPS data collection methods provide the most accurate travel data such as route taken, travel time, travel distance, etc. (Battelle 1997; Wermuth et al. 2002). The success of the Lexington study led to the use of GPS units in other studies, such as the Heavy-Duty Truck Activity Data collection survey (HDT) (Battelle 1999). The HDT was aimed at describing truck travel patterns in urban and rural areas by vehicle classes and to produce speed profiles, trip patterns, and improve the heavy-duty truck activity data that are used in forecasting on-road emissions.

The potential and possible applications of GPS to VMT estimation are discussed in Chapter 6.

2.3.2 Problems Associated with Demographic Survey Based Models

Demographic surveys, such as the NPTS, tend to serve as the nucleus of travel demand models. However, these surveys are usually fraught with certain problems that might affect the accuracy of the any model developed from the survey results. Some of the problems are listed below (Kumapley 1994; Griffith et al. 2000; Kuzmyak 1981; Greene 1984):

- Low response rates, or retrieval of invalid or inconsistent data, renders the results worthless or inadequate for accurate inferences to be drawn, and also reduces the effective sample size,
- The survey results might be biased, resulting in an inaccurate model.
- Most surveys rely on the respondent's recollection of trip making patterns, thus reducing the reliability of any estimates drawn from such data.

2.4 Fuel Sales Approach to VMT Estimation

Fuel sales have often been adopted for VMT estimation for over half a century (Kumapley, 1994). The Transportation Demand Module of the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) estimates VMT based on estimates of fuel cost of driving per mile and other demographic variables. Variables adopted in fuel-based VMT estimation models include (EIA 2000; West 2000):

- Statewide retail information of gasoline and diesel (special fuel) in number of gallons (easily obtained from fuel sales tax receipts)
- Vehicle type or fleet fuel economy
- Price per mile of travel (price per gallon of fuel divided by fuel economy)

Regression, logit, and other model types have been developed for VMT estimation based on fuel use and sales, however, a ballpark estimate of VMT can be generated by dividing the total number of gallons of fuel sold by the fleet fuel economy, in miles per gallon (mpg).

Table 2.1 History of Indiana fuel sales taxes

Year	Gasoline (¢/gal)	Diesel (¢/gal)	Diesel Surtax (¢/gal)
1923	2	-	-
1925	3	-	-
1929	4	-	-
1943	4	4	-
1957	6	6	-
1969	8	8	-
1980	8.5	8.5	-
1981	10.5	10.5	-
1982	11.1	11.1	-
1985	14	15	8
1988	15	16	11

Source: INDOT 1998

Table 2.2 History of fuel tax receipts and number of gallons sold in Indiana from FY92 through FY01

Fiscal Year	Gasoline Tax ($)	Total Number of Gallons – Gasoline	Special Fuel Tax ($)	Total Number of Gallons – Diesel
FY 92	399,849.10	2,665,661	94,888.30	593,052
FY 93	406,508.50	2,710,057	108,162.20	676,014
FY 94	420,237.50	2,801,583	125,911.30	786,946
FY 95	430,807.70	2,872,051	124,399.80	777,499
FY 96	437,096.30	2,913,975	143,727.00	898,294
FY 97	443,869.20	2,959,128	147,552.80	922,205
FY 98	455,569.60	3,037,131	151,245.00	945,281
FY 99	466,427.90	3,109,519	161,779.40	1,011,121
FY 00	464,152.80	3,094,352	186,794.00	1,167,463
FY 01	493,684.20	3,291,228	151,335.70	945,848

Source: Indiana Department of Revenue 2001

Table 2.3 Fuel economy standards (mpg) for passenger cars and light trucks model years 1992 through 2002

Model Year	Passenger Cars	Light Trucks
1992	27.5	20.2
1993	27.5	20.4
1994	27.5	20.5
1995	27.5	20.6
1996	27.5	20.7
1997	27.5	20.7
1998	27.5	20.7
1999	27.5	20.7
2000	27.5	20.7
2001	27.5	20.7
2002	27.5	20.7

Source: NHTSA 2000

Table 2.1 shows a history of Indiana's fuel taxes. The current tax rates per gallon of \$0.15 (gasoline) and \$0.16 (special fuel – diesel) were instituted in April 1988 (INDOT, 1998). The state fuel tax receipts can be obtained for each Fiscal Year from the Indiana Department of Revenue (DOR, 2001). Table 2.2 shows the total amount of fuel, in gallons, purchased in the state of Indiana from FY 92 through FY 01. Table 2.3 shows Federal vehicle economy standards for passenger cars and light trucks for the period 1992 through 2002.

VMT can be estimated from equation 2.3 shown below:

$$AVMT = TNG * FMPG \tag{2.3}$$

where

AVMT = Annual Vehicle miles Traveled

TNG = Total number of gallons of fuel sold (gasoline and diesel)

FMPG = Total fleet miles per gallon.

2.4.1 Problems Associated with Fuel-Based VMT Estimation Models

The estimation of fleet fuel economy, in miles per gallon (mpg), presents the most difficult problem for fuel-based VMT models. The mpg depends on the following: fleet age mix, condition or state of the vehicle, driving patterns and habits, weather, topography, fuel loss in motion (evaporation, spillage etc.). Improvements in combustion technology, together with federal legislations on emissions, complicate the estimation of fleet fuel economy. Manufacturers' claims of fuel economy may not be representative of fleet economy due to driving and other characteristics. Commercial vehicles (trucks) have lower fuel efficiency than automobiles and light trucks. Data are currently not available to facilitate the estimation of fleet (all vehicles) fuel economy.

Due to differences in the unit price of fuel across the country, drivers tend to buy fuel in states with lower fuel prices during interstate travel, thus estimation of the amount of fuel bought in the state, used for travel on state roads is even more difficult to estimate. Indiana is known to have lower fuel taxes, hence lower unit fuel prices, than its bordering states (FHWA 1995 - 2000), thus drivers living in other states but close to Indiana's borders, say Illinois (Chicago), have been known to regularly purchase fuel in Indiana.

An estimate of VMT derived from such fuel-based models can be grossly overestimated because of problems listed above.

2.5 Geographic Information Systems (GIS) Based VMT Estimation Methods

Geographic Information Systems (GIS) have been adopted as a data storage and presentation medium by many public and private agencies. GIS has been used to improve on network sampling methods (Bowling and Aultman-Hall 2001), generate VMT estimates from regression models using roadway and socioeconomic characteristics (Zhao and Chung 2000), improve on statewide traffic data collection programs (Lee Engineering 2001), and estimate VMT from vehicle emission and dispersion models (Brandmeyer-Cawlfield and Jeffries 1996). GIS is primarily used as a data analysis or presentation medium in all these studies.

Bowling and Aultman-Hall (2001) developed a GIS grid-based random sampling procedure to select traffic count locations to improve on statewide VMT estimates in Kentucky. This study was to address the problem of inadequate representation of lower functional classes of roads (local, minor collector, etc.) within the existing traffic count program. A GIS database of three counties -- Henderson, Pike and Fayette -- was used for this study. The GIS map was split into square grids of equal size. GIS databases usually store roadways as segments (resulting in individual features) at intersections and many other points, some unsystematic. These road segments, within a grid, represented the population from which a random sample was drawn. The sampling process was developed for local roads, therefore the local road segments within the grid were sampled for traffic data collection. This procedure could, however, be extended to all functional classes within the grid to enhance regional traffic data collection. Four grid sizes (0.05-mile, 0.15-mile, 0.1-mile, and 0.2-mile) were tested to reduce sampling bias, and to reduce computer time and space. The different densities and lengths of roads within the grids created some bias in sampling, particularly in urban areas. Weights were developed to account for bias due to road lengths. This is because, for two roads of the same functional class within a grid, the longer road will have more segments, resulting in a higher probability of being selected. Grid sizes of 0.1 miles and 0.2miles were selected for urban and rural area types, respectively. The randomly selected traffic count locations could be presented graphically to data collection crews to ensure correct site identification.

Lee Engineering (2001) undertook a study for the Arizona Department of Transportation (ADOT) to improve statewide traffic count programs. Lee Engineering recommended the implementation of a statewide program, involving all local agencies, utilizing a single traffic count data collection and reporting format. ADOT, prior to 1992, administered a statewide data collection program where local governments and agencies were trained and equipped to collect traffic count data and report these to ADOT. Traffic data obtained from local development requirements (such as traffic signal warrants or commercial developments) and research-related studies were thus reported to ADOT. This provided an immense database of traffic counts, most of which were not required under the HPMS. The Lee Engineering study found many locations where traffic counts were undertaken by both local and state agencies because there was minimal communication among the agencies. This redundancy could be eliminated by the use of GIS as a data-reporting medium, where all proposed counts at locations for which data are available could be relocated. An inherent problem with this recommendation, however, is the reliability of data obtained from the other agencies.

2.6 Use of Satellites and Unmanned Aerial Vehicles as VMT Estimation Tools

Studies are being conducted into the use of satellites and unmanned aerial vehicles (UAVs) as traffic data collection media (MCCord et al. 1998; Merry 2001). The impetus for these studies is to identify the temporal distribution (time of day variability) of traffic on different segments of the same road, and also the spatial distribution (area-to-area variability) of traffic on a state's road network for proper assignment of seasonal expansion factors (MCCord et al. 1998; Merry 2001). Satellite and UAVs as potential VMT estimation tools, are discussed in Sections 6.2 and 6.3.

2.7 Chapter Summary

This chapter discussed the VMT estimation methods currently developed by state DOTs and other researchers. A review of the HPMS is presented discussing the shortcomings and problems associated with its use. VMT estimation methods have been developed based on demographic survey data, state fuel sales, and GIS methods. Problems associated with these methods have been discussed in this chapter. Technological advancements in traffic data collection media (satellites and unmanned aerial vehicles) as potential VMT estimation tools are introduced in this chapter. However, the use of these advanced traffic data collection media is discussed in Chapter 6.

CHAPTER 3. DATA COMPILATION PROCEDURES

3.1 Introduction

Demographic characteristics have long been identified as good predictors of highway travel (Greene 1987; Kumapley 1994; Patterson et al. 1998). Some of the characteristics that have been considered include: population, age, gender, household characteristics, income, and auto ownership. Travel estimation models have been developed based on various combinations of these variables (Kumapley 1994; Greene 1987; Maring 1974).

Demographic estimates and forecasts of travel are robust if data on the selected indicators are easily obtained with a reliable level of accuracy. Forecasts of the selected exogenous variables should also be fairly simple to guarantee the ease of updating the model, if necessary. The cost of motor fuel has not been an effective predictor of travel because variability in fuel prices is even more difficult to predict than variability in travel, and travel has been known to be inelastic to fuel prices (Greene 1987).

Two cross-classification models were developed in this study, from the NPTS travel data:

- A licensed-driver based VMT estimation model that estimates statewide VMT from average annual mileage estimates per licensed driver and the population of licensed drivers in the state by sex and age cohort, and
- Three household-based VMT estimation models that generate statewide VMT estimates from the population of households and average annual household VMT by area type and each of the following socioeconomic characteristics: *annual household income*, *number of household vehicles*, and *household size*.

3.2 Licensed Driver Based VMT Estimation Models

Cross-classification VMT estimation and forecasting models have been developed with statistics on licensed drivers as the primary variable (Kumapley 1994; Greene 1984). Licensed driver data are readily updated by state departments and considered to be reliable. The success of such models is based on the premise that the distribution of the driving-age population of a community is easily predictable over the next twenty years (Greene 1987). This assumption is, however, dependent on the constancy (or growth rate) of drivers per capita within each age group. The value of licensed drivers per capita, within an age group, is constrained by a definite bound of 1, and the ratio seems to be converging on 1 (Greene 1987).

An estimate of miles driven annually per licensed driver is also a variable that is required in licensed driver based VMT estimation models. The concept of travel time budgets, considering all social functions to be performed by an individual, assigns an upper bound of 1 to 2 hours a day for travel (Greene 1987). This constraint is necessary to assess the growth rates of travel, because most records on annual miles per licensed driver are based on a subject's memory during travel survey interviews. The annual miles per licensed driver, however, are affected by vehicle occupancy rates, residential trends and travel characteristics (Greene 1987; Kumapley 1994). This is because:

- The incidence of urban sprawl results in longer commute lengths and times, hence longer average annual miles driven,
- Changes in household sizes, and vehicle ownership will probably result in different driving patterns, hence different average annual vehicle miles driven per licensed driver.

Greene (1987), Kumapley (1994), and Maring (1974) developed separate models based on licensed driver records and annual miles driven per driver to estimate and forecast VMT. The process adopted by all three researchers was as follows:

Step 1: Input number of licensed drivers per age group and/or sex, or ratio per capita.

Step 2: Multiply number of licensed drivers by estimates or forecasts of annual miles driven, by age and/or sex, to obtain total vehicle miles within each class.

Step 3: Aggregate estimates of vehicle miles within each class to obtain the total VMT.

The process can be represented by either of the following equations:

$$\text{AVMT} = \sum_i \sum_j (P_{ij} * r_{ij} * v_{ij}) \tag{3.1}$$

or

$$\text{AVMT} = \sum_i \sum_j (l_{ij} * v_{ij}) \tag{3.2}$$

where

AVMT represents the total annual vehicle miles traveled,

P_{ij} represents the population of sex i, and age cohort j,

r_{ij} represents the ratio of licensed drivers per capita for sex i, and age cohort j,

l_{ij} represents the number of licensed drivers (if data are available; otherwise could be from $P_{ij} * r_{ij}$), and

v_{ij} represents the estimates of annual miles driven per licensed driver for sex i and age cohort j.

Greene (1981) and Maring (1974) developed their models to achieve nationwide estimates of VMT, but Kumapley's (1994) model calculated statewide VMT.

3.2.1 Data Sources for Previous Licensed Driver Based VMT Models

Reliability of data is crucial for the accuracy of any model. Licensed driver populations and estimates of miles driven per driver are available by sex and age groups. The Nationwide Personal Transportation Study (NPTS) provides an opportunity to examine the veracity of the postulates that:

1) License driver holding rates per capita by age group and sex remain relatively constant over time, and
2) Annual estimates of miles driven per licensed driver by age and sex remain relatively constant over time.

The FHWA publication, *Highway Statistics*, is a reliable source of licensed driver holding rates by age and sex. *Highway Statistics* has been published annually from 1945, and contains statistical data on all highway related matter:

- Motor fuel consumption,

- Highway use tax,
- State highway financing,
- Driver licensing, and
- Roadway extent, characteristics and performance.

The data published in *Highway Statistics* are submitted to FHWA by the 50 states and the District of Columbia. Census forecasts are an alternative source of data if the ratio of licensed drivers per capita by sex and age cohort is known. Population forecasts can be obtained from census counts to determine the number of licensed drivers.

The NPTS is a survey of the civilian population of the United States sponsored by four agencies of the U.S. Department of Transportation: FHWA, BTS, FTA, and NHTSA. The NPTS was first conducted in 1969, and subsequently in 1977, 1983, 1990, and 1995. The NPTS has been combined with the American Travel Survey (ATS) for the year 2001, to comprise the National Household Travel Survey (NHTS), which will be a more comprehensive database. The NPTS data assesses travel behavior, analyzes changes and trends in travel over time, and primarily serves as a benchmark for assessing local travel data (RTI 1997). Data on the NPTS include:

- Household level data – size, income, education, etc.
- Motor vehicle information – estimates of annual VMT, age, etc.
- Public transportation - use, availability, etc.
- Drivers – annual miles driven etc.
- Trips – length, travel time, etc.
- Description of geographic area characteristics for households and workplaces.

NPTS data, prior to 1990, were only available at the national level, however, subsequent studies have been compiled at the statewide level.

The 1995 NPTS survey was conducted by a Computer-Assisted Telephone Interviewing (CATI) process (RTI 1997). The number of completed household interviews in the five surveys is shown in Table 3.1.

Table 3.1 Households in NPTS from 1969 through 1995

Year	Number of Households
1969	15,000
1977	18,000
1983	6,500
1990	22,317
1995	42,033

Source: Research Triangle Institute 1997

The NPTS is the source of the annual miles driven per licensed driver by sex and age cohort for this study. The NPTS respondents are asked how many miles they drive in a year in all motor vehicles, as the principal driver. The responses are interpreted as estimates of annual miles driven by that respondent.

3.3 Replication of Statewide Licensed Driver Based VMT Model

Kumapley (1994) developed a cross-classification model for the statewide estimation of VMT for Indiana. The model was based on travel estimates from the 1990 NPTS and licensed driver distribution forecasts for the state, by sex and age cohort, from the *Highway Statistics* series.

This model was reproduced to assess its precision in estimating VMT. The model was programmed in an MS Excel spreadsheet. Kumapley (1994) developed his model with travel data for Indiana from the 1990 NPTS travel survey. This model was modified by computing estimates of miles driven per licensed driver for selected neighboring states with similar travel characteristics. The decision to consider states other than Indiana was to assess the improvement in the generation of annual estimates of miles per licensed driver from a larger sample size. Kumapley (1994) could not generate long-term forecasts of VMT because it was not possible to obtain growth rates for miles per licensed driver. Prior NPTS studies (1967, 1977, and 1983) did not have data at the statewide level. Growth rates can now be generated using the 1995 and 1990 NPTS travel estimates, for use in long-term VMT forecasting. Results from the estimation of VMT with this model will be discussed in Chapter 4.

3.4 Data Compilation Process for Model Development

The licensed driver-based model developed in this study is based on the same concept as Maring (1974), Greene (1987) and Kumapley (1994). The 1990 and 1995 NPTS were used for generation of estimates of annual miles driven per licensed driver. This model is developed to estimate and forecast VMT for the State of Indiana. However, the NPTS sample size for Indiana was considered inadequate, so data for the following states were aggregated to generate estimates of annual miles driven per driver: Indiana, Ohio, Iowa, Wisconsin and Kentucky. These states were selected because they were considered to have similar travel characteristics. Average travel times and lengths for home-based work trips and other trip purposes defined in the 1995 NPTS were similar for the five states. The similarity in average travel times and trip lengths among the five states cannot, however, be used as the only basis for aggregating estimates of annual miles driven by drivers in these states. The average annual mileage estimates generated by aggregating data from the five states would have to be statistically compared to average annual mileage estimates by licensed drivers from Indiana.

Nonparametric statistical analyses were thus conducted on the two datasets -- Indiana and the five selected states -- to determine if the estimates of miles per driver generated from the selected states could be used for estimating VMT in Indiana. The statistical analysis is discussed in Section 4.2.5.1.

3.4.1 Mean Annual Miles Driven Per Licensed Driver by Sex and Age from the NPTS

The data for the 1990 and 1995 NPTS were downloaded, as zipped files, from the NPTS website in SAS Export format. Data on the NPTS survey were compiled in six files: Household, Person, Vehicle, Day Trip, Segmented Trip, and Period Trip files. The zipped files had to be unzipped before any data manipulation could be undertaken.

The relevant files for this study were the Household and Person Files. The 1990 and 1995 NPTS surveys were selected for analysis because they were the most recent surveys conducted, and they were the only two surveys for which data were available at the state level.

The mean annual miles per licensed driver is computed for males and females according to the age groups for which licensed driver data are reported in the *Highway Statistics* series. The age groups are different from those in Kumapley's (1994) model. This is because the age groups reported in *Highway Statistics* were revised in 1994. Table 3.2 shows the age groups prior to and after 1994. The revised age groups were adopted for consistency in reporting of data to the FHWA. The 1990 NPTS-based VMT model developed by Kumapley (1994) was revised to reflect the current age groupings reported in *Highway Statistics*.

Table 3.2 Age groups reported in *Highway Statistics* before and after 1994

Highway Statistics Age Groups Before 1994	Highway Statistics Age Groups After 1994
16 – 19	16 – 19
20 – 24	20 – 24
25 – 29	25 – 29
30 – 34	30 – 34
35 – 39	35 – 39
40 – 44	40 – 44
45 – 49	45 – 49
50 – 54	50 – 54
55 – 59	55 – 59
60 – 64	60 – 64
65 – 69	65 – 69
70 – 74	70 – 74
75 and over	75 – 79
	80 – 84
	85 and over

3.4.2 Estimation of Mean Annual Miles Driven Per Licensed Driver from the 1990 NPTS

The household file in the NPTS datasets contains information on household demographics for each household interviewed. The NPTS sample households are expected to represent, statistically, household characteristics across the nation. Each household is assigned a unique identification number. The person file contains information on all persons in the households: sex, age, education, travel behavior, etc. Each person in the person file is assigned a unique identification number, and the corresponding household number. The presence of the household identification number on both household and person files facilitates the merging of the files for data analysis.

The SAS System for Windows, version 8, was used for all analysis of the NPTS data. The mean annual miles per licensed driver are extracted from the NPTS survey by a SAS program as described below.

3.4.2.1 Unzipping of NPTS Downloaded Files

The files, as downloaded from the NPTS websites, were zipped to reduce the size of the files. The files had to be unzipped and saved on disk before any manipulation of the data could be undertaken.

3.4.2.2 Extraction of Total Number of Households for Selected States from the1990 NPTS

The household identifying numbers of all households in the following states were extracted: Indiana, Ohio, Iowa, Wisconsin, and Kentucky. The variables of interest on the household file were:

- HOUSEID – household identifying number, and
- HHSTFIPS – state FIPS code.

The state FIPS codes are assigned to each of the fifty states and the District of Columbia. The FIPS codes for the states considered in this study are shown in Table 3.3. The SAS program is coded to read through all entries in the NPTS, and extract all records with the HHSTFIPS values listed in Table 3.3.

Table 3.3 State FIPS code for the five selected states

State	FIPS Code (HHSTFIPS)
Indiana	18
Iowa	19
Kentucky	21
Ohio	39
Wisconsin	55

The output for this part of the program, showing the total number of households included in the NPTS for these states, is shown in Table 3.4. The total number of households is 3,004, which is a much bigger sample size than the 1,328 households sampled in the State of Indiana.

Table 3.4 Total number of households in the 1990 NPTS survey for selected states

State	Total Number of Households in 1990 NPTS
Indiana	1,328
Iowa	218
Kentucky	256
Ohio	815
Wisconsin	387
Total	3,004

3.4.2.3 Extraction of Licensed Driver Data for Selected States in the 1990 NPTS

The person file contains records on all members of households interviewed. The variables of interest on the person file include:

- HOUSEID – House identification number,
- LIC-DRVR – Identifies the respondent as a licensed driver,
- R_AGE – Age of household respondent,
- R_SEX – Sex of household respondent, and
- YEARMILE – Total miles driven in past 12 months.

The SAS program is coded to extract the required variables from the person file of the 1990 NPTS. The records cannot be extracted for the selected states at this stage because the person file does not contain information at the state level. The household and person files have to be merged to extract person-level data for individual states. The HOUSEID variable is the primary variable for merging the two files. The SAS program is coded to merge the person and household files, extracting records for the household files with the FIPS codes of the selected states, and by comparing the HOUSEID variable of both files, extract records with common house identification numbers belonging to those states.

Licensed drivers are identified on the person file by a dummy variable LIC_DRVR. The variable assumes the value of "01", if the respondent is a licensed driver and "02" if not a licensed driver. The SAS program is thus coded to extracted records from the merged files with the LIC_DRVR variable taking on the value "01". The output of this Section, showing the total number of licensed drivers on the 1990 NPTS for the selected states, is presented in Table 3.5.

Table 3.5 Total number of licensed drivers from the selected states in the 1990 NPTS

State	Total number of licensed drivers	Licensed drivers who gave estimates of annual miles driven
Indiana	2,025	1,734
Iowa	366	310
Kentucky	420	341
Ohio	1,355	1,145
Wisconsin	652	574
Total	4,818	4,104

Licensed driver data in the NPTS are distributed by sex, using the variable R_SEX. R_SEX is a dummy variable for identifying the respondent as male or female. The variable R_SEX assumes the values "01" for male respondents and "02" for female respondents. The SAS program is coded to subset the results on licensed drivers by sex, by separating all records with R_SEX = 01 from records with R_SEX=02.

The respondents are asked to estimate how many miles they drove in the past twelve months. The response is recorded under the variable YEARMILE. The records under this variable were analyzed by the Oak Ridge National Laboratory to censor any doubtful estimates. Certain respondents also refused to answer this question regarding the annual miles driven. Such records were assigned the following dummy values:

999994 - Legitimately skipped the question,

999998 - Response not ascertained, and

999999 – Refused to answer question.

These dummy values had to be excluded from the dataset before any estimates of annual mile driven could be undertaken. The SAS program was coded to exclude all such records. Table 3.5 presents the total number of licensed drivers from each state that responded with reasonable estimates of annual miles driven.

The SAS program was then coded to create the age groups presented in Table 3.2. The total population of licensed was distributed into age groups corresponding to the *Highway Statistics* series.

3.4.3 Estimation of Mean Annual Miles Driven Per Licensed Driver from the 1995 NPTS

The compilation of files for the 1995 NPTS is similar to that for the 1990 NPTS. The process of estimating mean annual miles driven per licensed driver by sex and age cohort was the same, however, certain variables had been modified in the 1995 NPTS. The data extraction process of the 1990 NPTS was adopted for the 1995 NPTS, but this had to be slightly modified because of changes in the 1995 survey process. The data extraction process is discussed below.

3.4.3.1 Extraction of Total Number of Households for Selected States in the1995 NPTS

The variables in the household files remained unchanged. The number of households on the 1995 NPTS for the five selected states (Indiana, Iowa, Kentucky, Ohio, and Wisconsin) is presented in Table 3.6. The total number of households is 2,369 for the five states, with 465 households in the state of Indiana.

Table 3.6 Total number of households on the 1995 NPTS for the five selected states

State	Total Number of Households in the 1995 NPTS
Indiana	465
Iowa	236
Kentucky	261
Ohio	932
Wisconsin	475
Total	2,369

3.4.3.2 Extraction of Licensed Driver Data for Selected States in the 1995 NPTS

The person file contains records on all members of households interviewed. The variables of interest on the person file include:

- HOUSEID – House identification number,
- DRIVER – Identifies the respondent as a licensed driver,
- R_AGE – Age of household respondent,
- R_SEX – Sex of household respondent, and
- YEARMIL2 – Total miles driven in past 12 months.

The variable LIC_DRVR on the 1990 NPTS was changed to DRIVER for the 1995 NPTS data. Licensed drivers are identified by a dummy variable DRIVER. The values of the DRIVER are the same as that of LIC_DRVR in the 1990 NPTS. The same procedure was used for the extraction of licensed drivers from the 1995 NPTS as from the 1990 NPTS.

The 1995 NPTS had two variables reporting the annual miles driven per licensed driver: YEARMILE and YEARMIL2. The YEARMILE variable contained the estimates of annual miles driven reported by the respondents. The Oak Ridge National Laboratory created the variable YEARMIL2 from YEARMILE to adjust for inconsistencies in reported mileage estimates (RTI 1997). YEARMIL2 was thus used for the computation of the estimates of annual miles driven per licensed driver. The following dummy values were assigned to respondents (in the YEARMIL2 variable) who failed to answer the question regarding the annual miles driven:

999994 - Legitimately skipped the question,

999998 - Response not ascertained, and

999999 – Refused to answer question.

The dummy values of estimates of annual miles driven were excluded from the dataset before any estimates of annual miles driven could be undertaken.

Table 3.7 presents the total number of licensed drivers from each state that responded with reasonable estimates of annual miles driven.

Table 3.7 Total number of licensed drivers from the selected states in the 1990 NPTS

State	Licensed drivers who gave estimates of annual miles driven
Indiana	707
Iowa	351
Kentucky	366
Ohio	1,416
Wisconsin	759
Total	3,599

3.5 Data Compilation for Household Level VMT Estimation

The variables considered in this study for the estimation of household level VMT are *household size*, *household income*, *number of vehicles* and *vehicles per licensed driver*. These variables were selected because they are considered to be primary indicators of household travel (Patterson and Schaper 1998). The average annual household VMT is estimated for households by area type (rural, dense urban, and light urban) at the census tract level, for the various predictor variables listed above.

Household size is considered a good predictor of travel because the total number of trips made in a household is dependent on the number of persons in the household. A household of greater size is expected to make more trips than a household of smaller size. The number of *vehicles per licensed driver*, for each household, is an indication of the level of utilization of the vehicles.

The 1995 NPTS household file contains information on the household characteristics, including:

- Number of vehicles in the household (HHVEHCNT),
- Household family income category (HHFAMINC),
- Household size (HHSIZE),
- Household identification number (HOUSEID),
- Final household weight (WTHHFIN),
- Number of licensed drivers in the household (DRVRCNT), and
- Area type, defined by census tracts (HTHUR) and block groups (HBHUR).

The 1995 NPTS contains records on a total of 42,033 households.

The 1995 NPTS vehicle file contains information on each vehicle in a household, including:

- Self-reported annualized VMT (ANNMILES),
- Odometer-recorded annualized VMT for certain vehicles (ANNUALZD),
- Vehicle type (VEHTYPE),
- Household identification number (HOUSEID), and
- Vehicle identification number (VEHID).

The 1995 NPTS contains records on 75,217 vehicles.

The household identification number is a unique number assigned to each household represented in the survey. The vehicle identification number is a number assigned to each vehicle in a household. Records are maintained for each household and for each vehicle in a household. For any household that has more than one vehicle, the vehicles are numbered sequentially from 1. A household with four vehicles would have vehicle identification numbers of 1, 2, 3 and 4. Households with more than one vehicle can be traced by matching the household identification numbers on each vehicle record.

Respondents were asked to estimate how many miles each vehicle traveled in the last twelve months. This estimate of VMT was recorded as a self-reported annualized

VMT (ANNMILES). This estimate of VMT is not considered reliable and is not utilized, in this study, for the estimation of average annual household VMT. The odometers of the vehicles sampled were also recorded at various stages of the survey to accurately record the total mileage traveled. Due to various anomalies in the data records, only 31,847 vehicles out of the total sample of 75,217 vehicles had usable data, or data considered accurate. These 31,847 vehicles, from 21,258 households, were used for the estimation of household VMT.

The information on area type on the 1995 NPTS survey was classified based on the population density of the area within which each sampled house was located. The density was determined by dividing the United States into grids, to reduce the effect of variation in land area among census tracts or block groups (RTI 1997). The estimated densities were converted to quintiles and graded as follows:

- Rural area type (first quintile),
- Small town area type (second quintile),
- Suburban area type (third quintile),
- Second city area type (fourth quintile), and
- Urban area type (fifth quintile).

The area type classification used in this study for the estimation of average annual household VMT was done by clustering the urban and second city area types to create an dense urban area type, and the small town and suburban area types to create the light urban area type. The area type classification for the study is as follows:

- Rural area type (first quintile),
- Light urban area type (second and third quintiles), and
- Dense urban area type (fourth and fifth quintiles).

3.5.1 Estimation of Average Annual Household VMT from the 1995 NPTS Survey

The data from the 1995 NPTS were compiled in six files: Household, Person, Vehicle, Day Trip, Segmented Trip, and Period Trip files. The relevant files for this study were the Household and Vehicle Files. The 1995 NPTS survey was selected for analysis because earlier surveys conducted did not contain information on vehicle odometer records. The average annual household VMT is computed for different household travel predictors and area type.

The extraction and manipulation of data on household VMT are discussed in Sections 3.5.1.2 through 3.5.1.9.

3.5.1.1 Extraction of Vehicles with Odometer-Based VMT from the 1995 NPTS Survey

A SAS program was coded to extract from the 1995 NPTS vehicle file all vehicle entries with records on annual mileage estimated from odometer readings. This data are stored under the variable ANNUALZD. Vehicles that did not have odometer-based VMT estimates, either because the owners refused or the odometer recordings were not considered accurate, could be identified by the following dummy values:

- 999994 – Legitimate skip,
- 999998 – Not ascertained, and
- 999999 – Refused.

Other variables that were extracted from the 1995 NPTS vehicle files included the vehicle identification numbers, VEHID, and the household identification numbers, HOUSEID. The SAS program extracted 31,847 entries with correct odometer readings from the vehicle file.

3.5.1.2 Extraction of Household Characteristics from the 1995 NPTS

The household variables adopted in this study are enumerated in Section 3.5. The SAS program was coded to extract only the required variables, because the 1995 NPTS household file contains 182 variables.

Some geographic areas purchased add-on contracts for planning purposes. The add-on samples accounted for 55.2% of the entire NPTS survey data. Results from these add-on samples were included in the public use datasets. This results in over-sampling within certain geographic areas. To eliminate the effect of over-sampling, weights (WTHHFIN) were estimated for each household to account for the regional and geographic differences in sampling (RTI 1997). The SAS program was coded to extract the household weight for each entry.

3.5.1.3 Merging of Household and Vehicle Characteristics from the 1995 NPTS

The data extracted from the Household and Vehicle files were merged before any meaningful analysis could be undertaken. The HOUSEID variable was common to both files, so data from the two files with the same household identification number were merged to create a single vehicle file. The merged file was exported to Microsoft Excel® to facilitate data manipulation.

3.5.1.4 Estimation of Household VMT from the 1995 NPTS

The entries on the merged file represented data on each vehicle and also household characteristics for the household to which the vehicle belonged. This means the household data were duplicated for all households with more than one vehicle. The household VMT was estimated by summing, for all households with more than one vehicle, the annualized odometer readings.

A macro was written in Microsoft Excel® to sum the annualized odometer readings (ANNUALZD) for all vehicles within a household. This sum represents the household VMT, because all vehicles in households with more than one vehicle have odometer readings for all the vehicles recorded together with the house identification numbers. Thus, a house with more than one vehicle would have the household identification number recorded for all the vehicles belonging to that household. Table 3.8 shows a section of the merged file in spreadsheet format.

Table 3.8 Section of merged file from 1995 NPTS household and vehicle files

HOUSEID	VEHID	ANNUALZD	HHFAMINC	WTHHFIN	HTHUR
1000454	1	13,987	18	3,552.76	T
1000454	2	26,828	18	3,552.76	T
1000587	1	19,980	17	3,167.59	T
1000728	1	15,082	06	3,305.52	S
1000728	2	8,306	06	3,305.52	S

The shaded rows in Table 3.8 show data on households with more than one vehicle. The HOUSEID column lists the identification numbers for each vehicle entry and the VEHID column shows the vehicle identification number for each vehicle in the household. The household with identification number 1000454 has two vehicles. The annual household VMT for this household is thus estimated by summing the annualized odometer readings (ANNUALZD) for both vehicles in the household. The estimation of annual household VMT for the household with identification number 1000454 is shown below:

Number of vehicles in household = 2 vehicles

Annual miles driven by vehicle 1 = 13,987 miles

Annual miles driven by vehicle 2 = 26,828 miles

Total household vehicle mileage = 13,987 + 26,828 = 40,815 miles.

The household VMT for the household with identification number 1000587 is 19,980 miles, because it has only one vehicle.

Certain households did not have odometer-based VMT estimates for all vehicles belonging to the household. This results in the underestimation of household VMT for those households, because the data available represents fewer vehicles than the household possesses. The data had to be further sifted through to remove all households that had entries for fewer vehicles than the household reported, querying the data in Microsoft Access® to determine the number of vehicle record entries available for each household identification number (HOUSEID). This count of vehicle entries was compared to the number of vehicles reported for that household, and all households for which the two numbers did not match were removed. Table 3.9 shows a section of the queried data.

Table 3.9 Section of queried data from merged 1995 NPTS household and vehicle files

HOUSEID	HHVEHCNT	NumREC
1000454	3	2
1000462	2	1
1000587	2	1
1000728	2	2
1000736	2	1
1000777	2	2
1000850	2	1
1001130	2	2
1001817	2	2
1001890	1	1
1002047	2	2
1002054	1	1

The HHVEHCNT column in Table 3.9 shows the number of vehicles belonging to the household with identification number HOUSEID, as stated by the respondent. The NumREC column lists the number of vehicle entries present on the merged NPTS files obtained from the queried data. The shaded rows on Table 3.9 represent households in the 1995 NPTS *vehicle file* with data on fewer vehicles than the household reported. The household with identification number 1000454 reported owning three vehicles, however, records are available for only two of those vehicles. Any estimate of household VMT generated from these two vehicles would be less than the total household VMT.

The final data, which contained records on 21,086 vehicles from 12,919 households, were used for the estimation of household VMT by area type and other demographic characteristics.

3.5.1.5 Definition of Area Types from 1995 NPTS

Analyses of the 1995 NPTS data for the estimation of household VMT were done using the census tract definition of area type. The 1995 NPTS survey contained information on households by census tracts and block groups. The NPTS area types were based on population densities within census tracts, HTHUR, and block groups, HBHUR.

The NPTS data had five classifications: urban (U), second city (C), suburban (S), small town (T) and rural (R) area types. The area type designations adopted for this study, as explained earlier, were dense urban (DU), light urban (LU) and rural (R), so all 'C' and 'U' entries on the household file were changed to 'DU', and all 'S' and 'T' entries were changed to 'LU'. The number '8' was assigned to area types that could not be ascertained. 126 households within the merged files did not have defined area types and were discarded.

3.5.1.6 Creation of Household Income Categories

The HHFAMINC variable is a dummy variable containing information on household income. The variable was created from responses to questions on income in the 1995 NPTS survey. Income classes were created because most people are reluctant to disclose their actual income. HHFAMINC represents the aggregate household income group. Table 3.10 shows the income groups under the dummy variable HHFAMINC.

Six income groups were created for the analysis of average annual household VMT with respect to income in increments of $20,000. The HHFAMINC values were thus merged to create the income classes for the estimation of household VMT. The income groups adopted for the analysis, together with the HHFAMINC values merged, are shown in Table 3.11.

Table 3.10 Household income groups in the 1995 NPTS

HHFAMINC Value	Income Groups	HHFAMINC Value	Income Groups
01	Less than $5,000	11	$50,000 - $54,999
02	$5,000 - $9,999	12	$55,000 - $59,999
03	$10,000 - $14,999	13	$60,000 - $64,999
04	$15,000 - $19,999	14	$65,000 - $69,999
05	$20,000 - $24,999	15	$70,000 - $74,999
06	$25,000 - $29,999	16	$75,000 - $79,999
07	$30,000 - $34,999	17	$80,000 - $99,999
08	$35,000 - $39,999	18	$100,000 and over
09	$40,000 - $44,999	98	Not Ascertained
10	$45,000 - $49,999	99	Refused

Source: Research Triangle Institute 1997

Table 3.11 Income groups adopted for analysis of household VMT from 1995 NPTS

Income Groups	Number of Households	HHFAMINC Values Merged
Less than $20,000	1,096	01, 02, 03, 04
$20,000 - $39,999	993	05, 06, 07, 08
$40,000 - $59,999	2,264	09, 10, 11, 12
$60,000 - $79,999	4,535	13, 14, 15, 16
$80,000 - $99,999	6,019	17
$100,000 and over	3,020	18

All entries for which the income group could not be ascertained were discarded. The final dataset on household income contained 11,051 households. The average annual household VMT by area type and household income was estimated using these households.

3.5.1.7 Creation of Household Vehicle Count Data

The 1995 NPTS survey contained information on the number of vehicles in each sampled household. This information was stored under the variable HHVEHCNT representing the household vehicle count. Table 3.12 shows the distribution of households for the HHVEHCNT variable on the queried data.

Table 3.12 Distribution of households for HHVEHCNT variable

Number of Vehicles	Sample Size (Households)
1	5,905
2	6,082
3	827
4	98
5	6
10	1
Total	12,919

Source: Research Triangle Institute 1997

Because most of households (about 99%) sampled had 3 or fewer vehicles, households with 3 or more vehicles were clustered into a single group. Data were not available in the NPTS database to estimate household VMT for households with no cars.

3.5.1.8 Creation of Vehicle per Licensed Driver Categories

A second analysis of vehicle ownership on household travel was conducted on the 1995 NPTS data, with emphasis on the number of vehicles per licensed driver within a household. The rationale for this analysis was to assess the impact of household vehicles to licensed driver ratios on total household VMT.

The merged files contained information on household size (HHSIZE), number of licensed drivers in a household (HHDRVRCNT), and the household vehicle count (HHVEHCNT). A new variable VEHDRVR was created to represent the *vehicles per licensed driver ratio*. This variable was created by dividing, for each household, the number of vehicles (HHVEHCNT) by the number of licensed drivers within each household (HHDRVRCNT). Table 3.13 shows the distribution of households for the *vehicles per licensed driver* categories.

Table 3.13 Distribution of households by vehicle per licensed driver for estimation of VMT

Vehicles per licensed driver	Number of Households
<1	1,855
1	10,312
>1	739

3.5.1.9 Creation of Household Size Categories

The impact of household size on total household VMT was investigated by estimating, for each area type, any trends in average annual household VMT for various household sizes. The distribution of households, on the merged files, for the various household sizes is shown in Table 3.14. Because most of the households (93%) consisted of 4 or fewer members, it was decided to restrict the analysis to a maximum of 4 members for each household. Households with 4 or more members were clustered to form one group.

Table 3.14 Distribution of households for various household sizes

Household Size	Number of Households
1	3,297
2	4,895
3	1,898
4	1,923
5	677
6	161
7	45
8	16
9	2
10	4

Source: Research Triangle Institute 1997

3.6 Data Compilation for Commercial Vehicle Travel Estimation

The NPTS survey does not adequately represent commercial vehicle (truck) activity. Indiana is known to have considerable commercial vehicle activity on its roads. Because of the geographic location of Indiana, there is a considerable amount of through commercial vehicle trips, particularly on the interstate system. The vehicle travel activity reported in INDOT's 2000 HPMS data shows that truck VMT constitutes as much as 30 percent of total statewide rural interstate VMT. It was intended to account for truck activity in this VMT estimation model using the following sources: the 1997 Commodity Flow Survey (CFS), the 1997 Vehicle Inventory and Use Survey, and the International Fuel Tax Agreement (IFTA) truck mileage database.

The CFS was last conducted in 1997. Prior to 1997, the amount of commercial activity reported in the 1993 CFS, reported in ton-miles, was for travel within, to, from and through each of the 50 states and the District of Columbia. Changes in the survey format for 1997 prevented the calculation of these travel estimates. The VIUS is an inventory of trucks in each of the 50 states and the District of Columbia. Information on vehicle use in the VIUS could not be utilized for the estimation of truck VMTs because the VIUS data are related to the range of operation of the vehicle, and not the total miles traveled.

All commercial enterprises that undertake motor carrier operations in the United States and Canada are expected to apply for fuel tax licenses. The International Fuel Tax Agreement (IFTA) is an agreement among 58 jurisdictions in the United States and Canada to facilitate interstate commercial vehicle travel among the jurisdictions. The Intrastate Motor Carrier Fuel Tax (MCFT) is a fuel tax imposed on commercial vehicle carriers registered for travel only on Indiana roads. The IFTA and MCFT require the carriers to report the total annual miles traveled by all qualified vehicles for tax estimation purposes. These annual miles represent total Indiana commercial vehicle VMT and were adopted in this study for the estimation of commercial vehicle VMT.

The estimation of interstate and intrastate commercial vehicle activity will be discussed in Sections 3.6.1 and 3.6.2, respectively.

3.6.1 Estimation of Interstate Commercial Vehicle Activity

The International Fuel Tax Agreement (IFTA) was implemented to promote equitable and efficient use of the nation's highway system (IFTA Inc. 1996). This agreement facilitates the uniform and consistent administration of motor fuels taxation concerning motor carriers operating in the United States and Canada. IFTA facilitates the operation of commercial vehicles in other jurisdictions without the burden of having to apply for motor carrier fuel tax permits in each state. There are currently 58 IFTA member jurisdictions, including 48 states (excluding Alaska, Hawii, and Washington D. C.) and 10 Canadian provinces (except the Northwest Territories, Labrador and Yukon provinces). All carriers operating in two or more of these jurisdictions may apply for an IFTA license. All commercial vehicles are eligible for IFTA licensing, whether they are owned or leased by the carrier. Carriers that qualify for IFTA licensing but decline to participate are, however, required to obtain travel permits when traveling through the member jurisdictions. IFTA vehicles are required to have apportioned license plates under the International Registration Plan (IRP) and a US DOT number. Each carrier applies for the IFTA license in its base jurisdiction. The base jurisdiction is the state or province (member jurisdiction) where the carrier's vehicles are based for vehicle registration purposes (IRP registration) and/or operational control and records of the licensee's fleet are maintained or available. Carriers operating from (or based in) different jurisdictions may consolidate their fleets to ease administration of the vehicle records.

Vehicles qualify for licensing under the IFTA program if they meet any of the following requirements and configurations:

- Two axles and a gross vehicle weight (GVW) exceeding 26,000 pounds,
- Two axles and a registered weight exceeding 26,000 pounds,
- Three or more axles, regardless of vehicle weight,
- Passenger vehicles that have seats for more than nine persons, and
- Combined vehicle weight exceeding 26,000 pounds (for combination vehicles).

However, the following vehicles are exempt from the IFTA program:

- Recreational vehicles,

- Vehicles registered exclusively for farm use,
- Vehicles not registered for commercial purposes (no compensation is accrued from use of that vehicle),
- School buses,
- Commercial vehicles registered entirely for intrastate travel, and
- Government vehicles.

Farm vehicles and school buses may require IFTA licensing if they travel to other jurisdictions that require them. IFTA-licensed vehicles can be recognized from IFTA decals placed on exterior portions of the vehicle's passenger and driver's sides. IFTA licenses are renewed annually.

Carriers are required to maintain mileage and fuel records for each vehicle trip. These data are required for purposes of completing fuel tax reports. Each vehicle is expected to have the following information for every trip:

- The vehicle identification and fleet numbers,
- The licensee's name,
- The trip's starting and ending date(s),
- The origin and destination points, and all intermediate stops,
- The odometer (and/or hubometer) readings for mileage estimation,
- The routes of travel,
- The total trip length (miles), and
- The total mileage by jurisdiction.

The licensee must also maintain complete fuel records for all trips. The total distance traveled should also be reported by fuel type. The fuel records must include:

- Retail fuel purchase information and receipts, and
- The details of bulk storage fuel used in connection with the trip.

This information can be recorded manually on an Individual Vehicle Mileage Record (IVMR) sheet, or electronically by on-board recording devices, vehicle tracking systems, or other electronic data recording systems.

Carriers are required to file quarterly tax returns, with their base jurisdiction, for each vehicle licensed under the IFTA program. Carriers that have a fleet annual mileage not exceeding 5,000 miles may be eligible to file annual tax returns. The quarterly tax reports must contain records on total mileage (taxable and non-taxable) by fuel type (compressed natural gas (CNG), diesel, gasohol, gasoline, kerosene, and liquefied petroleum gas (LPG)) for travel on all public roads. The amount of travel (by fuel type) in each member jurisdiction must also be reported. The criteria for estimating non-taxable miles are determined by the member jurisdictions. Indiana currently has no vehicle, fuel and distance exemptions. The reporting period and due dates for the quarterly tax reports are shown in Table 3.15. IFTA requires the base jurisdictions to audit at least 3 percent of all IFTA licensees (IFTA Inc. 1996). The carriers are required to retain all mileage and fuel records for a period of at least four years, for auditing purposes.

Table 3.15 IFTA tax reporting quarters and tax due dates

Reporting Quarter	Due Date
January - March	April 30
April - June	July 31
July - September	October 31
October - December	January 31

3.6.1.1 Estimation of Indiana Truck VMT from IFTA Records

The Indiana Department of Revenue (DOR) is the IFTA governing organization for the State of Indiana. All carriers in Indiana report their quarterly tax returns to the Motor Carrier Services Division of the Indiana Department of Revenue. The Motor Carrier Services Division also receives quarterly and annual mileage and fuel records from the other jurisdictions for travel on Indiana roads by vehicles licensed in the other jurisdictions.

Data on total truck activity by fuel type for the 58 jurisdictions were obtained from the Indiana DOR for the period 1999 though 2001. The total miles driven by all vehicles from all jurisdictions, for all fuel types, are taken as the interstate commercial vehicle component of Indiana VMT.

3.6.2 Estimation of Intrastate Commercial Vehicle Activity

The Indiana Motor Carriers Fuel Tax License (MCFT) is required by all Indiana based carriers whose activities are entirely within the state. Vehicles that qualify for the MCFT must meet the same eligibility conditions as IFTA-licensed vehicles, except the MCFT-licensed vehicles do not leave the State of Indiana. All intrastate commercial vehicles are eligible for MCFT licensing whether they are owned or leased by the carrier. MCFT-licensed vehicles are required to have a US DOT number and a valid Indiana address. Government vehicles are exempt from the MCFT program.

Carriers are required to maintain the same mileage and fuel records for each vehicle trip as for IFTA-licensed vehicles. Because the vehicles do not leave the state, the mileage and fuel totals are not recorded by jurisdiction. These data are required for purposes of completing the quarterly MCFT tax returns. Carriers are required to file quarterly tax returns, with the Indiana DOR, for each vehicle licensed under the MCFT program. The quarterly tax reports must contain records on total mileage (taxable and non-taxable) by fuel type [compressed natural gas (CNG), diesel, gasohol, gasoline, kerosene, and liquefied petroleum gas (LPG)] for travel on all public roads in the state.

3.6.2.1 <u>Estimation of Indiana Truck VMT from MCFT Records</u>

All intrastate carriers in Indiana report their quarterly tax returns to the Motor Carrier Services Division of the Indiana Department of Revenue. Data on total truck activity by fuel type for all intrastate vehicles were obtained from the Indiana DOR for the period 1999 though 2001. The total miles driven by all vehicles for all fuel types are taken as the intrastate commercial vehicle component of Indiana VMT.

3.6.3 Assumptions Supporting the Estimation of Commercial Vehicle VMT from Fuel Tax Reports

The fuel tax-based records obtained from the Indiana DOR contained information on the amount of travel by commercial vehicles on public roads in Indiana. The total mileage reported by the DOR represents the total statewide commercial vehicle VMT.

The commercial vehicle VMT obtained from the Indiana DOR is assumed, in this study, to represent the total statewide vehicle travel by all buses and non-light trucks. Because it was not possible to obtain information on the annual statewide VMT accumulated by vehicles exempt from the fuel tax program, the reported statewide VMT estimates are expected to represent the lower bound of the actual statewide VMT by all buses and non-light trucks on public roads in Indiana.

The mileage records reported by the carriers are assumed to accurately represent the amount of travel undertaken by all vehicles operated by the licensee. The mileage records are reported to substantiate information reported on the periodic tax returns. Licensees will, therefore, be expected to ensure the accurate calibration of distance-measuring equipment installed in the vehicles. Because licensees will be reluctant to pay higher fuel taxes than they should, the reported mileage estimates are expected to represent the lower bound of total statewide commercial vehicle VMT.

3.7 Chapter Summary

This chapter enumerates the data compilation process undertaken in this study for the development of two demographic survey-based statewide VMT estimation models based on licensed driver and household characteristics. The concept behind licensed driver-based VMT estimation models was also discussed, along with potential data sources for validating and applying these models. The data manipulation process required for the estimation of average annual miles driven per licensed driver by sex and age cohort, and the estimation of average annual household VMT by area type and four demographic characteristics (income, household size, vehicle ownership, and vehicles per licensed driver) is discussed.

The commercial vehicle component of the statewide VMT is very important for a state like Indiana. The geographic location of Indiana results in considerable interstate commercial vehicle activity. The International Fuel Tax Agreement (IFTA) facilitates the estimation of interstate commercial vehicle VMT by fuel type and jurisdiction. The Motor Carriers Fuel Tax License (MCFT) assists in the estimation of intrastate commercial vehicle activity. The total VMT from both IFTA and MCFT represent the commercial vehicle VMT for Indiana. This chapter discusses the application of IFTA and MCFT to the estimation of statewide commercial vehicle VMT. The assumptions supporting the estimation of commercial vehicle VMT from fuel tax reports are discussed in this chapter.

CHAPTER 4. DEVELOPMENT OF VMT ESTIMATION MODELS

4.1 Introduction

Two cross-classification statewide VMT estimation and forecasting models have been developed in this study. The models are based on survey results from the Nationwide Personal Transportation Survey. The models are developed in a spreadsheet format using MS Excel 2000. This section describes the models' assumptions and development, and discusses the process of estimating statewide vehicle miles of travel.

4.2 Data Sources for the Licensed Driver-based VMT Estimation and Forecasting Model

The model developed in this study is a travel survey based model. The variables of interest are:

- Population of the state of Indiana,
- Number of licensed drivers in the state, and
- Average annual miles driven per licensed driver.

The population projections for Indiana for the years 1994 through 2020 were obtained from the U.S Census Bureau. The population projections are available by sex, race and age. The projections were computed using a time series model based on state-to-state migration observed from 1975 to 1976 through 1993 to 1994 (Campbell 1996). The population estimates and projections are shown in Table 4.1. The population figures for the year 2000 were obtained from the 2000 U.S. Census.

Licensed driver data for each state, by sex and age cohorts, are available in the *Highway Statistics* series. The data are reported by each state to the FHWA. The total number of licensed drivers was compared to the proportion of the statewide population aged 16 years or older. This was to establish a trend in the proportion of the population eligible to drive, who are licensed to do so. Table 4.2 shows the distribution and percentages of licensed drivers from 1994 through 2000, the last year for which licensed driver data are available.

The state population shown in Table 4.1 for the years 1990 and 2000 were obtained from the 1990 and 2000 Census, respectively. The percentage of the population eligible to drive (16 years and older) has consistently increased from 76.6 percent in 1990 to 77.6 percent in 2000. However, the number of licensed drivers reported in *Highway Statistics* from 1994 through 2000 does not follow the same trend. The number of licensed drivers in the state increased from 3.86 million in 1994 to 3.98 million in 1998, and subsequently decreased to 3.68 million in 2000. The number of licensed drivers in the state is expected to exhibit a trend similar to that of the eligible population. Because the percentage of the eligible population that are actually registered as licensed drivers does not follow any clear trend, the average percentage of the licensed driver ratio to the percentage of the state population eligible to drive (16 years and over), over the six-year period, is adopted in determining the population of licensed drivers, required for the estimating and forecasting of VMT for the years 2000 through 2010. Eighty-four percent of the eligible population would be assumed, in this study, to be registered as licensed drivers. The licensed driver-based VMT estimation model developed in this study will provide the option to perform a sensitivity analysis on the effect of the licensed driver to eligible population ratio on VMT. This is discussed in Section 5.2.2.

Table 4.1 Population by sex for Indiana from 1990 through 2010

Year	Total	% of Total 16 and over	Male	% of Male 16 and over	Female	% of Female 16 and over
1990	5,544,156	76.6	2,688,236	75.2	2,855,920	77.8
1991	5,602,062	77.0	2,716,904	75.7	2,885,158	78.3
1992	5,648,649	77.0	2,741,058	75.8	2,907,591	78.3
1993	5,701,965	77.2	2,768,716	75.9	2,933,249	78.4
1994	5,745,626	77.2	2,790,710	75.9	2,954,916	78.4
1995	5,791,819	77.2	2,814,468	76.0	2,977,351	78.4
1996	5,834,908	77.4	2,836,714	76.2	2,998,194	78.6
1997	5,872,370	77.3	2,856,199	76.1	3,016,171	78.5
1998	5,907,617	77.3	2,873,759	76.1	3,033,858	78.5
1999	5,942,901	77.3	2,891,620	76.1	3,051,281	78.4
2000	6,080,485	77.6	2,982,474	76.2	3,098,011	78.3
2001	6,085,165	77.9	2,965,548	76.8	3,119,617	79.0
2002	6,122,436	78.0	2,984,819	76.9	3,137,617	79.1
2003	6,156,496	78.1	3,002,407	77.0	3,154,089	79.1
2004	6,187,323	78.2	3,018,314	77.1	3,169,009	79.3
2005	6,215,296	78.4	3,032,847	77.3	3,182,449	79.4
2006	6,240,403	78.5	3,045,924	77.5	3,194,479	79.6
2007	6,263,069	78.7	3,057,839	77.6	3,205,230	79.7
2008	6,283,117	78.9	3,068,454	77.8	3,214,663	79.9
2009	6,300,808	79.0	3,077,900	78.0	3,222,908	80.0
2010	6,318,404	79.1	3,087,311	78.1	3,231,093	80.1

The percent distribution of licensed drivers by sex was estimated for the years 1994 through 2000, using the licensed driver statistics in the *Highway Statistics* series. It was determined that male licensed drivers have consistently represented 51% of the licensed driver population of the state of Indiana. The total licensed driver population estimated from the model is thus distributed by sex, and subsequently into the various age groups. Table 4.3 shows the history of licensed driver distribution by sex. The estimates of average annual miles driven per licensed driver, by sex and age cohort, were obtained from the NPTS survey, as discussed in Section 3.4.

Table 4.2 Licensed driver and population distribution for Indiana for 1994 through 2000

Year	Total	% of Total 16 years and over	Total pop 16 years and over	Total number of licensed drivers	Drivers as percent of total pop 16+
1994	5,745,626	77.2	4,436,920	3,860,329	87.0
1995	5,791,819	77.2	4,474,075	3,706,182	82.8
1996	5,834,908	77.4	4,517,175	3,704,156	82.0
1997	5,872,370	77.3	4,540,755	3,923,614	86.4
1998	5,907,617	77.3	4,567,167	3,976,241	87.1
1999	5,942,901	77.3	4,593,168	3,856,177	84.0
2000	6,080,485	77.6	4,682,392	3,676,241	78.5
Average percentage of drivers to total pop. 16 years and over					84

Source: FHWA (1994 – 2000)

Table 4.3 The history of total licensed driver distribution from 1994 through 1999

Year	Total	Males		Females	
		Number	% of Total	Number	% of Total
1994	3,860,329	1,979,042	51	1,881,287	49
1995	3,706,182	1,900,016	51	1,806,166	49
1996	3,704,156	1,898,978	51	1,805,178	49
1997	3,923,614	2,011,485	51	1,912,129	49
1998	3,976,241	2,032,562	51	1,943,679	49
1999	3,856,177	1,977,338	51	1,878,839	49
2000	3,676,241	2,032,062	51	1,944,179	48

Source: FHWA (1994 – 2000)

4.2.1 Assumptions Supporting the Licensed Driver-Based VMT Estimation Model

The travel survey based VMT model developed in this study required some assumptions to be made in order to utilize the NPTS survey results. The assumptions supporting the validity of the VMT estimation model include:

- The VMT estimation model is based on Indiana licensed drivers. The location of Indiana within the United States attracts a lot of through traffic, particularly on the interstates. The obvious implication of adopting a model based on locally registered drivers is the elimination of travel undertaken by out-of-state licensed drivers on Indiana roads. Kumapley (1994) assumed the total average miles driven by Indiana licensed drivers on out-of-state roads is equal to the total average miles driven by out-of-state drivers on Indiana roads. It was intended, in this study, to investigate the validity of this assumption with the American Travel Survey (ATS). The ATS is a survey conducted to investigate long distance travel patterns within the nation. The survey seeks to obtain information on personal trips longer than 75 miles, of persons living in the United States. It was not possible to extrapolate the output from the sampled ATS survey data to estimate the overall interstate passenger travel. To illustrate this problem, a sample output would be presented. The number of vehicle trips on the ATS from Indiana to Illinois is 535, however, it was not possible to estimate the percentage of total trips between the two states that is represented by this number of trips. The assumption is, however, adopted in this study even though it was not possible to ascertain its validity.
- Current vehicle occupancy rates are not expected to vary significantly within the next five to ten years. VMT is affected by the number of vehicles on the road, which is also affected by the vehicle occupancy rates. Changes in vehicle occupancy rates will substantially modify the resulting VMTs, as fewer or more vehicles would be present on the roads, assuming no modification to trip making patterns.

4.2.2 Estimation of Mean Annual Miles Driven by Sex and Age Cohort from the 1990 NPTS

The mean annual miles driven per licensed driver by sex and age cohort was estimated for two sets of data:

- Licensed drivers in Indiana only, and
- Licensed drivers in all five selected states.

The PROC MEANS option in SAS was used to estimate mean annual miles driven per licensed driver. The output for this procedure included the number of observations, mean miles driven and standard deviation. Tables 4.4 and 4.5 present the output for male and female licensed drivers, respectively. Figures 4.1 and 4.2 show plots of the results from Tables 4.4 and 4.5. Results from these tables and figures will be discussed in Section 4.2.4.

Table 4.4 Average annual miles driven by male licensed drivers

	Indiana			Selected states		
Age Groups	Sample size	Mean annual miles driven	Standard deviation	Sample size	Mean annual miles driven	Standard deviation
16 - 19	33	12,733	28,411	112	10,025	18,721
20 - 24	90	18,236	13,974	197	16,685	14,270
25 - 29	131	20,082	21,613	257	18,582	19,465
30 - 34	101	20,754	22,669	251	18,063	21,226
35 - 39	106	16,318	12,111	250	16,907	14,466
40 - 44	75	19,467	16,449	200	20,301	21,477
45 - 49	54	18,916	18,050	151	18,410	16,738
50 - 54	54	18,685	14,361	138	19,563	20,595
55 - 59	43	17,729	18,381	113	20,531	24,387
60 - 64	41	15,522	16,067	121	14,921	13,154
65 - 69	48	14,656	19,456	90	12,849	15,000
70 - 74	21	9,500	7,563	71	10,266	8,085
75 - 79	20	10,590	9,841	47	10,221	8,350
80 - 84	11	6,205	4,461	26	5,414	3,923
85 and over	9	8,961	8,674	23	10,110	8,553

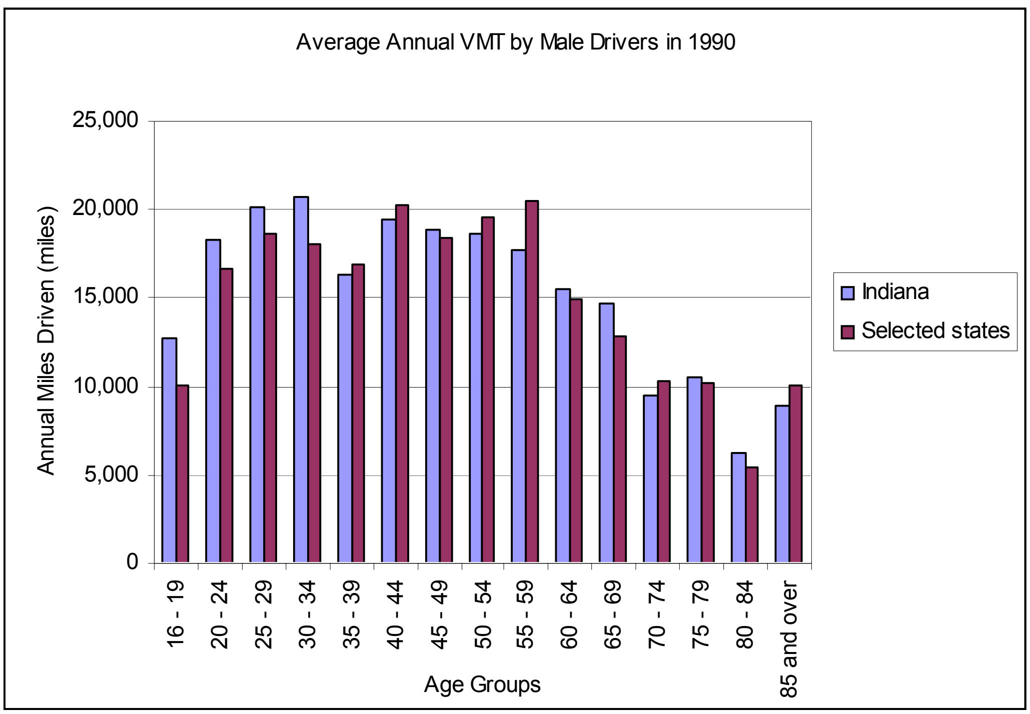


Figure 4.1 Average annual miles driven by male drivers – 1990 NPTS

Table 4.5 Average annual miles driven by female licensed drivers

	Indiana			Selected states		
Age Groups	Sample size	Mean annual miles driven	Standard deviation	Sample size	Mean annual miles driven	Standard deviation
16 - 19	45	9,634	10,527	115	6,709	8,625
20 - 24	105	12,986	11,883	215	12,201	10,686
25 - 29	115	12,026	12,548	242	10,988	10,599
30 - 34	131	10,574	8,260	265	10,656	8,746
35 - 39	100	11,122	12,461	245	11,713	13,145
40 - 44	73	10,113	9,870	208	10,308	10,518
45 - 49	53	7,928	6,534	152	8,735	6,970
50 - 54	51	8,577	6,988	121	8,391	8,564
55 - 59	54	7,057	6,878	136	7,281	6,387
60 - 64	46	5,358	4,743	93	5,298	4,620
65 - 69	42	4,783	5,010	94	5,518	5,405
70 - 74	38	3,416	3,987	82	4,226	3,934
75 - 79	18	4,504	3,501	38	3,936	3,859
80 - 84	10	5,050	5,895	21	3,138	4,481
85 and over	16	5,469	4,566	30	6,383	5,610

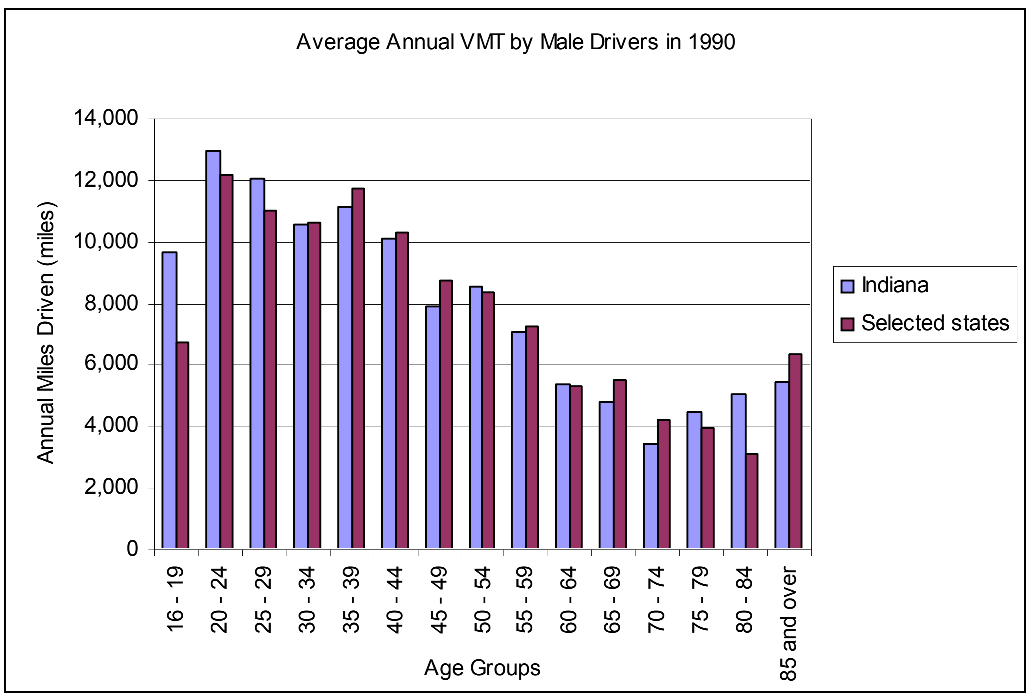


Figure 4.2 Average annual miles driven by female drivers – 1990 NPTS

4.2.3 Estimation of Mean Annual Miles Driven by Sex and Age Cohort from the 1995 NPTS

The process of estimating mean annual miles driven by sex and age cohort was similar to that for the 1990 NPTS. Tables 4.6 and 4.7 present the output for male and female licensed drivers, respectively. Figures 4.3 and 4.4 present plots of the data in Tables 4.6 and 4.7.

4.2.4 Interpretation of Estimates of Mean Annual Miles Driven per Licensed Driver

The plots of the mean annual miles driven per licensed driver by age that are presented in Figures 4.1 through 4.4 reveal some interesting features.

The mean annual miles driven by males in 1990 tends to increase from the 16-19 age group, peaking around the 30-34 and 40-44 age groups, then decreasing to the 80 –84 age group and increasing slightly for the 85 and over age group. The mean annual miles driven by males in 1995 shows a similar pattern, but the slight increase for the 85 and over age group is absent. The slight increase in miles driven for males ages 85 and over in 1990, however, cannot be explained especially because it was present in both data sets: Indiana and the selected states. The small sample sizes of the 80-84 and 85-and-over age groups might be a contributing factor in misrepresenting travel within these age groups.

The plot of mean annual miles driven by females shows a different pattern. The annual miles driven by females increases sharply from the 16-19 age group, peaking around the 20-24 and 25-29 age groups and decreasing gradually to the 85 and over age groups.

Table 4.6 Average annual miles driven by male licensed drivers

	Indiana			Selected states		
Age Groups	Sample size	Mean annual miles driven	Standard deviation	Sample size	Mean annual miles driven	Standard deviation
16 - 19	17	8,382	7,354	99	6,345	7,299
20 - 24	23	14,654	8,618	106	14,304	10,959
25 - 29	23	15,465	12,395	159	22,851	23,673
30 - 34	37	20,270	14,698	207	20,286	18,857
35 - 39	42	23,182	32,592	194	18,465	19,189
40 - 44	37	16,589	10,249	198	17,927	15,280
45 - 49	49	22,527	25,021	197	19,910	22,419
50 - 54	32	16,106	11,203	161	20,288	23,958
55 - 59	25	16,572	8,279	102	15,893	12,096
60 - 64	23	15,335	12,158	126	16,413	16,718
65 - 69	17	14,294	6,687	85	12,541	7,839
70 - 74	8	13,006	8,814	87	10,799	10,006
75 - 79	13	7,900	7,761	63	8,193	8,958
80 - 84	5	9,800	7,155	19	7,813	5,706
85 and over	2	8,500	707	9	5,133	3,619

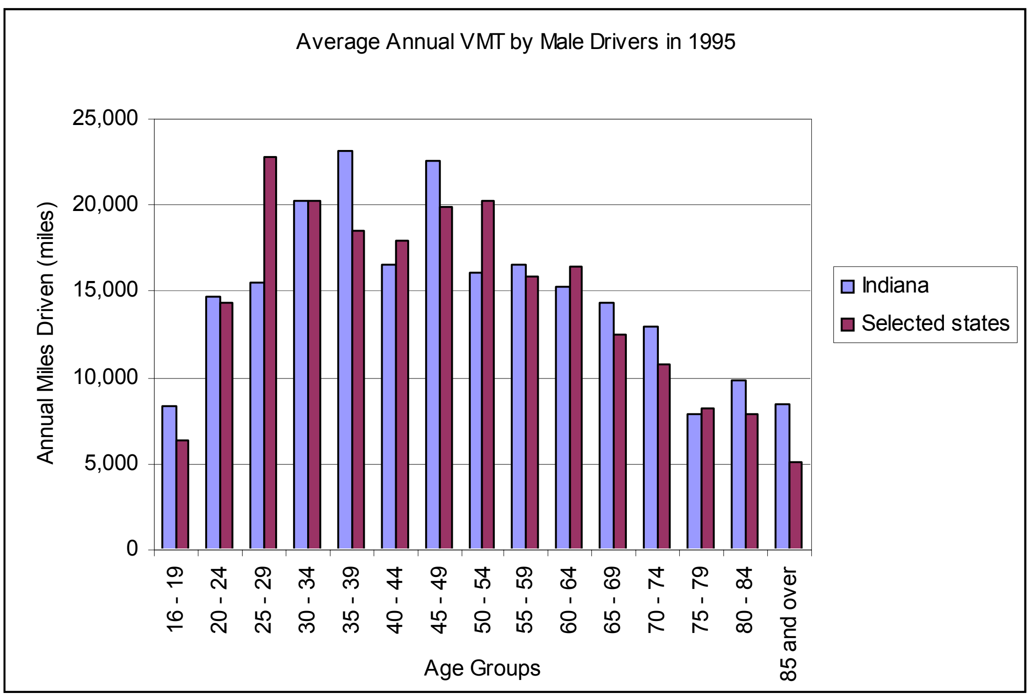


Figure 4.3 Average annual miles driven by male drivers – 1995 NPTS

Table 4.7 Average annual miles driven by female licensed drivers

	Indiana			Selected states		
Age Groups	Sample size	Mean annual miles driven	Standard deviation	Sample size	Mean annual miles driven	Standard deviation
16 - 19	11	2,659	3,211	87	6,397	15,005
20 - 24	23	15,004	20,205	107	11,269	11,846
25 - 29	27	14,804	3,131	156	13,034	10,625
30 - 34	31	9,761	6,738	182	13,089	16,168
35 - 39	51	11,678	7,296	225	11,996	9,640
40 - 44	40	10,800	7,235	197	12,289	9,528
45 - 49	41	9,508	6,807	204	11,501	15,235
50 - 54	33	13,441	10,968	153	10,579	8,714
55 - 59	27	7,287	6,965	117	8,315	11,125
60 - 64	23	6,344	5,181	117	6,091	5,119
65 - 69	16	5,597	6,279	94	4,414	5,389
70 - 74	15	6,279	3,657	79	5,727	10,433
75 - 79	8	4,939	4,108	40	3,943	8,046
80 - 84	5	1,820	1,270	17	2,864	2,280
85 and over	3	533	404	12	1,727	1,869

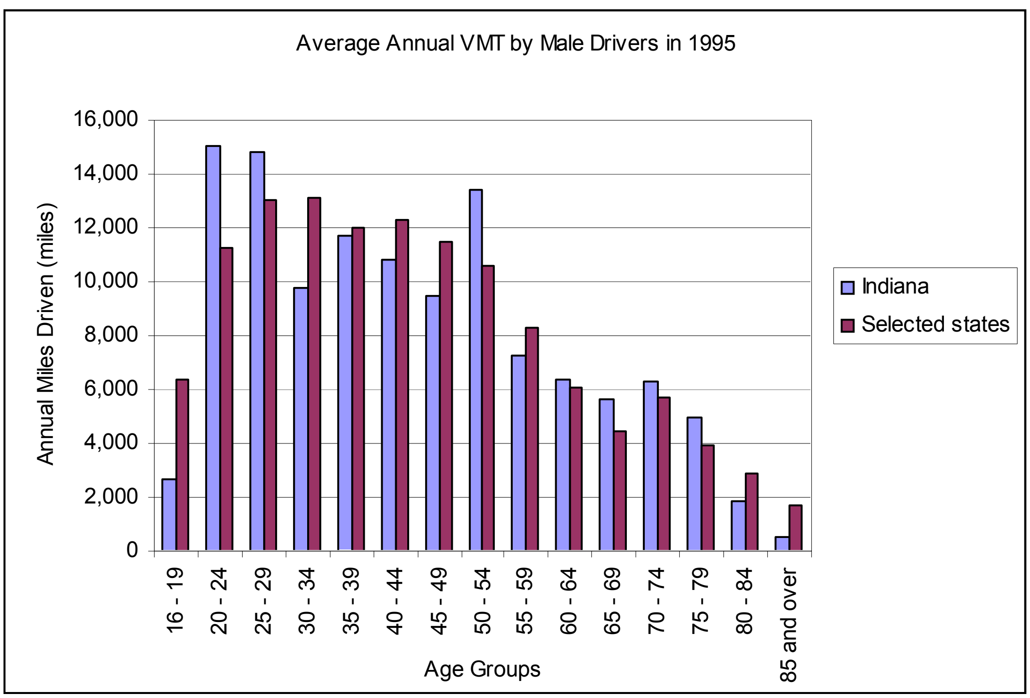


Figure 4.4 Average annual miles driven by female drivers – 1995 NPTS

The mean annual miles driven by males are consistently higher than that for females of corresponding age groups. The issue of which sex drives more miles in a household is debatable. Households are believed to be located closer to the woman's workplace, however, women are believed to make more trips -- shopping, work trips, etc. -- which might increase their total miles of travel.

Another potential explanation for the consistently higher miles for males than females would be from the answering of the questions. Because respondents are expected to guess their total annual mileage, males might tend to overestimate their total annual miles driven, while females might underestimate their total annual miles driven. It was not possible, however, to obtain any corroboration to support this belief.

4.2.5 Data Analysis on Mean Annual Miles Driven per Licensed Driver by Sex and Age Cohort

Statistical comparative testing was carried out to determine the possibility of substituting mean annual miles per licensed driver for Indiana with the mean annual miles per licensed driver for the selected states. The decision to consider this approach to estimating statewide VMT for Indiana, by using data for other states, was to make up for the inadequate sample sizes for the various age groups on the NPTS records for Indiana. The reason for adopting these particular states is discussed in Section 3.4

4.2.5.1 Nonparametric Comparative Statistical Testing

Nonparametric comparative testing methods were adopted because no underlying statistical distribution had to be assumed for the annual estimates of miles presented in Tables 4.4 and 4.5 for the 1990 NPTS, and Tables 4.6 and 4.7 for the 1995 NPTS (McGhee 1985; McCuen 1985).

Parametric statistical testing procedures require assumptions to be made about the distribution of the underlying population (McGhee 1985). The testing of specified characteristics of the population is then undertaken, relying on the properties of the assumed distribution, to make certain inferences about the characteristics of the population. It was not possible, with the high standard deviations obtained from the estimation of annual miles per licensed driver, to identify any known distribution to fit the distribution of annual miles driven with respect to the age groups. An advantage of nonparametric comparative statistical testing is that it enables the population to be tested while having to make no or minimal assumptions, and this is appropriate for dealing with problems of small sample sizes (McCuen 1985).

The nonparametric method adopted for this study was the Wilcoxon Matched Pair Signed Rank Test (McCuen 1985; McGhee 1985). This procedure assesses the equality of two population means for matched pairs of data by ranking the differences between the population means. The median of the population of differences is expected to equal zero for similar population means. The absolute differences, $d_i = x_i - y_i$, between the two means, x_i and y_i, for n pairs of samples are ranked in order of magnitude. Any difference of zero between matched pairs is deleted and the sample size, n, reduced by 1.

When x_i is consistently greater than y_i, the difference d_i is always positive, thus the median diverges from zero. For conditions of x_i being consistently less than y_i, the difference d_i, is always negative and the median once again diverges from zero. The median of differences, n_D, between the two population means is expected to converge to zero for conditions where the distribution of the difference between x_i and y_i is symmetrical (McGhee 1985). The required properties for the Wilcoxon test are:

- The number of sample pairs, n, does not exceed 30,
- The population of the differences between the means is continuous, and
- The differences are a random sample from the population of differences.

The mean annual miles driven are a random and continuous quantity because trip lengths are expected to vary among respondents by values that are continuous. The four sets of data on which the Wilcoxon test is performed are:

1. The mean annual miles per licensed driver for males in Indiana (y_i) and the selected states (x_i) for the 1990 NPTS (Table 4.4),
2. The mean annual miles per licensed driver for females in Indiana (y_i) and the selected states (x_i) for the 1990 NPTS (Table 4.5),

3. The mean annual miles per licensed driver for males in Indiana (y_i) and the selected states (x_i) for the 1995 NPTS (Table 4.6), and
4. The mean annual miles per licensed driver for females in Indiana (y_i) and the selected states (x_i) for the 1995 NPTS (Table 4.7).

The sample size, n, for all tests is 15 – the age groups.

The two-tailed Wilcoxon test is performed in this study. The test hypotheses are:

H_o: The population distributions are equal, or $n_D = 0$

H_1: The population distributions are different, or $n_D \neq 0$

The significance level, α, is the risk of not rejecting the null hypothesis when in fact there is a difference. The significance level is set at 5% or 0.05.

The Wilcoxon test is performed by computing the sums T_+ and T_- of the signed ranks. The test statistic, T, is the smaller of the absolute values T_+ and T_-. The test statistic T is compared to the critical value $T_{\alpha/2}$, which is available in most statistics tables. The null hypothesis is rejected if $T < T_{\alpha/2}$. The differences in population means, and the ranking of differences for the four sets of comparison tests are presented in Tables 4.8 through 4.11.

The Wilcoxon Matched Pair Signed Rank Test for this study was conducted using the PROC UNIVARIATE option of SAS in the differences in population means presented in Tables 4.8 through 4.11. Alternatively, the normal distribution may be used when there are greater than 10 matched pairs. The standardized test statistic for the normal test option is computed as follows (McGhee 1985):

$$Z = \frac{T - n(n+1)/4}{\sqrt{\frac{n(n+1)(2n+1)}{24}}} \qquad (4.1)$$

where

T is the smaller of the absolute values T_+ and T_-, and

n is the sample size.

The test statistics and conclusions are presented in Table 4.12.

Table 4.8 Summary of differences in mean annual miles driven for males - 1990

	Mean annual miles driven - males 1990					
Age groups	Selected states	Indiana	Difference	Abs. Diff	Rank	Signed rank
75 - 79	10,221	10,590	-369	369	1	-1
45 - 49	18,410	18,916	-505	505	2	-2
35 - 39	16,907	16,318	588	588	3	3
60 - 64	14,921	15,522	-601	601	4	-4
70 - 74	10,266	9,500	766	766	5	5
80 - 84	5,414	6,205	-792	792	6	-6
40 - 44	20,301	19,467	834	834	7	7
50 - 54	19,563	18,685	878	878	8	8
85 and over	10,110	8,961	1,149	1,149	9	9
25 - 29	18,582	20,082	-1,500	1,500	10	-10
20 - 24	16,685	18,236	-1,551	1,551	11	-11
65 - 69	12,849	14,656	-1,807	1,807	12	-12
30 - 34	18,063	20,754	-2,692	2,692	13	-13
16 - 19	10,025	12,733	-2,708	2,708	14	-14
55 - 59	20,531	17,729	2,801	2,801	15	-15

Table 4.9 Summary of differences in mean annual miles driven for females - 1990

	Mean annual miles driven - females 1990					
Age groups	Selected states	Indiana	Difference	Abs. Diff	Rank	Signed rank
60 - 64	5,298	5,358	-61	61	1	-1
30 - 34	10,656	10,574	83	83	2	2
50 - 54	8,391	8,577	-186	186	3	-3
40 - 44	10,308	10,113	196	196	4	4
55 - 59	7,281	7,057	224	224	5	5
75 - 79	3,936	4,504	-569	569	6	-6
35 - 39	11,713	11,122	592	592	7	7
65 - 69	5,518	4,783	734	734	8	8
20 - 24	12,201	12,986	-785	785	9	-9
45 - 49	8,735	7,928	806	806	10	10
70 - 74	4,226	3,416	809	809	11	11
85 and over	6,383	5,469	914	914	12	12
25 - 29	10,988	12,026	-1,038	1,038	13	-13
80 - 84	3,138	5,050	-1,912	1,912	14	-14
16 - 19	6,709	9,634	-2,925	2,925	15	-15

Table 4.10 Summary of differences in mean annual miles driven for males - 1995

	Mean annual miles driven - males 1995					
Age groups	Selected states	Indiana	Difference	Abs. Diff	Rank	Signed rank
30 - 34	20,286	20,270	16	16	1	1
75 - 79	8,193	7,900	293	293	2	2
20 - 24	14,304	14,654	-350	350	3	-3
55 - 59	15,893	16,572	-679	679	4	-4
60 - 64	16,413	15,335	1,078	1,078	5	5
40 - 44	17,927	16,589	1,339	1,339	6	6
65 - 69	12,541	14,294	-1,753	1,753	7	-7
80 - 84	7,813	9,800	-1,987	1,987	8	-8
16 - 19	6,345	8,382	-2,037	2,037	9	-9
70 - 74	10,799	13,006	-2,207	2,207	10	-10
45 - 49	19,910	22,527	-2,616	2,616	11	-11
85 and over	5,133	8,500	-3,367	3,367	12	-12
50 - 54	20,288	16,106	4,182	4,182	13	13
35 - 39	18,465	23,182	-4,716	4,716	14	-14
25 - 29	22,851	15,465	7,386	7,386	15	15

Table 4.11 Summary of differences in mean annual miles driven for females - 1995

	Mean annual miles driven - females 1995					
Age groups	Selected states	Indiana	Difference	Abs. Diff	Rank	Signed rank
60 - 64	6,091	6,344	-253	253	1	-1
35 - 39	11,996	11,678	318	318	2	2
70 - 74	5,727	6,279	-552	552	3	-3
75 - 79	3,943	4,939	-996	996	4	-4
55 - 59	8,315	7,287	1,028	1,028	5	5
80 - 84	2,864	1,820	1,044	1,044	6	6
65 - 69	4,414	5,597	-1,183	1,183	7	-7
85 and over	1,727	533	1,193	1,193	8	8
40 - 44	12,289	10,800	1,489	1,489	9	9
25 - 29	13,034	14,804	-1,770	1,770	10	-10
45 - 49	11,501	9,508	1,994	1,994	11	-11
50 - 54	10,579	13,441	-2,862	2,862	12	-12
30 - 34	13,089	9,761	3,327	3,327	13	13
20 - 24	11,269	15,004	-3,735	3,735	14	-14
16 - 19	6,397	2,659	3,738	3,738	15	15

Table 4.12 Summary of results from the Wilcoxon Signed Rank Test

Year	Sex	T-	T+	T	$T_{\alpha/2}$	Conclusion
1990	Male	88	32	32	25	DNR H_0
1990	Female	61	51	51	25	DNR H_0
1995	Male	78	42	42	25	DNR H_0
1995	Female	62	58	58	25	DNR H_0

DNR H_0– Do not reject the null hypothesis

The results show that the estimates of mean average annual miles driven by drivers in the selected states can be substituted for the mean annual miles driven by drivers in Indiana.

4.3 Description of the Licensed Driver-Based VMT Model

The licensed driver-based model developed in this study estimates and forecasts short-term and long-term VMT for Indiana. The model has been developed in a spreadsheet format using Microsoft Excel®. The spreadsheet is made up of seven worksheets:

- An input and output sheet – the only input for this model is the subject year for which the estimate is required. The output from the model, which is the estimate of statewide annual vehicle-miles of travel, is presented in the same worksheet.
- Two worksheets perform the VMT estimation analysis using average annual miles estimates computed for licensed drivers in the five selected states, and licensed drivers in Indiana, respectively.
- Four worksheets contain population distribution data and licensed driver data by age and sex.

There are three look-up tables for licensed driver data compiled from the *Highway Statistics* series. These tables could be easily updated when the records are published. The three tables contain statistics (historical data) on female licensed drivers by age cohorts, male licensed drivers by age cohorts, and the total distribution of licensed drivers by sex.

The VMT estimation worksheets contain three tables. The first table, presented in Table 4.13, estimates the total population of the state for the subject year and the total licensed driver distribution by sex and age. The data are extracted from the look-up worksheets by matching the input year to the data on the relevant table. Considering an input year of 2002, the model looks up the population worksheet and extracts the total population for 2002 and the percentage of the population older than 15. The percentages of licensed drivers by sex are converted to numbers by multiplying by the population of the state.

Table 4.13 Estimation of licensed driver population by sex for input year from VMT model

Input subject year:	2002
Population for subject year:	6,122,436
% of pop. 16 years and over:	78.0
% of licensed drivers as males in Indiana	51.0
% of licensed drivers as females in Indiana	49.0
Percentage of population 16 years and over as drivers	85
Estimate of pop. 16 years and over	4,775,500
Estimate of licensed drivers in Indiana	4,297,950
Estimate of licensed drivers as males in Indiana	2,191,955
Estimate of licensed drivers as females in Indiana	2,105,996

The second table on the VMT estimation worksheet contains the licensed driver distribution by sex and age cohorts. The look-up tables on male and female licensed drivers contain historical data from 1994 through 1999 by age cohorts, on licensed drivers reported in the *Highway Statistics* series. The distribution of the percentage by age groups of licensed drivers is presented in Tables 4.14 and 4.15 for males and females, respectively. A peculiar trend was identified in the licensed driver data reported in the *Highway Statistics* series. The percentages of licensed drivers within each age cohort were constant for the years 1994 through 1997. The shaded rows in Tables 4.14 and 4.15 show the constant percentages of licensed driver for this period. The licensed driver percentages for the years 1994 through 1997 are, therefore, not used in the estimation of the average percentage of the distribution of licensed drivers by age groups.

Table 4.14 Distribution of the percentages by age cohort of male licensed drivers reported in the *Highway Statistics* series from 1994 through 2000

Year	16-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54
1994	5.2	9.7	11.8	12.6	11.4	9.8	7.6	6.0
1995	5.2	9.7	11.8	12.6	11.4	9.8	7.6	6.0
1996	5.2	9.7	11.8	12.6	11.4	9.8	7.6	6.0
1997	5.2	9.7	11.8	12.6	11.4	9.8	7.6	6.0
1998	6.3	9.0	9.2	9.8	11.2	11.2	10.1	8.4
1999	5.5	8.9	9.0	9.4	11.1	11.3	10.4	8.9
2000	6.3	9.0	9.5	10.0	11.3	11.3	10.1	8.4
Average	6.0	9.0	9.2	9.7	11.2	11.3	10.2	8.6

Table 4.14, continued

Year	55-59	60-64	65-69	70-74	75-79	80-84	85+
1994	5.2	5.2	4.9	4.1	3.4	2.0	1.3
1995	5.2	5.2	4.9	4.1	3.4	2.0	1.3
1996	5.2	5.2	4.9	4.1	3.4	2.0	1.3
1997	5.2	5.2	4.9	4.1	3.4	2.0	1.3
1998	6.6	5.3	4.4	3.9	2.3	1.4	0.9
1999	6.9	5.4	4.5	3.9	2.4	1.5	1.0
2000	6.6	5.2	4.4	3.9	2.0	1.2	0.8
Average	6.7	5.3	4.4	3.9	2.2	1.4	0.9

Table 4.15 Distribution of the percentages by age cohort of female licensed drivers reported in the *Highway Statistics* series from 1994 through 2000

Year	16-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54
1994	4.9	9.4	11.7	12.5	11.3	9.9	7.6	6.1
1995	4.9	9.4	11.7	12.5	11.3	9.9	7.6	6.1
1996	4.9	9.4	11.7	12.5	11.3	9.9	7.6	6.1
1997	4.9	9.4	11.7	12.5	11.3	9.9	7.6	6.1
1998	6.2	8.6	9.1	9.2	10.7	10.8	9.8	8.5
1999	5.4	8.6	8.6	8.9	10.6	10.9	10.1	9.0
2000	6.2	8.5	8.8	9.0	10.5	10.7	9.8	8.4
Average	5.9	8.6	8.8	9.0	10.6	10.8	9.9	8.6

Table 4.15, continued

Year	55-59	60-64	65-69	70-74	75-79	80-84	85+
1994	5.3	5.3	5.1	4.3	2.8	2.0	1.9
1995	5.3	5.3	5.1	4.3	2.8	2.0	1.9
1996	5.3	5.3	5.1	4.3	2.8	2.0	1.9
1997	5.3	5.3	5.1	4.3	2.8	2.0	1.9
1998	6.8	5.4	4.8	4.4	2.4	1.7	1.7
1999	7.0	5.6	4.8	4.4	2.5	1.8	1.8
2000	6.8	5.4	4.8	4.5	2.7	1.9	1.9
Average	6.9	5.5	4.8	4.4	2.5	1.8	1.8

Because the licensed driver distribution, by sex and age cohort, for the 3 years (1998, 1999, and 2000) shown in Tables 4.14 and 4.15 show no clear trend, average percentages of licensed drivers by sex and age cohort are used in the estimation and forecasting of VMT from the year 2000 through 2010. The average percentages are used as distribution factors for the estimation of the total numbers of male and female licensed drivers in each age group.

The process is represented mathematically as follows:

$$L_{ij} = (PDF_{ij} * l_j)/100 \tag{4.2}$$

where

L_{ij} represents the number of licensed drivers for age group i and sex j

PDF_{ij} represents the percentage distribution factor for age group i and sex j

l_j represents the number of licensed drivers of sex j estimated from the first table on VMT estimation worksheet.

The estimation of the number of female licensed drivers in the 25-29 age group for the year 2001 is shown below:

Population estimate of Indiana for the year 2001	-	6,085,165
Percentage of population 16 years and over	-	77.9
Percentage of male licensed drivers in Indiana	-	51
Percentage of female licensed drivers in Indiana	-	49
Percentage of eligible population that drives	-	85

Estimate of population 16 years and older =(77.9*6,085,165)/100
= 4,740,344

Estimate of male licensed drivers in Indiana ($l_{i=m}$) =(0.85*4740344*0.51)
=2,054,939

Estimate of female licensed drivers in Indiana ($l_{i=f}$) =(0.85*0.49*4740344)
=1,974,353

(The percentage distribution factor of female licensed drivers for the 25-29 age group, as shown in Table 4.15, is 8.8.)

Number of female licensed drivers in this age class =0.088 * 1,974,353
= 171,367.

The third table on the VMT estimation worksheet evaluates the total vehicle-miles traveled for all licensed drivers by sex and age cohort. The total vehicle-miles driven for all licensed drivers by sex are then the aggregation of the total miles driven by each age cohort. The sum of the total vehicle-miles driven by male and female licensed drivers is taken as the estimate of statewide VMT for that year. The estimate of statewide VMT is computed for estimates of average annual miles per licensed driver determined from both the 1990 and 1995 NPTS surveys.

The four estimates of statewide VMT evaluated from the 1990 and 1995 NPTS surveys, for both Indiana and the selected states, are copied to the input-output sheet of the spreadsheet model. The mathematical representation of the VMT estimation process is presented in the previous section. Table 4.16 shows the evaluation of the total statewide VMT for the year 2001, using the 1990 NPTS results and average annual miles per licensed driver for Indiana. Table 4.17 shows the corresponding adjusted total VMT using the 1995 NPTS survey results. The VMT estimates generated from the 1990 NPTS survey are not adjusted because the growth rates are based on the 1995 NPTS survey data. The commercial vehicle component of the statewide VMT is discussed in Section 4.5.1.

Table 4.16 The estimation of statewide VMT from average annual miles per licensed driver from the 1990 NPTS survey

	1990 NPTS Survey Results			
Age Group	*Male Drivers*		*Female Drivers*	
	Avg. Annual VMT	*VMT for input year*	*Avg. Annual VMT*	*VMT for input year*
16 - 19	12,733	1,662,281,193	9,634	1,188,261,478
20 - 24	18,236	3,570,962,642	12,986	2,334,634,566
25 - 29	20,082	4,019,854,848	12,026	2,212,294,237
30 - 34	20,754	4,380,318,343	10,574	1,989,375,052
35 - 39	16,318	3,976,656,686	11,122	2,464,487,494
40 - 44	19,467	4,786,219,503	10,113	2,283,200,280
45 - 49	18,916	4,198,034,560	7,928	1,640,857,236
50 - 54	18,685	3,496,378,745	8,577	1,541,985,329
55 - 59	17,729	2,584,601,236	7,057	1,017,920,642
60 - 64	15,522	1,790,021,970	5,358	616,091,781
65 - 69	14,656	1,403,130,428	4,783	479,969,490
70 - 74	9,500	806,140,451	3,416	314,211,994
75 - 79	10,590	506,922,004	4,504	235,398,227
80 - 84	6,205	189,026,990	5,050	190,025,677
85+	8,961	175,479,674	5,469	205,782,757
Total		37,546,029,274		18,714,496,241
Total VMT for registered drivers - 1990 NPTS			56,260,525,515	

Table 4.17 The estimation of adjusted statewide VMT from average annual miles per licensed driver from the 1995 NPTS survey

	1995 NPTS Survey Results			
Age Group	*Male Drivers*		*Female Drivers*	
	Avg. Annual VMT	*VMT for input year*	*Avg. Annual VMT*	*VMT for input year*
16 - 19	8,382	1,094,307,921	2,659	327,969,497
20 - 24	14,654	2,869,667,447	15,004	2,697,516,086
25 - 29	15,465	3,095,753,921	14,804	2,723,336,792
30 - 34	20,270	4,278,127,954	9,761	1,836,530,439
35 - 39	23,182	5,649,177,800	11,678	2,587,761,394
40 - 44	16,589	4,078,608,214	10,800	2,438,349,284
45 - 49	22,527	4,999,389,475	9,508	1,967,671,862
50 - 54	16,106	3,013,806,665	13,441	2,416,437,296
55 - 59	16,572	2,415,862,593	7,287	1,051,111,167
60 - 64	15,335	1,768,381,331	6,344	729,454,536
65 - 69	14,294	1,368,461,558	5,597	561,611,043
70 - 74	13,006	1,103,669,921	6,279	577,540,672
75 - 79	7,900	378,157,113	4,939	258,110,372
80 - 84	9,800	298,522,186	1,820	68,484,502
85+	8,500	166,450,053	533	20,068,593
Total		36,578,344,151		20,261,953,536
Adjusted Total VMT for registered drivers - 1995 NPTS			57,878,777,986	

4.4 Estimation of Average Annual Household VMT by Area Type and Various Household Characteristics

The average annual household VMT was estimated for the following sets of household characteristics in the 1995 NPTS:

- Household income and area type.
- Household vehicle count and area type.
- Household size and area type.
- Vehicles per licensed driver and area type.

The PROC MEANS option in SAS was used for the estimation of average annual household VMT. The output from this procedure included the number of observations, mean miles driven and standard deviation. Tables 4.18 through 4.21 present the output for the various household characteristics. Figures 4.5 through 4.8 show plots of the results from Tables 4.18 through 4.21. Results from the tables will be discussed in Section 4.3.1. The area type definitions shown in Tables 4.18 through 4.21 are discussed in Section 3.5.

Table 4.18 Average annual household VMT by household income and area type

Income Group \ Area Type	Rural	Light urban (LU)	Dense urban (DU)
< $20K	14,673	11,879	9,306
$20K TO $40K	20,727	15,899	12,977
$40 TO $60K	26,828	22,596	18,273
$60K TO $80 K	33,334	24,401	18,750
$80K TO $100K	32,006	25,797	22,191
> $100K	32,884	26,525	21,204

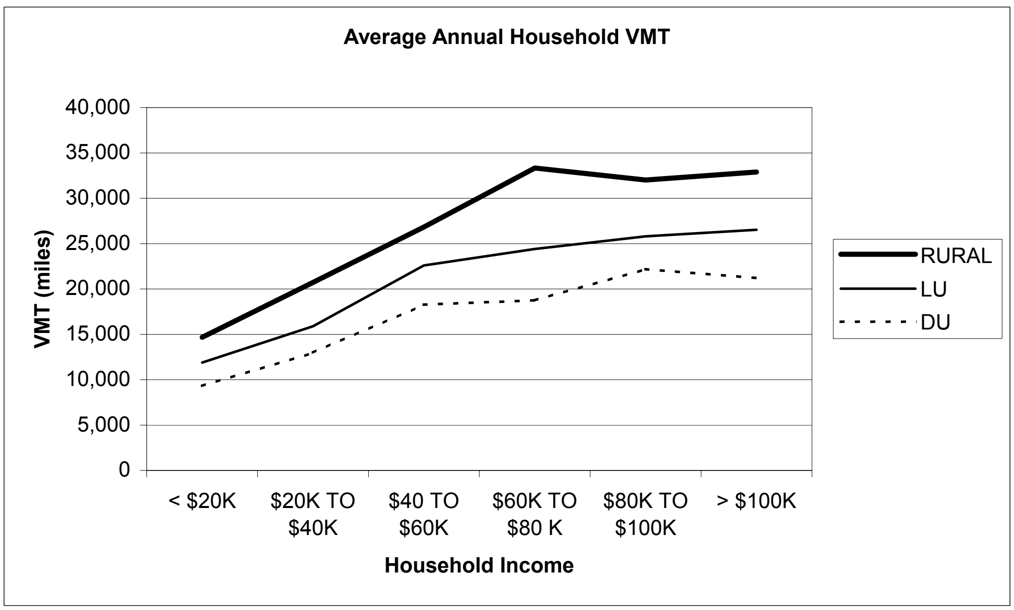


Figure 4.5 Plot of average annual household VMT by income groups and area type

Table 4.19 Average annual household VMT by household vehicle count and area type

Number of Vehicles \ Area Type	Rural	Light urban (LU)	Dense urban (DU)
1	13,389	11,539	9,439
2	24,153	23,196	21,098
3+	36,914	32,991	29,180

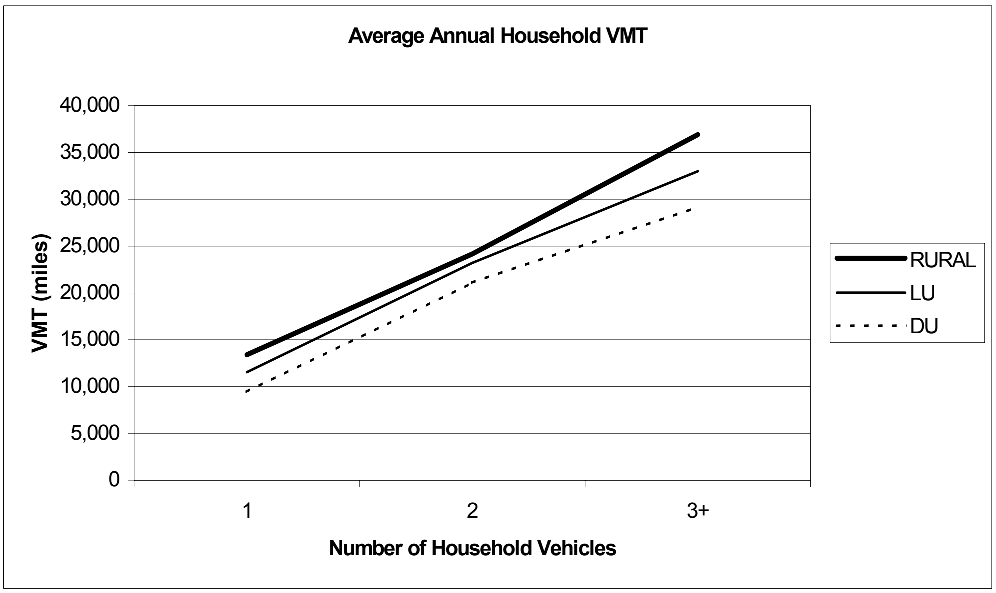


Figure 4.6 Plot of average annual household VMT by household vehicle count and area type

Table 4.20 Average annual household VMT by household size and area type

Household Size \ Area Type	Rural	Light urban (LU)	Dense urban (DU)
1	11,957	10,378	8,165
2	20,865	18,139	14,995
3	28,017	24,072	20,317
4+	28,979	27,471	23,012

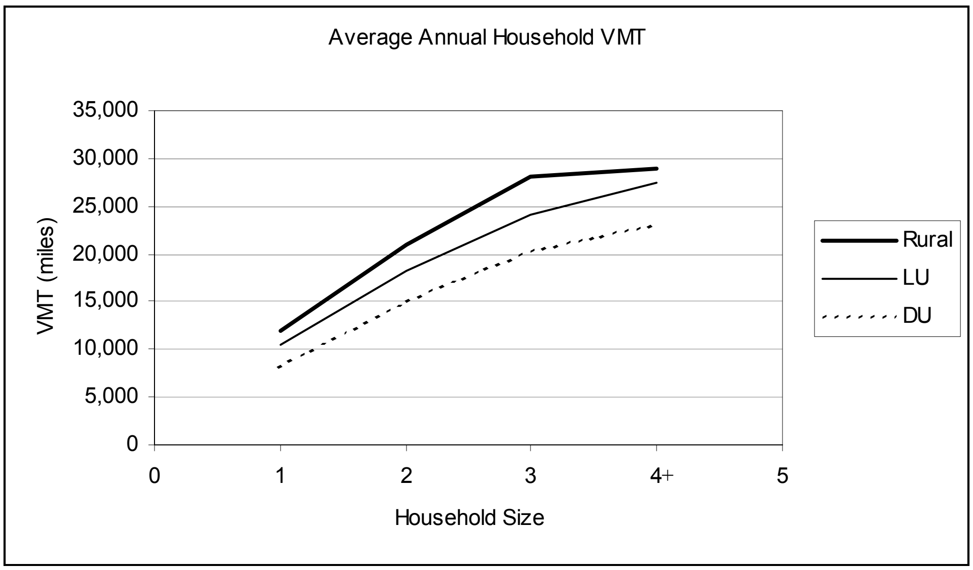


Figure 4.7 Plot of average annual household VMT by household size and area type

Table 4.21 Average annual household VMT by vehicles per licensed driver ratio and area type

Vehicle per driver \ Area Type	Rural	Light urban (LU)	Dense urban
<1	22,215	18,430	14,954
1	19,872	18,636	14,051
>1	22,689	21,812	19,148

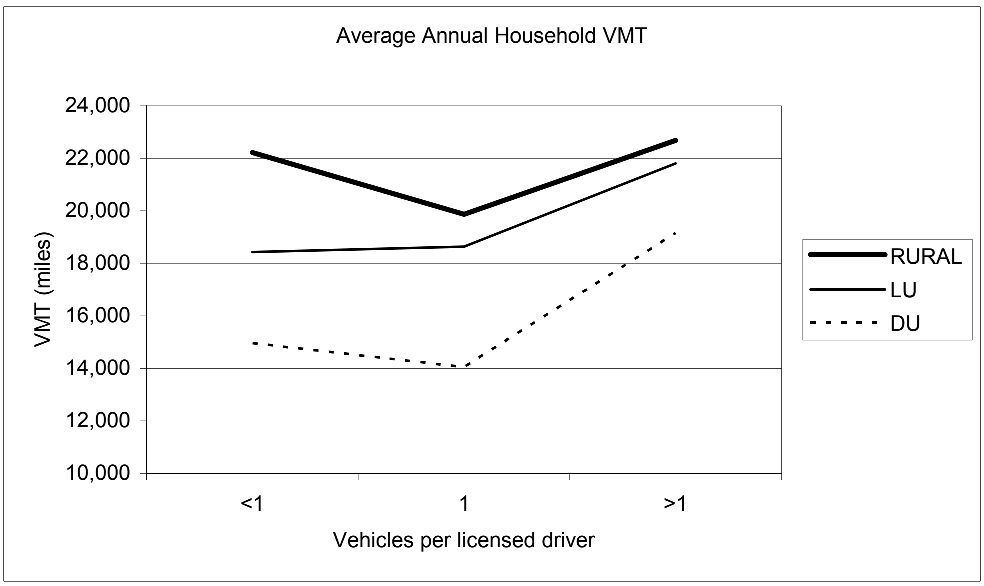


Figure 4.8 Plot of average annual household VMT by vehicles per licensed driver and area type

4.4.1 Interpretation of Average Annual Household VMT Estimates

The plots of average annual household VMT by income groups and household size shown in Figures 4.5 through 4.8 reveal some interesting trends on average household travel for the various socioeconomic characteristics considered. The results from the estimates of average annual average household VMTs are discussed for each household characteristic.

4.4.1.1 Household Income

Households within any income group have the highest average household VMTs for those households in rural areas and the least average annual household VMTs in dense urban areas, as shown in Figure 4.5. This is expected, because more travel mode choices would be available in urban areas and also lower trip lengths are expected in urban areas than in suburban or rural areas. Light urban (may be considered as suburban) household VMTs are expected to be higher than dense urban household VMTS because light urban households typically commute to their work places, often located in dense-urban areas.

The average annual household VMT for households in rural areas typically increases linearly with increasing income, however, a decrease in household VMT is experienced in the $80,000 - $100,000 income category. No explanation could be found for this peculiar behavior, especially because the next higher income category shows an increase.

The average annual household VMT for light urban households increases with increasing total household income. The rate of increase decreases, however, for households after the $40,000 to $60,000 income category. A slight decrease in household VMT is observed for households earning more than $100,000. Dense-urban households have an average annual household VMT that also increases with increasing household income. The average household VMT seems to level off for households earning an annual income of $60,000 and higher.

4.4.1.2 Number of Household Vehicles

The average annual household VMT is typically highest for households in rural areas and lowest for households in dense urban areas, as shown in Figure 4.6. Light-urban household VMT increases linearly with an increasing number of vehicles. The rate of change, however, decreases slightly for households with more than 2 vehicles. Dense urban household VMT shows a similar pattern to that of light urban households.

4.4.1.3 Household Size

Rural households have the highest average annual household VMT irrespective of the household size, as shown in Figure 4.7. Dense urban households have the lowest household VMT for any given household size. The average household VMT increases with increasing household size for all area types, however, the change in rural annual household VMT for a household with more than four members is minimal.

Households with more members are expected to accumulate a higher total VMT than smaller households because larger households typically undertake more trips than smaller households. If a larger household should own only one car, the principal driver is likely to trip-chain, frequently resulting in a higher VMT.

Households with two or three members are expected to make more trips than one-member households, irrespective of the ages of the second and third members. The trip-making behavior of households with four or more members is not expected to differ considerably from that of three-member households, unless all members of the larger households are adults.

4.4.1.4 Number of Vehicles per Licensed Driver

Households in the rural areas have the highest aggregate household VMT and dense urban households have the least VMT for any ratio of vehicles to licensed drivers, as shown in Figure 4.8. No distinctive trends could be established from the results of the average annual household VMT by number of vehicles per licensed drivers. The average household VMTs for rural and light urban area types were similar for households with more than, or less than, one vehicle per licensed drive.

Higher-income households are typically expected to have a vehicle to licensed driver ratio of one or higher, however, lower-income households could also have a similar vehicle to licensed driver ratio. Households with less than one vehicle per licensed driver were expected to have the least average annual household VMT because a vehicle could only be driven by one person at a time, thus the total aggregated household VMT is expected to be less than that of households with a vehicle to licensed driver ratio of one or more.

This household characteristic is eliminated due to the unexplained results obtained.

4.4.2 Estimation of Statewide VMT from Average Annual Household VMT

The objective of this study is to estimate and forecast annual vehicle miles traveled in the state of Indiana. The use of socioeconomic indicators in this study is based on the premise that VMT growth, or any change in VMT, depends on changes in socioeconomic characteristics (Patterson and Schaper 1998). The estimation of annual statewide VMT depends on the availability of reliable and accurate data on the socioeconomic characteristics, by area type, used in this study.

The three variables -- *income groups*, *household size* and *vehicle ownership* -- are intended to present alternative sources of statewide VMT for comparison. The statewide VMT estimation procedure is discussed below:

Step 1: Input the number of households in the study area for each cell of the VMT estimation matrix – by area type and socioeconomic characteristics

Step 2: Multiply the number of households by the estimates of nationwide average annual household VMT for each cell

Step 3: Aggregate estimates of total household miles within each cell to obtain the VMT.

The process could be represented by the following equation:

$$\text{AVMT} = \sum_i \sum_j (H_{ij} * v_{ij}) \tag{4.3}$$

where

AVMT represents the total annual vehicle miles traveled,

H_{ij} represents the number of households in the study area for group i of the relevant socioeconomic characteristic, and area type j

v_{ij} represents the average annual household VMT for group i of the relevant socioeconomic characteristic and area type j.

Statewide VMT estimates could thus be generated for each of the three socioeconomic characteristics.

4.5 Estimation of Statewide Commercial Vehicle VMT

Data on commercial vehicle activity, for the period 1999 through 2001 were obtained from the Indiana DOR. The total annual vehicle miles were reported by jurisdiction and fuel type. The total vehicle-miles reported by all carriers, from all jurisdictions, represent the total annual statewide commercial vehicle VMT. Table 4.22 shows commercial vehicle mileage data from fourteen jurisdictions, for the year 2000. Because long-haul commercial traffic is usually dominated by diesel-powered vehicles, mileage data are usually not reported for the other fuel types, especially for jurisdictions farther away from Indiana. The total mileages reported by all fifty-eight jurisdictions, for all fuel types, are summed up to represent total annual statewide commercial vehicle VMT.

The mileage records reported for the Indiana jurisdiction includes interstate (IFTA) and intrastate (MCFT) commercial vehicle activity.

Table 4.22 Commercial Vehicle Mileage Records from Fourteen Jurisdictions, by Fuel Type, for the Year 2000

Jurisdiction	Total miles by fuel type					Total Miles
	Diesel	Gasoline	Gasohol	Natural Gas	Propane	
Alberta	5,671,810	-	-	-	-	5,671,810
Alabama	29,003,053	4,374,010	-	-	-	33,377,063
Arkansas	7,737,991	1,646,864	-	-	-	9,384,855
British Columbia	1,771,641	-	-	-	-	1,771,641
California	15,730,765	5,076,626	-	-	-	20,807,391
Connecticut	1,281,573	387,485	-	-	-	1,669,058
Florida	42,440,884	41,405,446	-	-	-	83,846,330
Georgia	25,978,938	6,440,012	-	-	-	32,418,950
Iowa	196,659,731	193,470,712	-	-	121,407,200	511,537,643
Illinois	660,594,441	660,497,292	421,671,126	-	477,406,415	2,220,169,274
Indiana	1,400,115,396	1,318,965,534	288,490,436	214,558,778	1,227,539,690	4,449,669,834
Kentucky	75,302,183	75,302,183	-	-	68,180,087	218,784,453
Minnesota	144,045,289	106,559,498	-	80,039,026	-	330,643,813
Missouri	158,974,412	136,485,144	-	-	103,515,833	398,975,389

4.6 Problems Encountered in the Development of the Travel Survey Based VMT Models

The NPTS is a nationwide survey conducted to serve as a comprehensive database on travel patterns in the United States. The respondents are usually expected to recollect all trips made, the lengths of those trips, and the total mileage driven as a principal driver. The responses are very subjective and it could be concluded that the accuracy of any model developed from such data is questionable. However, in the absence of any better database on travel in the nation, the NPTS serves as a logical choice for describing travel behavior in the United States. Any results obtained from this model must be treated with caution, however. The problems encountered during the development of the travel survey-based VMT models, and any solutions, will be discussed here.

4.6.1 Licensed Driver-Based VMT Model

Licensed driver data obtained from the Indiana Bureau of Motor Vehicles (BMV) contained some inconsistent values. The total number of licensed drivers in the state, obtained from the BMV, exceeded the state's eligible population. The total number of licensed drivers reported to the *Highway Statistics* series is a representation of total license drivers in force, which represents the total number of licenses issued, less expired and suspended licenses. The total number of net licenses in force, reported in the BMV data, was not distributed by sex, yet data on statewide licensed drivers presented in the *Highway Statistics* series were distributed by sex. Table 4.23 shows the total number of licenses issued, the number of suspended and expired licenses, and the number of licenses reported in *Highway Statistic*s for the period 1994 through 1999. The number of expired licenses reported for 1996 was exceedingly high. The resulting net licenses in force were lower than that reported in *Highway Statistics* by one million licenses. A typographical error might be responsible for this difference, however, it was not possible to obtain a logical explanation from the BMV. The numbers of licenses are also different for 1999. It was presumed that data in the *Highway Statistics* series are distributed by predetermined constants, as evident in Tables 4.14 and 4.15 above. The total number of licensed drivers presented in the *Highway Statistics* series may not be accurate. The degree of error could not, however, be estimated. It is thus pertinent to mention that these discrepancies in the licensed driver data may affect the accuracy of any VMT estimates obtained from the model.

One of the objectives of this study was to determine growth factors for annual estimates of miles driven per licensed driver by sex and age cohort between the 1990 and 1995 NPTS survey results. It was intended to estimate the growth rates for each age group by sex, and also to estimate the average growth rate across all age groups. The variation in the growth rates estimated was so diverse across the age groups for both Indiana and the selected states that no reasons could be found to explain the anomaly. Average growth rates for Indiana showed an increase of 0.5 percent, over the five years, for average annual miles driven by male licensed drivers and 1.66 percent for female licensed drivers. Corresponding "growth rates" for average annual mile driven per licensed drivers from the selected states were actually a *decrease* of 14.88 and 14.98 percent, respectively. The summary of estimated growth rates is shown in Table 4.24. The average growth rates of 0.50 percent and 1.66 percent over five years will be adopted for the adjustment of the estimated annual miles driven per licensed driver over five-year periods. Subsequent NPTS surveys could be evaluated to assess any change in growth rates, and the model updated to reflect such changes. Table 4.25 shows the growth rates to be applied to the average annual miles driven per licensed driver by sex.

The NPTS data do not facilitate the estimation of statewide VMT by highway functional class. The various legislation require state DOTs to report VMT by highway functional class. The Indiana DOT will thus be able to utilize the VMT estimates generated by the licensed driver-based model as a control tool.

Table 4.23 Licensed driver data obtained from BMV and *Highway Statistics*

		Number of licenses issued by the BMV				Number of licensed drivers reported in *Highway Statistics*
Year	Total pop 16 years and over	Total	Suspended licenses	Expired licenses	Net licenses in force	
1,994	4,436,920	5,086,119	105,679	1,120,111	3,860,329	3,860,329
1,995	4,474,075	5,246,601	144,351	1,396,068	3,706,182	3,706,182
1,996	4,517,175	5,352,418	121,644	2,526,618	2,704,156	3,704,156
1,997	4,540,755	5,026,020	129,571	972,835	3,923,614	3,923,614
1,998	4,567,167	5,196,049	121,724	1,098,084	3,976,241	3,976,241
1,999	4,593,168	5,282,073	125,975	1,340,433	3,815,665	3,856,177

Table 4.24 Growth rates for average annual miles driven per licensed driver by sex and age cohort between the 1990 and 1995 NPTS survey results

Age group	Male licensed drivers		Female licensed drivers	
	Indiana	Selected states	Indiana	Selected states
16 - 19	-34.17	-74.12	-72.40	-69.50
20 - 24	-19.64	-38.33	15.54	70.02
25 - 29	-22.99	-42.65	23.10	-75.05
30 - 34	-2.33	-35.16	-7.68	-18.42
35 - 39	42.06	169.12	5.00	-41.45
40 - 44	-14.78	-37.69	6.80	-26.70
45 - 49	19.09	38.63	19.92	4.18
50 - 54	-13.80	-21.99	56.71	56.96
55 - 59	-6.53	-54.96	3.26	1.27
60 - 64	-1.21	-24.33	18.40	9.24
65 - 69	-2.47	-65.63	17.01	25.32
70 - 74	36.91	16.54	83.81	-8.27
75 - 79	-25.40	-21.13	9.65	17.34
80 - 84	57.93	60.41	-63.96	-78.46
85 and over	-5.15	-91.85	-90.25	-91.15
Average	0.50	-14.88	1.66	-14.98

Table 4.25 Five-year growth rates for the adjustment of average annual miles driven per licensed driver by sex

Period	Applicable growth rate (%)	
	Male	Female
2000 - 2004	1	3.32
2005 - 2009	1.5	4.98
2010 - 2014	2	6.64
2015 - 2019	2.5	8.3
2020	3	9.96

4.6.2 Household-Based VMT Model

The NPTS survey provides comprehensive data on travel in the United States. However, problems encountered during the use of the data reduce the confidence in the results generated from any analysis based on the data.

4.6.2.1 Reliability of Odometer-Recorded Vehicle Mileages

Vehicle odometer readings were taken during various stages of the NPTS travel survey. Respondents were asked to record their vehicle odometer readings, together with the day, month and year of the reading at two selected periods during the survey. The Oak Ridge National Laboratory developed a model for the estimation of annualized odometer-based VMTs from the recorded odometer readings (RTI 1997). The odometer-based VMT was presented as the variable ANNUALZD in the NPTS 'Vehicle File' (RTI 1997).

It was discovered, however, during the comparison of odometer-recorded vehicle mileages to self-reported vehicle mileages that the percentage difference between annual odometer-recorded mileages and self-reported annual vehicle mileages were very high for certain vehicles, sometimes exceeding 1000%. This prompted the need to examine the survey vehicle data for any possible explanation for the large difference between the two estimates of vehicle travel. One possible reason is the difference in time periods for the vehicle mileage estimates. The self-reported vehicle mileage estimate was in response to a question asking how many miles the vehicle had been driven in the previous year, whereas the odometer-recorded vehicle mileage estimates reported in the NPTS were for trips made in the survey year (RTI 1997). Vehicle mileage estimates were, however, not expected to change drastically over a one year period unless:

- A newer vehicle had been acquired that was made the principal vehicle,
- The vehicle had broken down sometime during the survey, and was out of service.

Certain peculiar problems were identified during the scrutiny of the NPTS vehicle data. Some of these problems are discussed below:

1. It was discovered during the examination of the data that the two odometer readings for some vehicles were not extrapolated to represent a 12-month travel period. Differences between the two odometer readings were reported on the NPTS as annual vehicle mileages even though the readings were taken much less than a year apart. This results in the underestimation of annual vehicle travel for such vehicles on the NPTS. For vehicles that had the annualized odometer mileage estimate less than the difference between the two odometer readings (the annualized mileage estimates were based on a daily rate -- odometer mileage per week-day of recording), the annualized mileage estimate was set to be the difference between the two odometer readings taken during the survey (RTI 1997). This was done for 3,005 vehicles on the NPTS dataset. Thirteen examples of the 3,005 anomalies are shown in Table 4.26. Vehicles with this problem were discarded from the household vehicle database generated in this study.
2. A second odometer reading could not be obtained for certain vehicles on the NPTS dataset. A dummy value, 999,998, was reported as the odometer reading, and such vehicles were assigned an annual odometer mileage of zero in the NPTS database. This was done for 306 vehicles. Four of the vehicles that have this problem have been shown in the last four rows in Table 4.26. These vehicles do not pose any problem in the analysis process because they were excluded from the sample used in estimating average annual household VMT by area type and each of the following household demographic characteristics: *Household income*, *household size* and *number of household vehicles*. Vehicles with this problem were discarded from the household vehicle database generated in this study.
3. The first odometer readings of some vehicles were below 1,000 miles. These vehicles may have been acquired shortly before the start of the NPTS survey, although annual self-reported estimates of over 3,000 miles were sometimes quoted for such vehicles. Respondents may have wrongly interpreted the question on vehicle mileage, thus quoting estimates for vehicles that may have

not yet been acquired. 8,103 vehicles had odometer differences as much as six times lower than respondent-reported vehicle mileage (VEHMILES), and 11,756 vehicles had lower first odometer readings than annualized self-reported mileage estimates (ANNMILES). Table 4.27 shows six examples of the vehicles with discrepancies between the first odometer reading and self-reported mileage estimates. All vehicles in Table 4.27 have a higher self-reported estimate of vehicle mileage than the first odometer reading at the start of the survey.

4. Although two odometer readings could not be obtained for certain vehicles, the vehicle file contained annualized odometer mileage estimates for such vehicles. It is not possible to explain how annualized odometer mileages could be estimated based on only one odometer reading. Table 4.28 shows a section of the data, highlighting this problem. This was observed for 77 vehicles in the NPTS dataset. Vehicles with this problem were discarded from the household vehicle database generated in this study.

Table 4.26 Comparison of differences in odometer readings to the NPTS reported annualized odometer mileages (ANNUALZD) on the NPTS

FIRST ODOMETER READING				SECOND ODOMETER READING				Difference between odometer readings	NPTS Annualized Odometer Readings (ANNUALZD)	NPTS Self-Reported Vehicle Mileage (ANNMILES)
Day	Month	Year	Odometer Reading	Day	Month	Year	Odometer Reading			
3	January	96	26,542	11	March	96	26,658	116	116	1,000
4	January	96	26,778	30	April	96	26,966	188	188	5,000
4	January	96	154,368	28	June	96	154,550	182	182	999,998
4	January	96	149,752	19	March	96	149,914	162	162	999,998
5	January	96	24,905	19	March	96	25,077	172	172	10
6	January	96	34,650	7	June	96	34,771	121	121	1,000
7	January	96	65,817	1	July	96	65,827	10	10	2,000
7	January	96	162,784	11	March	96	162,880	96	96	2,400
7	January	96	53,473	4	May	96	53,508	35	35	500
4	January	96	152,000	28	June	96	999,998	-	0	999,998
7	January	96	84,914	19	March	96	999,998	-	0	999,998
8	January	96	140,000	28	June	96	999,998	-	0	2,000

Table 4.27 Section of data showing difference between initial odometer reading and self-reported mileage estimates

FIRST ODOMETER READING				SECOND ODOMETER READING				Difference between odometer readings	NPTS Annualized Odometer Readings (ANNUALZD)	NPTS Self-Reported Vehicle Mileage (ANNMILES)
1st Day	Month	Year	Odometer Reading	2nd Day	Month	Year	Odometer Reading			
16	May	95	1	28	December	95	2	1	1	3,000
12	January	96	45	9	April	96	999,998	-	0	2,000
8	May	96	396	16	July	96	575	179	179	3,000
31	May	95	780	15	May	96	900	120	120	1,149
19	September	95	800	17	December	95	999,998	-	0	9,000
24	April	96	979	7	June	96	1,059	80	80	6,000

Table 4.28 Highlighting the estimation of annualized odometer mileage estimates from one odometer reading

First Odometer Reading				Second Odometer Reading				Difference between odometer readings	NPTS Annualized Odometer Readings (ANNUALZD)
Day	Month	Year	Odometer Reading	Day	Month	Year	Odometer Reading		
13	February	96	75,853	23	April	96	999,998	-	193
13	February	96	54,300	23	April	96	999,998	-	193
4	March	96	18,612	1	May	96	999,998	-	188
31	January	96	42,715	17	April	96	999,998	-	175
4	August	95	190,451	2	October	95	999,998	-	143
27	January	96	109,072	16	April	96	999,998	-	141
2	October	95	67,882	19	June	96	999,998	-	123
17	November	95	127,912	17	March	96	999,998	-	89
27	April	96	205,847	10	June	96	999,998	-	68

4.6.2.2 Self-Reported Vehicle Mileage Estimates

Self-reported mileage estimates were reported for most of the 75,217 vehicles on the NPTS vehicle file. Certain respondents, however, refused to give such estimates of travel and dummy values of 999,998 were assigned to vehicles for which self-reported estimates were not available. Two variables, ANNMILES and VEHMILES were created for the reporting of self-reported vehicle mileages on the 1995 NPTS. VEHMILES represented the actual estimates given by the respondent, and ANNMILES represented adjusted (annualized) self-reported estimates for vehicles that had been acquired in less than a year from the reporting time. The value of the ANNMILES variable was either higher than, or equal to the value of the VEHMILES variable.

It was observed that certain vehicles had respondent-reported estimates of vehicle miles (VEHMILES) but the ANNMILES variable was given a dummy variable, 999,998, identifying that vehicle as one for which the respondent refused to give an estimate. It is not clear why these self-reported estimates were deleted (the ANNMILES variable has been recommended for use in estimating any vehicle travel characteristics). 689 vehicles in the NPTS dataset were observed with this problem. Table 4.29 shows a section of the data highlighting this problem. Because the self-reported VMT estimates were not utilized in this study, this problem should not affect estimation of the average annual household VMT.

Table 4.29 Section of Vehicle data showing deleted self-reported vehicle mileage estimates

First Odometer Reading			Second Odometer Reading			Odometer recorded vehicle mileage estimates			Self-reported vehicle mileage estimates	
Day	Month	Year	Day	Month	Year	Difference between odometer readings	Difference between odometer readings and ANNUALZD	NPTS annualized odometer readings ANNUALZD	Annualized self-reported vehicle mileage (ANNMILES)	Self-reported vehicle mileage (VEHMILES)
19	March	96	20	May	96	951	3,199	4,150	999,998	100,000
6	December	95	28	June	96	19,131	14,297	33,428	999,998	50,000
7	December	95	12	June	96	29,571	28,204	57,775	999,998	50,000
25	February	96	5	June	96	29,801	74,427	104,228	999,998	45,000
25	March	96	27	June	96	7,712	20,759	28,471	999,998	40,000
31	March	96	6	June	96	4,163	16,957	21,120	999,998	35,000
23	March	96	26	June	96	2,562	4,919	7,481	999,998	30,000
1	June	96	22	July	96	2,983	14,277	17,260	999,998	30,000
1	December	95	4	June	96	3,672	2,978	6,650	999,998	30,000

4.7 Chapter Summary

This chapter discusses the data sources available for the development of a demographic-based VMT estimation model. The assumptions supporting the licensed driver-based VMT estimation model, the estimation and interpretation of average annual miles driven per licensed driver by sex and age cohort are also discussed. Because of the low number of Indiana licensed drivers sampled in the 1995 NPTS, licensed drivers from five sates were pooled for the estimation of average annual miles driven per licensed driver. Statistical comparative methods necessary to assess the use of data from five selected states in estimating Indiana VMT, and the description of the licensed driver-based VMT model are presented.

The chapter also discusses the estimation and interpretation of average annual household VMT by area type and the following demographic characteristics: household income, household size, and household vehicle count. Problems with data sources encountered in developing the licensed driver-based and the household travel-based VMT estimation models are also discussed. Commercial vehicle VMT is calculated from the statewide fuel tax records. The mileage records from fourteen jurisdictions are presented to highlight the process of calculating the statewide commercial vehicle VMT.

CHAPTER 5. RESULTS

5.1 Introduction

The results obtained from the statewide VMT estimation models developed in this study are presented in this chapter. Vehicle-miles traveled are calculated for statewide personal travel and commercial vehicle travel. Personal travel VMT represents total statewide VMT generated from the use of automobiles and light-trucks. The licensed driver-based and household-based models are used for the estimation of personal travel VMT. The commercial vehicle VMT is calculated from fuel tax records obtained from the Indiana Department of Revenue.

The U. S. Census Bureau released the 2000 Census household population data, at the census tract level, for Indiana on April 17, 2002. The 2000 Census data were used to validate the household-based model. This chapter also discusses procedures for assigning census tracts to the adopted area types.

5.2 Validation of Licensed-Driver-Based VMT Model

The licensed driver-based statewide VMT estimation model developed in this study was used to forecast VMT for future years through 2010. Travel patterns within this period are not expected to change significantly, thus estimates of average annual miles driven per licensed driver, by sex and age cohort, obtained from the 1995 NPTS will be used to forecast statewide VMT. An unexpected change in average annual mileage estimates per licensed driver, due to changes in the economic condition of the state, or the nation, may call for the license driver-based VMT model to be updated.

The estimates of average miles driven per licensed driver, obtained from the 1995 NPTS, will be adjusted with five-year growth factors obtained from the 1990 and 1995

NPTS. These five-year growth factors are presented in Table 4.23 of Chapter 4. The description of the licensed driver-based VMT estimation model is presented in Section 4.2, so only the results will be presented and discussed in this chapter.

5.2.1 Statewide VMT Estimates Obtained from the Licensed Driver-Based Model

The VMT estimates and forecasts for the period 2000 through 2005, using the estimated average annual miles per licensed driver for the selected states and Indiana, from the 1990 and 1995 NPTS surveys, are presented in Table 5.1. The results presented in Table 5.1 are based on the assumption that 85 percent of the eligible population --16 years and older -- is licensed to operate motor vehicles. Table 5.2 presents licensed driver-based VMT estimates for the same period, but adopting 90 percent as the percentage of the eligible population licensed to operate motor vehicles. The VMT estimates derived from the 1995 estimates of annual average miles per licensed driver are adjusted to reflect the growth in average annual miles driven per licensed driver over the 5-year period. The percentage growth in VMT over the 6-year period is shown in the last row of Table 5.1.

The growth in VMT over the nine-year period, shown as "% Growth" in Table 5.1, from the four data sources, is generally low. These low growth rates could be attributed to the following:

- The lack of any economic indicators in the VMT model.
- The assumption that travel on Indiana State roads by out-of-state drivers is equal to out-of-state driving by Indiana drivers.
- The poor representation of commercial vehicle activity in the NPTS.

Table 5.1 Statewide VMT for the period 2000 through 2005 adopting 85% of the eligible population as licensed drivers

Year	Selected States		Indiana	
	1990 NPTS	1995 NPTS	1990 NPTS	1995 NPTS
2000	53,164,985,763	54,295,192,655	54,858,779,630	54,410,898,274
2001	53,411,598,481	54,547,047,985	55,113,249,232	54,663,290,320
2002	53,807,723,203	54,951,593,717	55,521,994,170	55,068,698,158
2003	54,176,431,406	55,328,140,097	55,902,449,121	55,446,046,976
2004	54,517,420,706	55,676,378,312	56,254,302,067	55,795,027,303
2005	55,379,150,149	56,554,984,994	57,163,735,171	56,694,716,471
% Growth	4.0	4.0	4.0	4.0

Table 5.2 Statewide VMT for the period 2000 through 2005 adopting 90% of the eligible population as licensed drivers

Year	Selected States		Indiana	
	1990 NPTS	1995 NPTS	1990 NPTS	1995 NPTS
2000	56,292,337,867	57,489,027,517	58,085,766,667	57,611,539,349
2001	56,553,457,215	57,755,697,867	58,355,205,069	57,878,777,986
2002	56,972,883,391	58,184,040,407	58,787,993,827	58,308,033,344
2003	57,363,280,312	58,582,736,574	59,190,828,481	58,707,579,151
2004	57,724,327,806	58,951,459,389	59,563,378,659	59,077,087,732
2005	58,636,747,216	59,881,748,818	60,526,307,828	60,029,699,793

The personal vehicle VMT reported in *Highway Statistics 2000* is 61,294 million vehicle-miles. The total VMT calculated from the licensed driver-based VMT model for the year 2000, as shown in Table 5.1, were lower than the current statewide estimates reported in *Highway Statistics 2000* by about 10% for the model based on licensed drivers sampled in Indiana in the 1990 NPTS, and about 13% for the model based on licensed drivers sampled in the selected states in the 1990 NPTS. The corresponding percentage differences between the *Highway Statistics 2000* VMT estimate and the licensed driver-based statewide VMT estimate are 5% and 10%.

5.2.2 Sensitivity Analysis of VMT Estimates

Sensitivity analysis can be conducted on the VMT estimates generated from this study to assess the impact of, say migration, on statewide VMT. The percentage of licensed drivers to the state population, 16 years and over, was set at 85 percent for this study. This estimate of 85 percent is an average of the percentages reported in the *Highway Statistics* series over a seven-year period (1994 – 2000). The reason for adopting 85% as the percentage of the eligible population actually licensed to operate vehicles is discussed in Section 4.2. The average percentage of licensed drivers to the state population eligible to drive (16 years and over) can be easily adjusted in the model. Because of uncertainties associated with the Indiana licensed driver distribution, the percentage of licensed drivers to the eligible population can be changed in the model to assess the effect on the resulting statewide VMT. Table 5.3 shows estimates of statewide VMT for the year 2000, for the following percentages: 85%, 90%, and 95%.

Table 5.3 Estimates of statewide VMT for different percentage ratios of licensed drivers to the population eligible to drive

Percentage of licensed drivers to the population eligible to drive	VMT estimates for the year 2000 (in millions)			
	Selected States		Indiana	
	1990 NPTS	1995 NPTS - adjusted	1990 NPTS	1995 NPTS - adjusted
85	53,165	54,295	54,859	54,411
90	56,292	57,489	58,086	57,612
95	59,420	60,683	61,313	60,812

5.3 Validation of the Household-Based VMT model

The household-based VMT models require the population of households within each cluster for the estimation of total statewide VMT. The required demographic characteristics are household income groups, household size, and household vehicle count.

Table HCT6 –Household Size, of the Census 2000 Summary File 2, reports the number of households within each census tract by household size. Data on household population by household size in Indiana [by census tract] were released on April 17, 2002. Tables H-44 and HCT11 of the not-yet-released Census 2000 Summary File 3 will contain data on the number of households within each census tract by household vehicle count and median household income, respectively. Table 5.4 shows a segment of the household size data for four of the seven census tracts in Adams County, Indiana, from Table HCT6 of the Census 2000 Summary File 2. Tables H-44 and HCT11 contain data by tenure (ownership and rental), however, the total population of households can easily be obtained by adding up the number of households within each income and vehicle count group, respectively.

Table 5.4 Showing a segment of Table HCT-6 from the Census 2000 Summary File 2 for 4 census tracts in Adams County, IN

	Census Tract 301, Adams County, Indiana	Census Tract 302, Adams County, Indiana	Census Tract 303, Adams County, Indiana	Census Tract 304, Adams County, Indiana
Total:	1,703	2,091	2,343	1,066
1-person household	268	676	702	187
2-person household	597	671	697	330
3-person household	301	296	395	179
4-person household	314	274	323	192
5-person household	161	121	157	116
6-person household	50	38	54	37
7-or-more person household	12	15	15	25

Source: U. S. Census Bureau 2002

5.3.1 Census Tract Area Type Definitions

The census tract (CT) data in the Census 2000 Summary Files are not reported by area type. According to the 1990 Census, an urban place was defined as any place with a population of 2,500 or more, and a rural place defined as a place with a population of less than 2,500 (United States Census Bureau 2002). The 1990 Census urban and rural definitions have been changed for the 2000 Census (IBRC 2001). Indiana has a total of 1,412 census tracts.

The area types -- rural, light urban, and dense urban-- adopted for this study are based on census tract population densities. The area type definitions are discussed in Section 3.5. Indiana is reported, in Table PS-1 of the *Highway Statistics 2000*, to have 5.8 percent of its land area defined as urban. A cumulative distribution of the population densities of all census tracts in Indiana was produced. The median (50^{th} percentile) of the distribution was selected as the upper boundary for rural census tracts, and the third quartile (75^{th} percentile) was selected as the upper boundary for “light urban” census tracts. The rural area type definition for this study is, therefore, a census tract with a population density of 1,185 persons per square mile, or lower. The light urban area type definition is a census tract with a population density between 1,185 and 3,000 persons per square mile. A dense urban place is thus a census tract with a population density greater than 3,000 persons per square mile. These area type definitions were consistent with most land use characteristics in Tippecanoe County. However, the classification of a few census tracts, such as CT 1 in Lafayette, and CT 52 in West Lafayette -- both as light urban -- was questionable. A major proportion of CT 52 is densely populated, however, the presence of a recreational park (Happy Hollow Park) causes a decrease in the effective population density. CT 1 contains industrial and residential land uses. The area type definitions were used to classify all the 1,412 census tracts in the state. 706 census tracts were classified as rural, 340 census tracts were classified as light urban, and 366 census tracts were classified as dense urban. The total land area for the rural area type defined in this study is 34,760 square miles. The Tippecanoe County census tract definitions by area type are presented in Appendix B.

The total land area for the rural area type reported in Table PS-1 of the *Highway Statistics 2000* is 34,004 miles. The total land area of the light urban area type definition is 805 square miles and the total land area of the dense urban area type is 301 square miles. The total urban land area of 1,106 square miles, however, is not equal to the 2,093 square miles reported in Table PS-1 of *Highway Statistics 2000*. The total land area for Indiana reported in Table GCT-PH1 of the 2000 census is 35,866.90 square miles, which is equal to the total land area obtained from this study. The difference of 230 square miles in land area between the two data sources cannot be explained.

The household-based VMT model was validated with 2000 Census data for the state of Indiana. The area type definitions for Indiana were used to classify the census tracts according to area type. Table 5.5 shows the number of households in the state of Indiana for each combination of household size and area type.

Table 5.5 The number of households in Indiana by area type and household size

Household Size \ Area Type	Rural	Light urban (LU)	Dense urban (DU)
1	252,628	172,012	180,788
2	415,950	203,816	169,819
3	201,876	99,441	87,513
4+	303,966	132,662	115,835

Table 5.6 Total household VMT for the state of Indiana in million vehicle-miles

Household Size \ Area Type	Rural	Light urban (LU)	Dense urban (DU)
1	3,021	1,785	1,476
2	8,679	3,697	2,546
3	5,656	2,394	1,778
4+	8,809	3,644	2,666
Total	26,164	11,520	8,466
Total VMT	46,150		

Equation 4.3 is used to estimate statewide VMT. The average annual miles per household by size and area type are shown in Table 4.20. Table 5.6 shows the total household VMT for the state of Indiana. The household-based VMT estimate for Indiana is lower than the *Highway Statistics 2000* estimate by about 26 percent.

The difference between the household-based VMT estimate and the *Highway Statistic 2000* estimate is relatively large. The difference between the VMT estimates from the household-based model and the *Highway Statistics 2000* estimate can be attributed to the exclusion of vehicle-miles accumulated by non-household vehicles, such as, rental vehicles, taxis, and company vehicles from the household-based model.

Household population data is not updated at the census tract level between Census counts. Therefore, the household-based VMT model may not be functional for the calculation of household VMT for intermediate years. The model may, however, be applicable for land use planning purposes.

5.4 Statewide Fuel Tax-Based Commercial Vehicle VMT Estimates

The total annual statewide commercial vehicle VMTs calculated from the fuel tax records are presented in Table 5.7. The statewide commercial vehicle VMT obtained from the fuel tax-based was found to decrease, consistently, from 1999 through 2001. The total vehicle-miles reported to the administrative agencies are usually recorded from vehicle odometers or other electronic distance-measuring equipment. The mileages reported thus represent actual distances traveled on public roads in the state. Annual vehicle-miles data for a current year are usually available by March of the next year. However, because licensees file quarterly tax returns, it will be possible to obtain commercial vehicle mileage records after each quarterly tax period. It may be possible, therefore, to predict future commercial vehicle-miles if data are not available on other commercial travel predictors, such as economic indicators.

The statewide VMT calculated from the fuel tax-based mileage records were found to exceed the ground count-based VMT estimates reported by INDOT. INDOT's estimates of commercial vehicle VMT were lower than the fuel tax-based estimates by 45 percent for the year 1999, and 36 percent for the year 2000. The accuracy of INDOT's ground count-based VMT estimate can be affected by various factors, including: the accuracy of automated count equipment, the accuracy of vehicle detection and classification algorithms, the accuracy of seasonal adjustment factors, and the adequacy of the count locations. The fuel taxes are mandatory reporting systems, therefore, the there is no sampling procedure required. The total mileage reported represents travel by all eligible vehicles that are driven on public roads. The response rate is also very close to

100 percent because of the strict auditing procedures maintained by the administrative agencies.

The total commercial vehicle VMT reported by the Indiana DOR represents the lower bound of the total statewide bus and truck VMT as explained in Section 3.6.3. The total statewide VMT accumulated by all buses and trucks is, therefore, expected to exceed the current VMT calculated from the fuel tax records.

Table 5.7 Statewide commercial vehicle VMT for the period 1999 through 2001

Year	Mileage by Fuel Type (in million vehicle-miles)					Total Mileage	*Highway Statistics*-Reported Truck VMT	% Difference
	Diesel	Gasoline	Gasohol	Natural Gas	Propane			
1999	5,328	4,653	1,108	38	2,710	13,838	9,556	-45
2000	5,184	4,370	710	295	2,443	13,001	9,568	-36
2001	4,927	4,032	933	119	2,429	12,440		

5.5 Chapter Summary

This chapter presents the results from the licensed driver-based VMT estimation model. Statewide VMT (for Indiana) was calculated for the period 2002 through 2010. The personal travel VMT calculated from the licensed driver-based model is about 10 percent lower than the INDOT estimated VMT.

The census tracts in the state were assigned to the area types defined in the study. The household-based VMT model was validated with 2000 Census data for the state of Indiana. The resulting estimate of VMT was lower than the *Highway Statistics 2000* estimate by about 26 percent. Problems associated with the HPMS prevent a quantitative assessment of the VMT estimates obtained from the models developed in this study.

The commercial vehicle VMT reported by the Indiana DOR exceeded INDOT's ground count-based estimates by more than 35 percent for the years 1999 and 2000.

CHAPTER 6. ALTERNATIVE TRAFFIC DATA COLLECTION METHODS FOR THE ESTIMATION OF STATEWIDE VMT

6.1 Introduction

Remote sensing is a process of acquiring images of objects without being in physical contact with the said objects. The NASA Observatorium (NASA 2001) defines remote sensing as:

> "The acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation, or acoustic energy employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers, and other instruments."

Remote sensing in transportation, however, relates to the acquisition of data from roadside and airborne media: aircraft and earth-orbiting spacecraft. Current traffic data collection media have the limitation of collecting only the temporal distribution of traffic on the roads, but remote sensing platforms have the advantage of capturing the spatial or regional distribution of traffic at any instant. By increasing the percentage of road mileage that is monitored, a satellite system could supplement traditional traffic counting media to enhance statewide traffic counting programs. Densities, velocity and flow estimates of the traffic stream can easily be obtained from satellite photographs (McCord et al. 1999). Traffic flow data from loops (with good temporal coverage and poor spatial coverage) can be combined with satellite photographs (with good spatial coverage and poor temporal coverage) to enhance network level traffic estimates.

Remote sensing can also be used to complement incident management programs, because locations of data acquisition can easily be changed, and the wide spatial coverage of remote sensing data can assist in managing traffic streams. Two methods of remote sensing data collection methods will be discussed below: Satellites and Remotely Piloted Vehicles (RPVs).

Geographic Information Systems (GPS) are very versatile tools for acquiring travel information. The potential applications of GPS to VMT estimation are also discussed.

6.2 Traffic Data Acquisition from Satellite Imagery

The basic purpose of a traffic volume count is to determine the number of vehicles on a highway facility. Satellites have not been considered as traffic monitoring platforms, because of the following problems:

- Low-resolution images obtained from certain satellite systems prevented the identification of vehicles.
- Lack of cheap, efficient and competitive data processing procedures and equipment made data extraction very difficult.
- The high cost of satellite images restricts their use.

Satellite technology has been tremendously improved since the launch of the first satellite in 1957. The potential use of satellite images as traffic data collection tools has been greatly enhanced by the development of high-resolution satellites.

Research is currently underway by the National Consortia on Remote Sensing in Transportation to improve automated vehicle detection and counting procedures from satellite imagery. However, satellite media for traffic data collection are not anticipated to replace existing ground-based methods, but rather to supplement and improve the accuracy of ground based estimates. The extraction of vehicle counts from satellite photographs has been undertaken by image subtraction and transformation techniques with high accuracies, thus the prospect of satellite platforms as traffic data collection media is highly encouraging (McCord et al. 1998; McCord et al. 1999; Merry 2001).

6.2.1 Characteristics of Satellite Systems

6.2.1.1 Resolution of Satellite Images

The resolution of the satellite image, also known as spatial resolution, usually expressed in meters, represents the pictorial or visual detail in the photograph. The resolution represents the minimum distance between two objects to distinguish the objects in the photograph. This does not define the limiting size of the object for detection; however, positive identification of small objects may be related to the resolution of the image. Typical resolution values ranged from 1-m (very high) for the Ikonos-2 satellite, and 1,100-m (very low) for the Advanced Very High Resolution Radiometer (AVHRR) (NASA 2001; Space Imaging Inc. 2000). The low resolution (greater than 15-m resolution) and medium resolution (5-m to 15-m resolution) satellite images are suitable for meteorological, agricultural and environmental applications,

Figure 6.1 1m x 1m Resolution Image of Denver, Colorado (close to Mile High Stadium) Source: Space Imaging Incorporated 2000.

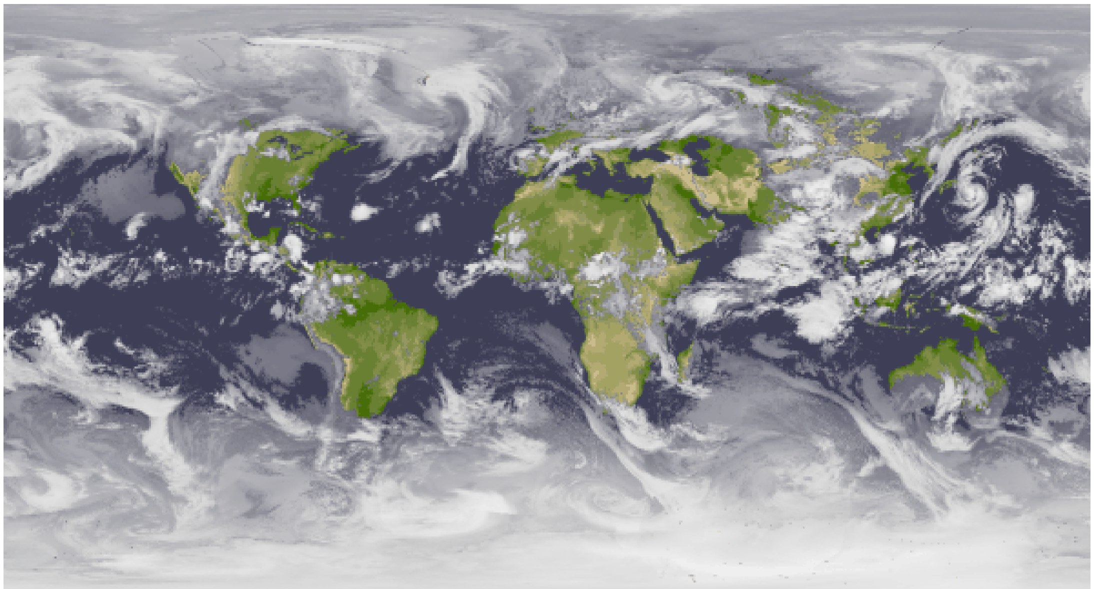


Figure 6.2 AVHRR Image of the Earth
Source: Schneider 2000.

whereas the high-resolution images (1 meter to 4 meter resolution) are used for urban and suburban applications (Jensen 2000). Figure 6.1 shows a 1-m by 1-m resolution image of Denver, Colorado, taken in August 2001 by the Ikonos-2 satellite, and Figure 6.2 shows an AVHRR image of the earth.

Panchromatic (black and white) sensors generally provide a better resolution than multi-spectral (color) sensors. The highest resolution of satellite imagery currently available is the 1-meter panchromatic image, in which objects 1 meter or longer can be clearly identified. The 1-m panchromatic image allows for the identification of vehicles in a traffic stream. Space Imaging Inc. launched the Ikonos-2 satellite with 1-m panchromatic and 4-m multi-spectral (blue, green, red, near IR) sensors in 2000, after the failure of the Ikonos-1 in 1999. Digital Globe Inc. launched the QuickBird in October 2001 (Eurimage 2001). Other private corporations have been unsuccessful in their launch of high-resolution satellites, however, it is anticipated that high-resolution images should be readily available from more commercial vendors within ten years.

6.2.1.2 Swath Widths

The swath width, also know as the footprint, represents the lateral extent or field of view covered in one pass of the satellite remote sensing system. The satellite 'observes' the earth one strip at a time. Figure 6.3 shows a schematic diagram of the swath width. The swath width is determined by the sensor type and flight altitude. The width of these strips is called the swath width. A single image of this Ikonos-2 satellite covers an area 11km wide.

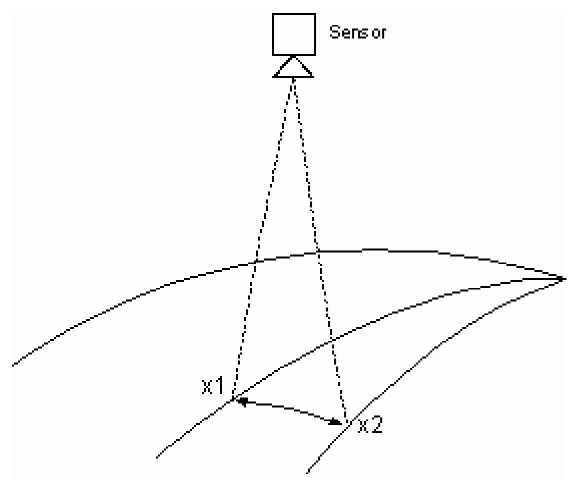


Fig 6.3 Schematic diagram of the swath width of a remote sensing platform

6.2.1.3 Orbital Information

The orbital information for a satellite describes the travel characteristics of the satellite. The altitude of the satellite affects the area of coverage and also the resolution of the resulting images. The high-resolution satellites orbit the earth at a much lower altitude. The revisit frequency of the satellite is the time it takes the satellite to return to the same location. The properties of the Ikonos-2 and other proposed high-resolution satellites are listed in Table 6.1 below.

The sensor is an instrument mounted in satellite, containing lots of detectors sensitive to electromagnetic radiation, for data capture. Sensors may be panchromatic (PAN) or multi-spectral (MS) (Turner 2000).

Table 6.1 Properties of current and proposed high-resolution satellites

System	Quickbird	Orbview3 and 4	Ikonos2
Sensor	PAN / MS	PAN / MS	PAN / MS
Altitude	450 km	470 km	680 km
Swath width	16.5 km	8 km	11 km
Launch date	2001	2000 (delayed)	2000

Source: Finnish Geodetic Institute 2000

6.2.3 Potential Problems with Use of Satellite Data

The problems that have been experienced in using satellite imagery for VMT estimation (McCord et al. 1998; McCord et al. 1999) include:

- The successful launch of only one high-resolution satellite has slowed current research progress in the area because of difficulties in obtaining data. The successful launch of the QuickBird should help address this problem.
- Because an image is received on each pass of the satellite, the revisit frequency of the satellite determines how many images can be acquired in a given period, say one year, if the weather is conducive. Space Imaging claims a 3-day revisit frequency of the Ikonos-2 satellite (Space Imaging Inc. 2000)
- The presence of inclement weather, such as extensive cloud cover, prevents the image acquisition process, and panchromatic satellite platforms cannot be used at night (McCord et al. 1998).
- The satellite images cannot capture the temporal distribution of traffic, because the images are still or "instantaneous" snapshots. Traffic data collection with satellites is an onerous task, because the combination of low revisit frequency and "instantaneous" snapshots causes a delay in the data collection process. Use of video coverage, if developed for satellite platforms, would address this problem.
- The cost of an image ranges between $12 and $360 per square kilometer for the various classes of products from Space Imaging incoporated (Space Imaging Inc. 2000), thus image acquisition (just for even a portion of the road network) is expensive.

- The Ikonos-2 satellite passes over a location at the same time of the day for every pass (Space Imaging Inc. 2000), thus the traffic pattern over the other periods of the day cannot be observed. The successful launch of other high-resolution satellites might solve this problem.

6.3 Traffic Data Acquisition from Remotely Piloted Vehicles (RPVs)

Aerial photography has been used extensively for traffic data collection and transportation system inventory surveys. Aerial surveys were traditionally conducted with manned aircraft, requiring a flight crew, camera crew, and other personnel. Aerial surveys have the advantage of presenting, over a large area, the images of traffic conditions at a specific location of interest. Aerial photographs are classified into six categories: vertical, oblique, fan, continuous strip, panoramic, and aerial cinematography (8th/15th Tactical Recon. Squadron 2000). The vertical, oblique and continuous strip categories are most favored for traffic data collection.

Remotely Piloted Vehicles (RPVs) are unmanned or remotely controlled aircraft that have been successfully used for surveillance and other purposes dating back to the 1920s (Jones et al. 1997). Fig 6.4 shows pictures of the Schiebel Camcopter®, a fully autonomous RPV with hovering capabilities that is also capable of transmitting images to a ground station (Schiebel Corporation 1999). Remotely controlled hot-air balloons and blimps, which are more stable in flight, have also been used as platforms for aerial photography. Video data collection might be more reliable from hot-air balloons than from other smaller RPVs, because the balloons tend to be more stable in flight. Established methods of aerial photography data acquisition (Rice 1963; Treiterer and Taylor 1966; Cyra 1971; Tamburri 1963; McCasland 1965) can be extended to the RPV platform, with the added advantage of remote transmission of images to a ground station to generate real-time traffic data conditions, if required.

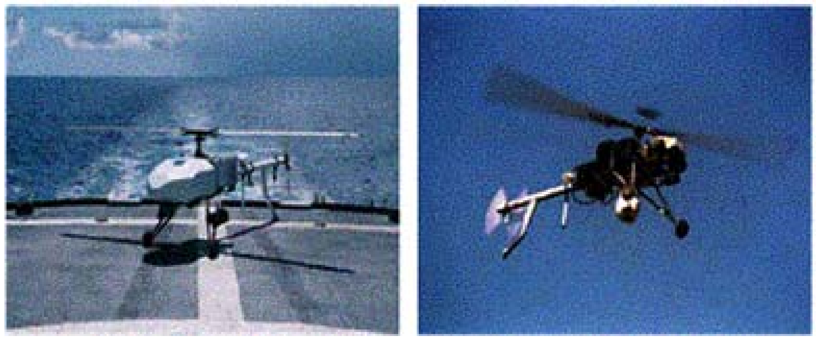


Fig 6.4 Fully autonomous RPV –The Schiebel Camcopter®
Source: Schiebel Corporation 1999

6.3.1 Guidance and Control Technology of Remotely Piloted Vehicles (RPVs)

The versatility of the RPV lies in its unmanned control. These attributes provided the impetus for further research into the development of smaller units and better platforms. The military has used the RPV extensively for surveillance and intelligence over Cuba, Vietnam, Iraq and Bosnia and other locations.

The control of RPVs ranges from simple handheld low-frequency remote control units to complex computerized systems. Certain RPVs can be controlled in both automatic and manual modes. The automatically controlled units are pre-programmable devices (by computer programs), which can be overridden or interrupted by an operator, with assistance from a mounted pilot camera to execute manual maneuvers. Control commands can be transmitted to and from the RPV by satellite communication data links (UHF or ku-Band). Most sophisticated units are guided by Global Positioning Systems (GPS) for accurate navigation and location of the RPV. Improvements in the development of miniature gyros and sensors have increased the reliability of RPV platforms in flight control. Some RPVs have a vertical take-off and landing feature and thus would not require a runway.

6.3.2 In-flight Characteristics of RPVs

RPVS have attained altitudes of 65,000 ft (8th/15th Tactical Recon. Squadron 2000), however, the use of RPVs for traffic data collection would require an altitude of not more than 3,000 ft. Most RPVs also have an altitude hold feature that allows the unit to hover over a particular location for a couple of hours. The total duration of holding an altitude depends on the design, fuel capacity and efficiency, and payload of the RPV; however, an average holding time of 6 hours has been obtained for most commercial RPVs (Schiebel Corporation 1999; Floatograph Technologies 2000).

The flight range of the RPVs depends on the control systems and fuel capacity. In 1998, the Aerosonde 'Laima' was flown nonstop from the Bell Island Airport in Newfoundland, across the North Atlantic, to DERA Benbecula Range in the Outer Hebrides, a distance of 2031 miles, in 27 hours (Aerosonde Limited 2000).

6.3.3 Potential Problems with Use of RPVs

Certain problems anticipated with the use of RPVs as traffic data collection media include:

1. Inclement weather would very much affect the use of the remotely piloted vehicles, if images cannot be acquired. Infrared cameras can detect objects through clouds, thus they would be a preferred choice of camera type if the RPV can be flown safely.
2. Smaller sized RPVs might not be detected by the flight crews of low flying aircraft. Thus, permits might be required for the use of the RPV in certain locations. Increase in the number of private flights, with non-declared fight paths, might exacerbate the problem. It is, however, not anticipated that the RPVs would fly at a high enough altitude to pose much danger to aircraft.

6.4 Global Positioning Systems (GPS)

The Global Positioning System (GPS), developed by the U. S. Department of Defense, is a global radio-based navigation system formed from a constellation of twenty-four NAVSTAR satellites, flying at an altitude of 10,900 nautical miles, and their ground stations (Trimble 2000). GPS systems employ the satellites as "benchmarks" to facilitate accurate positioning within a few meters. Different techniques, like the Differential GPS and carrier-phase GPS, have been developed to increase the accuracy of measurements to a few centimeters (Trimble 2000). The accuracy of GPS systems is not affected by inclement weather, so data can be collected all day and in any weather (Roden 1996).

GPS technology is currently being employed as a navigational and tracking aid in cars, boats, planes, laptop computers, etc.

6.4.1 How GPS Systems Work

GPS systems are based on a "triangulation" technique for the positioning of objects. Three satellites are required for this procedure, hence the term "triangulation". The spacing of the 24 satellites ensures that a minimum of 5 satellites are "in view" from any point on the globe at any given instant. Complex algorithms are used to calculate distances from the travel time of radio signals between the receiver and each of the satellites. A distance measurement from any satellite to the receiver, say 12,000 miles, locates the object (receiver) on a sphere of radius 12,000 miles, centered on the satellite. An intersection of the three spheres, from the three satellites, results in two possible points in space where the receiver could be located. A fourth satellite is usually employed to correct for the accurate 3-dimensional positioning of the receiver (Roden 1996). This stage is sometimes neglected, because one of the two possible locations of the receiver is usually far off the surface of the earth, thus reducing the number of possible locations to only one - the correct one.

6.4.2 Potential of GPS Applications to VMT Estimation

Wide Area Augmentation System (WAAS) is a type of Differential GPS (DGPS) implemented by the Federal Aviation Authority (FAA) to transmit nationwide, corrected differential errors resulting from a malfunctioning satellite. This is achieved by using approximately 25 ground receivers, two master or central processing stations on each coast, and two geostationary satellites, in addition to the 24 satellites dedicated to GPS (FAA 2000; Trimble 2000). WAAS has considerably improved the accuracy of GPS unit.

In-Vehicle Navigation Systems (IVNS) and In-Vehicle Information Systems (IVIS) have increasingly been adopted by automobile manufacturers (e.g., OnStar™), trucking and public transit agencies for vehicle tracking operations (e.g., Automatic Vehicle Location (AVL)). These systems, which are based on GPS technology, can be employed for accurate VMT estimation. Software is available for collecting latitude and longitude (or absolute location) data every second, or at selected time intervals, resulting in real-time tracking of vehicles (Gallagher 1996; Bullock et al. 1996). The real-time tracking of vehicles facilitates travel time estimation, identification of the location and extent of bottlenecks and queues for the estimation of project and network-level performance measures, and VMT estimation (Gallagher 1996).

A study by University of Iowa’s Public Policy Center to establish equity in payment of road user charges (Forkenbrock 2000) through effective road pricing, aims at providing real-time and equitable assessment of road user charges from the following variables:

- Actual vehicle operating weights and configuration,
- Mileage accrual,
- Type of road, and
- Time of day.

Data for the development, implementation and operation of this road pricing study are to be collected by on-board computer-controlled GPS units. Some new model cars already have this unit installed for security and navigational purposes. Data transmission is to be undertaken automatically or manually to a control center for the processing of billing statements. VMT estimates are derived as a byproduct of this procedure, because billing depends on amount of travel, or VMT. GIS maps are used to facilitate identification of road functional class.

The versatility of the GPS system is its ability to record the location of the vehicle at all times it is in operation. Data processing, related to VMT estimation, can reveal the following information (Battelle 1997; Battelle 1999):

- The route the vehicle traveled on.
- The start and end times of the trip.
- The total travel distance.

An added advantage of using a GPS/GIS system is that travel can be distributed by political jurisdiction, so VMT estimates within a county, MPO, State or region can be easily estimated. Vehicle identification information (say, classification, gross weight, wheel configuration etc.) can be easily preprogrammed into the GPS unit to obtain VMT estimates by vehicle type.

6.4.3 Potential Problems Related to GPS-Based VMT Estimation

A host of institutional, implementation and technological and operational issues will have to be dealt with before the GPS method can be implemented on a large scale. The success of the method will depend on how well these issues can be resolved.

6.4.3.1 Institutional Issues

Motorists might perceive this approach to travel data collection as an invasion of privacy. Origin-destination and time of day information are two of the primary data collected, thus motorists will have to be willing to have such information recorded. Trucking companies, and other commercial enterprises, might not be willing to participate, if they think the GPS collects proprietary information that competitors might get their hands on, or reveals information for government regulatory purposes.

Truck drivers, and to a lesser extent, owners selected for the Heavy-Duty Truck Activity survey in California survey seemed suspicious of the objectives of the survey.

The drivers voiced concerns over enforcement issues (such as hours of service, compliance to route, unscheduled stops, etc.) while the owners complained about use of the data as a source of additional regulations that may adversely impact their businesses (Battelle 1999).

6.4.3.2 Implementation Issues

State DOTs want to know how much travel is undertaken on roads under their jurisdiction, whether travel is by in-state vehicles or out-of-state vehicles. The success of the GPS method, particularly for a state like Indiana, will depend on a nationwide adoption of the program. This is because external-internal and external-external trips occur on Indiana roads. If out-of–state vehicles are not equipped with the GPS units, accurate estimation of statewide VMT will not be possible. Another concern is that GPS software and hardware installed in out-of-state vehicles might not be compatible with the system used in Indiana.

Data uploading or transmission is a critical component of the GPS procedure for VMT estimation. Wireless automated processing of data transmission will be the best, if it is readily available, consistently operational, and tamperproof. Data uploading could also be incorporated in vehicle licensing procedures if a manual data upload is required. Motorists could be required to present GPS travel information during renewal of vehicle registration.

6.4.3.3 Technological Issues

Some new model vehicles have factory installed on-board GPS units. However, the majority of vehicles on the roads do not have these units, either because the technology was not available (older model vehicles) or it was an option that car buyer did not consider to be worth the extra price. All vehicles will have to be installed with GPS units to obtain the most accurate VMT estimate. The cost of installing these units will be significant. The question would be whether to mandate their use, and who should cover the installation charges.

Certain GIS databases are known to be incomplete, or inaccurate (Wermuth et al. 2002). Lower classes of roads (local, minor collector) are usually not accurately represented in the database, because of their relatively low importance to the State DOTs. These inaccurate maps will affect the success of vehicle tracking processes on such roads, resulting in inaccurate estimates of the amount of travel or VMT. Bullock et al. (1996) addressed some of the problems associated with inaccurate GIS maps by producing base-maps from GPS data. These base-maps were matched to GIS maps to correct for deficiencies. However, applying this method at the network-level will require a lot of effort.

6.4.3.4 Operational Issues

GPS receivers require an unobstructed view of the satellites for accurately positioning the GPS receiver. The signal can be reflected or interrupted by tall buildings, dense vegetation cover, and tunnels (Roden 1996; Gallagher 1996). Problems with initially "contacting" the satellites have also been reporting in certain studies, particularly in urban areas (Gallagher 1996). This is a problem because no position data can be collected until satellites have been located. "Warm-up" periods of between 2 minutes and an hour or more have been reported.

The sheer volume of data obtained from a network-level application of the GPS procedure could be overwhelming. Each vehicle will accumulate, over a 24-hour period, 86,400 entries of data (if collected every second) that will have to be reduced to a usable format for VMT estimation. The volume of data obtained for a week for 1,000 vehicles is 604,800,000 entries. A very efficient data reduction process will have to be implemented to enable the timely estimation of VMT and other flow-related parameters.

6.5 Chapter Summary

This chapter discusses technological advancements in traffic data collection that could serve as potential sources of VMT estimation tools.

Tremendous improvements in satellite technology have led to accurate identification and classification of vehicles from satellite photographs. Two satellites have currently been launched with this capability. Remotely Piloted Vehicles (RPVs) are an alternative source of photographs for estimating VMT and other traffic flow parameters. These aerial platforms should address problems associated with spatial (region-to-region) coverage of traffic patterns, as current ground-based methods provide good temporal coverage (say, day-to-day), but poor spatial coverage.

Global Positioning Systems (GPS) facilitate accurate tracking of vehicles in real-time. Improvements in this technology have resulted in the availability of accurate positioning capabilities within reasonable costs.

Potential problems associated with these methods are also discussed.

CHAPTER 7. USER'S MANUAL FOR THE LICENSED DRIVER-BASED VMT ESTIMATION PROGRAM

7.1 Introduction

The licensed driver-based VMT estimation model would be presented in this chapter. The model has been presented in a Microsoft Excel ® spreadsheet. This chapter discusses the use of the spreadsheet program to calculate the total annual personal travel VMT. This program requires Microsoft Excel 97 or a higher version to operate. The licensed driver-based VMT estimation program is called LIC_VMT. This manual assumes users have some experience with the basic functions of the Microsoft Excel® program.

7.2 Starting the Program

Users can either run the program from the provided disk or save the program on the computer's hard drive. The program consists of the following four worksheets:

- Input and summary of VMT models
- VMT model – selected states
- VMT model – Indiana
- Summary sheet (pop)

The contents of the worksheet would be explained in later sections.

7.2.1 Worksheet 1: Input and Summary of VMT Model

This is the worksheet required to calculate VMT for the subject year. The input (subject year) and output from the program are presented in this worksheet. The only input required for calculating the annual statewide personal travel VMT is the subject year. The model has currently been programmed to calculate VMTs for the period 2000 through 2010. The program can easily be modified to calculate VMT for periods prior to 2000. The modification would be discussed later. The subject year is entered in cell 'F3' of this worksheet. The cell has been shaded grey for easy identification. The value in cell ‘F3’ is displayed in blue color.

The outputs from the program are presented in cells ‘F7’ and ‘F9’ for the 1990 and 1995 NPTS, respectively, for average annual miles per licensed driver estimates from the selected states. The corresponding outputs for average annual miles per licensed driver estimates from Indiana are presented in cells ‘F13’ and ‘F15’. The output is presented in a table called “Personal Travel VMT for Subject Year”.

7.2.2 Worksheet 2: VMT Model – Selected States

This worksheet performs the calculation of statewide annual personal travel VMT using the estimates of average annual miles per licensed driver derived from the selected states. The reason for providing this alternate source of average annual miles per licensed driver is discussed earlier in the text. Values in the cells of this worksheet are displayed either in red or blue color. All entries displayed in blue font color can be changed by the user, if required. It is not advisable to change any entry in red font color. This worksheet is also protected to prevent users from accidentally changing cell entries. Users can unprotect the worksheet by selecting “*Tools*” from the menu toolbar and clicking on “*Protection*” then “*Unprotect sheet*”. It is advisable to protect the worksheet after making any changes to the cell entries.

Rows 3 through 12 of this worksheet contain information on the population and the number of licensed drivers in the state. The information displayed in these rows is copied from the worksheet named ‘Summary sheet (pop)’ for the subject year. The percentage of eligible population licensed to operate motor vehicles is entered in cell ‘F8’ (in blue font color). This entry can be changed to assess the impact of the number of licensed drivers in the state to the resulting VMT.

Rows 16 through 35 present information on the number of licensed drivers by sex and age cohort. The number of licensed drivers can either be estimated from the default percent distributions by age and sex and the estimate of the eligible population licensed to operate vehicles. However, if the number of licensed drivers by sex and age cohort is known, the values can be entered into the appropriate cells.

Rows 38 through 57 contain information on the average annual miles driven per licensed driver by sex and age cohort. The total annual VMT generated by each age cohort for male and female licensed drivers is also calculated. The data are available for the 1990 and 1995 NPTS, respectively. The total annual VMT calculated from the 1990 and 1995 NPTS are shown in cells 'G57' and 'P57', respectively. These values are automatically copied to cells 'F7' and 'F9' of worksheet 1: "Input and Summary of VMT Models".

Rows 60 through 72 contain the adjustment factors for the calculated VMTs. The adjustment factors are calculated from growth factors derived from the 1990 and 1995 NPTS.

7.2.3 Worksheet 3: VMT Model - Indiana

The cell entries and information presented in this worksheet is similar to the previous worksheet -- Worksheet 2: VMT Model – selected states. It is advisable that any changes made to cells in Worksheet 2 should also be made to the corresponding cells in Worksheet 3. This worksheet is also protected to prevent users from accidentally changing the cell entries.

7.2.4 Worksheet 4: Summary Sheet (Pop)

This worksheet contains population estimates for the period 1990 through 2025. The proportion of the population eligible to operate vehicles is also presented in this worksheet. The eligible population represents all persons aged 16 years and older. The eligible population is distributed by sex and age for each year. This information is automatically copied to the appropriate years when the subject year is entered in cell 'F3' of worksheet 1. This worksheet is also protected. It is not advisable to change any entry in this worksheet.

7.3 Chapter Summary

This chapter discusses the operation of the licensed driver-based VMT estimation program. The VMT estimation model has been programmed into a Microsoft Excel® spreadsheet.

CHAPTER 8 CONCLUSIONS

8.1 Introduction

The study was undertaken to assist INDOT in generating an independent source of statewide VMT estimates. Because the local and minor road functional classes are not under INDOT's jurisdiction, traffic volumes on these roads have not been routinely counted, even though they represent extensive road mileage in the state. Estimates of vehicular travel on the lower functional classes usually reported to *Highway Statistics* are more of speculation than fact.

The HPMS requires state DOTs to report traffic data on all existing public roads within a 3-year cycle. Indiana currently has 4,373 universe sections and INDOT is not able to collect data on all universe sample sections within the stipulated 3-year period because of limited resources. Emphasis on environmental issues (air quality) has prompted a shift in the focus of highway performance monitoring from highway pavement management to the monitoring of highway travel. The EPA demands the use of the HPMS in the estimation of travel for evaluating air-quality compliance. Local and minor roads carry a majority of the 'cold start' vehicle trips that contribute immensely to air pollution. However, the HPMS does not propose any method or technique for data collection on these functional classes of roads. The state DOTs are, therefore, not comfortable with travel estimates reported on statewide roads. This study adopts non-traffic count-based methods for estimating statewide VMT. Two models are developed in this study for the estimation and forecasting of statewide VMT.

Statewide estimates of VMT produced from this study are intended to provide independent estimates of VMT as statewide control totals for planning purposes.

8.2 Overview of VMT Models Developed in this Study

The first model is based on average annual miles driven per licensed driver by sex and age cohort. Estimates of average annual miles per licensed driver were obtained from the 1990 and 1995 NPTS surveys. The total VMT, by age group, is obtained by multiplying the numbers of licensed drivers within each age group by the average annual miles driven by licensed drivers in that age group. The total statewide is then obtained by summing VMT estimates over all age groups.

The second model is based on average annual miles driven per household by area type and each of the following demographic characteristics: *household income*, *household size*, and *household vehicle count*. The estimates of average annual household VMT are obtained from odometer-based VMT estimates in the 1995 NPTS. The number of households within each group of area type and demographic characteristic is multiplied by the corresponding average annual household VMT to obtain the total statewide VMT. The area types –rural, light urban, and dense urban – are based on census tract population densities. Census tracts were selected as the primary area type definition because travel and demographic characteristics within a census tract are expected to be fairly consistent.

The NPTS is a survey of the civilian population of the United States to present trends in personal travel. Because the NPTS is a personal travel survey, commercial vehicle activity cannot be observed from the survey data. However, commercial vehicle activity is very crucial for a centrally-located state like Indiana. Truck-specific surveys, like the VIUS and CFS, could also not be used for estimating truck VMT on Indiana roads because the surveys were not developed to estimate such parameters at the statewide level. The International Fuel Tax Agreement (IFTA) is an agreement between 58 jurisdictions to facilitate the administration and collection of fuel taxes from interstate travel. The Motor Carrier Fuel Tax (MCFT) is a fuel tax imposed on commercial vehicles registered for intrastate travel -- only on Indiana public roads. IFTA and MCFT require the carriers to report the total annual miles traveled by all qualified vehicles for tax estimation purposes. Certain vehicles are exempt for the fuel tax programs, which would lower the total vehicle-miles calculated from the fuel tax records. Drivers are required to record the details of every trip, including the total mileage traveled in each jurisdiction. The licensees are required to file quarterly tax returns with their base jurisdiction, for each vehicle licensed under the IFTA and MCFT tax programs. The mileage data are reported for tax estimation purposes. The sum of all miles traveled by all vehicles from all jurisdictions on Indiana public roads represents the commercial vehicle VMT. The Indiana Department of Revenue is the administrative agency for the Indiana base jurisdiction.

8.3 Summary of Study Findings

VMT estimates obtained from the models primarily comprises of personal travel VMT. The VMT calculated for the year 2000 were compared to the component of the total Indiana VMT attributed to automobiles and light trucks in *Highway Statistics 2000.* The licensed driver-based model produces four VMT estimates because of the datasets adopted in this study. Differences between the VMTs calculated for the year 2000 from the licensed driver-based model and *Highway Statistics 2000* ranged between 10 and 13 percent when 85% of the eligible population is licensed to operate vehicles. The corresponding percentage difference between the two data sources reduces to between 5 and 10 percent when 90% of the eligible population is licensed to operate vehicles. The licensed driver data obtained from the Indiana BMV and also form the *Highway Statistics* series contained certain discrepancies, which created uncertainty in the estimated number of licensed drivers per capita. The number of licensed drivers per capita can thus be modified in the model to assess its impact on the calculated VMT. The licensed driver-based model produced results that were consistently lower than *Highway Statistics 2000.* The licensed driver-based VMT estimation method is transferable to other states and regions, however, the average annual miles driven per licensed driver would have to be estimated from data pertaining to that region.

One of the objectives of this study was to determine growth rates between average annual miles driven per licensed driver from 1990 through 1995. The growth rates were intended to facilitate the adjustment of average annual miles driven per licensed driver required to forecast VMT. Because there was no clear trend in the growth rates within each age group, the average 5-year growth rate across all age groups was used to adjust average annual mileage estimates per licensed driver. Female licensed drivers increased their average annual mileage estimates by 1.66% over the 5-year period. The corresponding 5-year growth rate for males was 0.5%.

The definitions of census tract area type required for the household-based model are presented. The area type definitions for the household VMT model are as follows:

- Rural census tracts have an upper boundary of 1,185 persons per square,
- Light urban census tracts have a population density of between 1,185 and 3,000 persons per square mile, and
- Dense urban census tracts have a population density of greater than 3,000 persons per square mile.

The household-based model was used to estimate statewide VMT for the state of Indiana. The U. S. Census Bureau released data on the population of households by size at the census tract level on April 17, 2002. The household VMT calculated from the household-based VMT model was lower than the *Highway Statistics 2000* estimate by about 26 percent. The relatively large difference between the two data sources can be attributed to the exclusion of non-household vehicles, such as taxis, rental vehicles, and company vehicles from the calculation of personal travel VMT.

The 2001 NHTS, which is a combination of the NPTS and ATS, is currently being conducted. The survey data should be available by May 2003. The NHTS 2001 data should afford the opportunity to improve on or update the models that have been developed in this study. Average annual mileage per licensed driver and average annual household VMT estimates obtained from the 2001 NHTS can be compared to the 1995 and 1990 NPTS estimates to determine any change in travel patterns. The models developed in this study would have to be updated to account for commercial vehicles when reliable truck-specific data are available.

The fuel tax-based commercial vehicle VMT represents the total annual statewide VMT for all buses and trucks. The exemption of certain vehicles from the tax programs results in a lower bound of the total amount of travel accumulated by these vehicle classes. The total VMTs accumulated by all IFTA and MCFT licensed vehicles were 13.8 and 13.0 billion vehicle-miles for the years 1999 and 2000, respectively. The fuel-tax-based VMT for the year 2000 was 12.4 billion vehicle miles. The fuel tax-based commercial vehicle VMT was 45 percent higher than the INDOT ground count-based VMT in 1999 and higher by 36 percent in 2000. The high percentage difference between the fuel tax-based VMT and the ground count-based VMTs warrants a reevaluation of INDOT's ground count program.

Remote sensing and other advanced technological systems are increasingly being adopted as traffic data collection media. High-resolution satellite systems are currently available with which vehicles can be identified and classified. Unmanned aerial vehicles are also being utilized in military surveillance applications due to their versatility.

Global Positioning Systems (GPS) are a versatile tool for travel data collection. Privacy issues and other institutional, operational, technological, and implementation limitations have prevented its utilization as a travel data source from which VMT can be estimated.

8.4 Problems Encountered in the Study

The model was developed with secondary data from the NPTS survey. The estimates of average annual miles per licensed driver are generated from self-reported mileage estimates. The reliability of such estimates is questionable. The NPTS was developed to establish trends in nationwide personal travel and does not adequately represent commercial vehicle activity. The NPTS data does not facilitate the calculation of VMT by highway functional class as required by the various legislation. The fuel tax-based mileage records are also not reported by highway functional class, therefore, the calculated VMT is also not distributed by functional class.

The number of licensed drivers reported in the *Highway Statistics* series is distributed by sex and age cohorts, however, data obtained directly from the reporting source -- Indiana Bureau of Motor Vehicles (BMV) -- was not distributed. It was not possible to obtain an explanation for this anomaly from either the BMV or the FHWA. The distribution of registered licensed drivers in the state is required for the estimation of

VMT for tracking purposes. Results obtained from the tracking model would thus have to be treated with caution.

Potential problems with the use of satellite systems as traffic data collection media may delay their inclusion into statewide traffic data collection programs. The low revisit frequency of the satellite system will delay any traffic data collection effort. The use of a data clearinghouse may reduce the wait time if consumers will not have to deal directly with individual vendors.

The accuracy of traffic data reported in *Highway Statistics* is questionable. It is not possible to determine if the HPMS produces higher or lower travel estimates than actual exists. This presents a problem when a model is being validated.

8.5 Conclusions

This study was conducted for the Indiana Department of Transportation (INDOT) to provide alternative statewide VMT estimation methods. The methods adopted in this study are based on driving characteristics of licensed drivers and households in Indiana for the estimation of total annual personal travel VMT. The annual VMT generated by buses and trucks, which represents commercial vehicles, is estimated from fuel tax records.

The licensed driver-based VMT estimation model is programmed into a Microsoft Excel® spreadsheet for easy implementation. The statewide personal travel VMTs calculated for the year 2000, were lower than INDOT's estimates by about 5 percent -- when 90 percent of the eligible population is licensed to operate motor vehicles -- and lower by 10 percent -- when 85 percent of the eligible population is licensed to operate vehicles. The statewide personal travel VMT calculated from the household-based model was lower the INDOT estimate by 26 percent because of the exclusion of non-household vehicles. The commercial vehicle VMT exceeded INDOT's estimate for the year 2000 by 36 percent.

The total miles driven by out-of-state drivers on Indiana roads was assumed study, to be equal to the total miles driven by Indiana drivers on out-of-state roads.

Because of the high amount of through traffic on Indiana roads, this assumption may probably result in a lower bound of the licensed driver-based personal travel VMT. To account for the potential shortfall, it is recommended that the 90 percent of the eligible population be adopted as the percentage of the eligible population licensed to operate motor vehicles in Indiana.

Because of the exclusion of non-household vehicles from the household-based method, the licensed driver-based VMT estimation method is recommended for the calculation of total annual personal travel VMT. The total statewide VMT obtained from this study is about 0.3 percent higher than INDOT's estimate for the year 2000. Because of the low difference between the VMT estimates obtained by INDOT and this study, there is no reason to revise INDOT's current method of VMT estimation, however, the negative impact of trucks on the highway pavement and the environment may require a review of the vehicle classification program to better estimate the volume of trucks on Indiana public roads.

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APPENDIX

TABLE A-1 Tippecanoe County Area Type Definitions

2000 population of the area covered by the record	Land area (sq. mi)	Population density - (persons/mi)	2000 census tract base	City	Area Type
6,825	0.29	23,228.21	104		Dense urban
6,302	0.53	11,948.83	54	West Lafayette	Dense urban
2,371	0.20	11,924.00	105		Dense urban
4,832	0.52	9,325.50	55	West Lafayette	Dense urban
3,869	0.51	7,523.02	103		Dense urban
3,125	0.44	7,156.24	53	West Lafayette	Dense urban
4,576	0.65	7,004.60	4	Lafayette	Dense urban
1,864	0.31	5,982.33	2	Lafayette	Dense urban
3,253	0.56	5,858.99	11	Lafayette	Dense urban
3,520	0.62	5,683.76	14	Lafayette	Dense urban
3,276	0.74	4,398.55	7	Lafayette	Dense urban
3,205	0.75	4,252.52	12	Lafayette	Dense urban
3,234	0.77	4,190.11	3	Lafayette	Dense urban
561	0.14	4,139.55	6	Lafayette	Dense urban
1,535	0.39	3,983.60	10	Lafayette	Dense urban
4,821	1.26	3,824.30	13	Lafayette	Dense urban
5,266	1.62	3,242.72	15.02	Lafayette	Dense urban
7,957	2.51	3,175.43	51	West Lafayette	Dense urban
3,436	1.16	2,969.37	9	Lafayette	Light urban
4,524	1.60	2,830.22	52	West Lafayette	Light urban
1,939	0.78	2,489.83	8	Lafayette	Light urban
4,018	2.23	1,802.63	19	Lafayette	Light urban
5,457	3.11	1,752.24	17	Lafayette	Light urban
3,673	2.17	1,695.42	15.01		Light urban
3,829	2.42	1,579.65	18	Lafayette	Light urban
2,104	1.39	1,514.12	1	Lafayette	Light urban
6,487	5.88	1,102.37	16	Lafayette	Rural
5,977	7.19	831.07	102.04	West Lafayette	Rural
4,450	11.67	381.20	108	Lafayette	Rural
3,626	12.71	285.20	102.03		Rural
5,322	36.10	147.42	109.01		Rural
5,490	54.89	100.02	101	Battleground	Rural
3,016	36.32	83.03	109.02	Dayton	Rural
4,703	71.22	66.03	102.01	Otterbein	Rural
1,568	24.91	62.96	107	Lafayette	Rural
5,150	85.83	60.00	106	Shadeland	Rural
3,794	125.38	30.26	110	Clarks Hill	Rural