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Travel Characteristics of Urban Freight Vehicles and their Effects on Air Quality

Annie Protopapas
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Annie Protopapas entitled "Travel Characteristics of Urban Freight Vehicles and their Effects on Air Quality." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Dr. Arun Chatterjee, Major Professor

We have read this dissertation and recommend its acceptance:

Dr. Terry Miller, Dr. Stephen Richards, Dr. Shih-Lung Shaw

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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

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Accepted for the Council:

Anne Mayhew
Vice Chancellor and Dean of
Graduate Studies

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

TRAVEL CHARACTERISTICS OF URBAN FREIGHT VEHICLES

AND THEIR EFFECTS ON AIR QUALITY

A Dissertation
Presented for the
Doctor of Philosophy Degree
The University of Tennessee, Knoxville

Annie Protopapas
August 2004

DEDICATION

This dissertation is dedicated to my parents, Andreas and Mary Protopapas, for their continuous support and advice in this endeavor. They always strived to provide me with well-rounded education of the best quality and impelled me to rise to my highest academic and human potential.

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ABSTRACT

This research study collected local commercial vehicle data in Knox County, Tennessee from the United States Postal Service and two companies engaged in package pickup and delivery. A second urban commercial vehicle dataset from a wider spectrum of companies in North Carolina was also obtained for comparative analysis. The two datasets are analyzed in a similar manner to develop and compare travel characteristics/parameters commonly used in transportation engineering, such as Daily VMT, Daily Number of Trips, Vehicle Speed, Trip Length, Trip Travel Time and Stop Duration. Statistical tests demonstrate the similarities between certain vehicle classes from the two datasets and four aggregated Vehicle Usage Classes are formed. A second type of analysis is also conducted to develop two sets of input parameters for use in place of the default values in EPA's MOBILE6 model, which estimates mobile source emissions. Two basic runs use all the developed inputs together and model the commercial vehicle datasets in their entirety. Four additional runs model each Vehicle Usage Class individually through the use of the average speed and starts per day specific to each class. Changes in the resulting emission factors in relation to the default run are discussed and the reasons are determined.

The study concludes that vehicles of different industries can show similarities in travel characteristics, independent of vehicle size and type, depending on the way they are used. Commercial vehicles show higher Annual Mileage Accumulation Rates than the default values, hence showing higher levels and longer terms of usage. Also their VMT and Engine Start distributions by Hour of Day are very different from the default curves, occurring primarily within the two daily peak traffic periods (am and pm). The study finds higher VOC, CO and NOx compared to the default run for USPS vehicles mainly due to their much lower than default average speed. Also higher VOC and CO are found for both gas and diesel Package PUD vehicles due to lower than default average speed (CO for gas and both VOC and CO for diesels) and higher than default starts per day (VOC for gas vehicles).

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Chapter 1

INTRODUCTION

The study of the operation of commercial vehicles in urban areas is a largely ignored topic, and detailed data are generally not available. This research develops and presents information on this subject, hoping to make a meaningful contribution to this subject area.

Commercial vehicles operating within an urban area can be classified into three categories. The first category deals with the movement of people, e.g. taxis and rental cars. The second category deals with the movement of goods, e.g. mail delivery, warehouse delivery, parcel pickup and delivery (PUD) etc. The third category deals with services, e.g. plumbing and machine maintenance. Vehicles used for public service such as transit buses and social service vehicles belong to a separate group, which are not purely commercial.

This research study is related to the second category, the movement of goods within an urban area and focuses on a specific subset of this category. Freight delivery vehicles operating within an urban area, for internal distribution of freight, primarily consist of single unit (SU) trucks and vans. A higher number of trips per vehicle has traditionally been thought to describe their intra-urban operation as compared to inter-urban freight vehicles, namely tractor-trailers. Thus, smaller freight vehicles engaged in pick-up and delivery (PUD) operations are assumed to have a much larger number of starts and stops per vehicle. In addition, their daily operations are characterized by less vehicle miles traveled, (VMT) per day, as compared to inter-urban freight vehicles. This group of SU trucks and vans provides a variety of services – food delivery, construction material delivery, household furniture and appliance delivery, small package pickup and delivery, etc. The focus of this research is the intra-urban SU trucks and vans providing small package and mail pickup or delivery services.

The number of truck trips within urban areas tends to grow with the growth of commercial activities. With the growth of internet use and catalog sales market this trend is likely to increase leading to more smaller, high value package deliveries. This type of service is provided by a few large companies such as United Parcel Service (UPS), Federal Express (FedEx), and the United States Postal Service (USPS).

Transportation officials know little about the volume and pattern of trips made by the PUD vehicles of these major companies and the USPS, or their impacts on air quality and local traffic operations. Further, without this information little can be done to accommodate the needs of these vehicles and minimize adverse environmental impacts.

Package PUD Activity Growth

The US experienced a tremendous growth in its Gross Domestic Product in the last 10 years or so. The GDP attributed to the Trucking and Warehousing industry had a parallel growth from 1994 to 1997, but from 1997 to 2001 its growth surpassed that of the US GDP. Although the package PUD sector is a subset of the Trucking and Warehousing industry, this may be a good indicator of how intertwined the US economy is with the movement of goods. Even at periods when the economy is sluggish, inventory reduction practices, mainly in the retail and manufacturing sectors, necessitate the timely transport of the required goods. This fact leads to higher numbers of pickups and deliveries and to higher truck VMT.

The latest Vehicle Inventory and Use Survey (1997) contains some VMT data pertaining to commercial trucks. Under the body type truck classification, there is a class termed 'Multistop or Stepvan'. These are the typical types of trucks used by package PUD companies. The annual percent growth in the average annual VMT per truck for all commercial trucks and for multistops/stepvans are shown in Appendix B, Figure 1 along with the annual percent growth of the US GDP and the Trucking and Warehousing GDP. Although the growth in the average annual VMT of both total trucks and multistops/stepvans is less steep than that of the US GDP, the VMT is shown to grow as the GDP grows.

The United States Postal Service is one of the key players in the package PUD business. It experienced a 14% growth in Total Domestic Mail Revenue from 1998 to 2003, with only a 3% growth in Total Domestic Mail Pieces in the same period (Figure 2). The number of Express Pieces fell by 16% whereas the respective Revenue grew by 4%. The number of Package Pieces grew by 10% in the same period, while the respective Revenue grew by 26% (Figure 3). These numbers may be attributed to the increase in competition by corporate PUD companies, which forced the USPS to take initiatives to reduce operating costs and increase efficiency.

The two major players in the corporate package PUD sector are United Parcel Service (UPS) and Federal Express (FedEx). Their growth in recent years both in volume and revenue has been much more dramatic than the USPS, and resembles closely the booming economy of the late 1990s. Between 1995 and 2002 UPS experienced a 9% growth in Delivery Volume and a 49% growth in Total Revenue (Figure 4).

Figure 5 demonstrates recent trends for Federal Express. Total Revenue grew by 77% from 1996 to 2003, an average of 11% per year. The Number of Packages grew by 158% between 1990 and 2000, an average of 16% per year. Between 1993 and 2000, Total Domestic Shipments grew by 132%, an average of about 19% per year. The High Tech portion grew by 232% and the Non High Tech portion grew by 128%.

Research Objectives and Scope

The first objective of this research is to quantify the overall operational characteristics and trip making patterns of certain types of urban freight vehicles, focusing on vehicles used for small package and mail pickup and delivery.
The second objective of this research is the development of input values based on the commercial vehicle and trip data and their comparison with the default input values of the Environmental Protection Agency's MOBILE6 Model.
The third objective of this research deals with the analysis and comparison of the similarities or differences in the emission factors resulting from the default run and those resulting from the use of the inputs developed from the two local commercial vehicle datasets, the North Carolina and the Knox County.

Objective 1

Although intra-urban freight vehicles comprise a large part of an urban area's road traffic, there exists a general lack of knowledge of their operational characteristics and trip making patterns. Whereas individual companies are in possession of data for their own operations, the research community, in general, does not have easy access to these data because of their 'proprietary' nature. This research involved a considerable effort for the collection of data for the freight vehicles of a few major companies in the Knoxville, Tennessee metropolitan area. Detailed information was obtained on the operations of the United States Postal Service as well as two major companies in the small package PUD sector. A complete picture of their operations focusing on the internal PUD portion is developed. The data collection enables the analysis for the vehicle and trip characteristics of these types of intra-urban freight vehicles to take place. The analysis develops average values, standard deviations and frequency distributions of various trip making parameters such as:

- Daily VMT per vehicle
- Daily Number of Trips per vehicle
- Daily Speed per vehicle
- Trip Length (VMT) per vehicle
- Trip Travel Time per vehicle
- Stop Duration per trip per vehicle
- Daily Number of Engine Starts per vehicle

In addition to analyzing the operation of these commercial vehicles in Knox County, the operational characteristics and trip making patterns of a sample of commercial vehicles in the Piedmont-Triad area of North Carolina, is also analyzed. The North Carolina data include a variety of freight vehicles. The development of similar trip making parameters for this second set of data permits a comparison of the results from the two analyses in order to help identify the similarities or differences in travel characteristics between different types of urban commercial vehicles, which is a subject area in which the research community in general has little knowledge. This research hopes to provide valuable information on the possible variations or common traits.

Objective 2

The MOBILE6 model estimates mobile source emissions. EPA used national fleet data, which include private and commercial vehicles, in order to develop the various input parameters required to estimate emission factors of atmospheric pollutants such as Carbon Monoxide, Nitrogen Oxides and Hydrocarbons in the geographic area of interest. The model provides these input parameters as 'default values' but the EPA suggests using locally collected data as much as possible in air quality analyses. Unfortunately, these data are generally not available. This research collected local commercial vehicle and trip data for use with the MOBILE6 model and offers insight in regard to the accuracy of the existing 'default' input values towards urban commercial vehicles.

The collected fleet data on freight vehicles of a few major companies in the Knoxville metropolitan area are used to develop a first set of input parameters. The model requires a variety of input parameters for a number of vehicle classes, pre-classified according to Vehicle Gross Weight, Fuel and Age. The freight vehicle types selected for this study tend to populate several of these vehicle classes. This research estimates values for the following MOBILE6 input parameters:

- Annual Mileage Accumulation Rates
- Vehicle Miles Traveled Fraction by Hour of the Day (weekdays)
- Vehicle Miles Traveled Fraction by Average Speed (on all roadway types combined)
- Vehicle Engine Starts Per Day (weekdays)
- Vehicle Engine Starts by Hour of the Day (weekdays)
- Vehicle Soak Time between Engine Starts (weekdays)
- Vehicle Trip Length (Duration) Distribution (weekdays)

The data collected are used to develop the input parameters for the vehicle classes, in order to analyze these commercial vehicles' specific effects on mobile source emissions. The development of specific MOBILE6 input parameters based on data of intra-urban commercial vehicles enables comparison with the default values, which are based on private and commercial vehicle data combined.

Input values for MOBILE6 are also developed based on the second dataset of locally collected freight vehicle fleet data in the Piedmont-Triad area in North Carolina. The similarities or differences in the MOBILE6 input parameter values among the default values supplied by the model, and the two local cases, the Knox County and North Carolina are investigated.

The development of two sets of M6 input parameters from two local commercial vehicle fleets enhances the knowledge of the research community in regard to differences or similarities between various types of commercial vehicles, as well as between local commercial vehicle fleets and the national (private and commercial) vehicle fleet represented in MOBILE6.

Objective 3

The MOBILE6 model reports the results as emission factors for the key atmospheric pollutants (HC, CO, and NOx) in grams of pollutant per vehicle mile traveled (VMT). Several runs of the MOBILE6 model are conducted, each run showing the changes in the emission factors in relation to the initial run which uses the default input parameters. The runs model the North Carolina and Knox County commercial vehicles in their entirety, as well as the vehicle classes individually. Examination of the changes in the emission factors resulting from the runs, leads to a closer look at their sensitivity towards the various input parameters of the various types of urban commercial vehicles.
The specific effects of urban commercial vehicles on air quality have been generally overlooked by the research community. This research hopes to contribute to current knowledge on this topic.

Chapter 2

REVIEW OF LITERATURE

Recent research efforts have been consulted and are presented in this chapter, organized into 3 general topics. The first literature review topic relates to studies or surveys focusing on commercial vehicles and their travel characteristics. The second literature review topic relates to Air Quality studies focusing on mobile sources. The third literature review topic exclusively describes the MOBILE6 model as it relates to this study.

Freight Vehicle Characteristics

The paper by Lau (1995) presents the literature on conducting truck travel surveys in the U.S. and abroad. It includes past experiences and current practices on truck surveys and truck travel demand forecasting to evaluate the need for new truck/freight planning tools. Metropolitan planning organizations can use truck travel data for truck travel model development, corridor/route analysis, air quality modeling, intermodal freight planning, pavement management, truck restrictions and enforcement and facilitation of public-private partnerships. Truck surveys and truck travel demand forecasting has occurred in relatively few urban areas in the country. In the last ten years they have been undertaken only in Chicago, Ontario, Vancouver, Phoenix, Alameda County, California, New York-New Jersey, El Paso and Houston-Galveston. In all of these studies, origin-destination data were collected with the exception of the New York-New Jersey study, which used trip diaries that collected land use at destination and truck odometer readings. Most classified trucks by weight, number of axles or truck type; the El Paso survey is the only one that collected route choice information. The most common uses of truck data have been for regional truck travel model development and corridor/route analysis. The most common survey method was the combined telephone-mailout-mailback method, which has been proven to be the most cost effective with a reasonably high response rate. The second most common survey method was roadside interviews; they produce very high response rates with complete information and are ideal for cordon and internal-external travel surveys. The most common source for drawing the survey sample is the Department of Motor Vehicles registration files. Commercial Vehicle Trips have been found to have the following characteristics:

- Average Trips per Commercial Vehicle: light trucks have a higher average trip frequency than heavy trucks
- Regional vs. Through Trips: most trucks trips serve local needs, with the few through trips made by heavy trucks
- Average Trip Length and Vehicle Miles Traveled: heavy trucks make longer trips than lighter trucks and log a higher VMT per day

- Time of first Commercial Vehicle Trip: most occur early in the morning (6-9 a.m.) but light trucks are most likely to start between 6 and 9 a.m. with heavy trucks starting before 6 a.m.
- Time-of-Day Distribution: most commercial vehicle trips occur midday between 9 a.m. and 3 p.m., with through truck traffic avoiding peak periods and traveling at night
- Truck Travel During Peak Periods: vary by urban area and location
- Truck Travel During Peak Periods as Percent of Total Vehicular Volume: has been found to range from 9 to 17 percent of the total volume at peak periods
- Day-of-Week Distribution: truck traffic occurs on weekdays mostly, decreasing on weekends
- Average Trip Duration: trip time increases with vehicle weight
- Truck Travel by Facility Type: few surveys have documented this factor; the Alameda County study found that most of the daily truck trips are local trips that never access a freeway
- Route Choice for Return Trips: the only survey to document this was in New York-New Jersey and found that 75% of truck drivers use the same route for the return trip
- On-Street Stops: The Phoenix survey was the only one to report the number of commercial vehicle on-street stops, which was about one- third of all stops.
- Trips by Land Use: light trucks make more residential trips; light/medium truck trips are attracted to retail; heavy trucks are attracted to terminal/warehouse land uses
- Activities at Trip Ends: light trucks are mostly used for service delivery whereas heavy trucks are most used for loading/unloading cargo.

Lau's recommendations for conducting a truck travel survey include the following:

- For internal-internal or internal-external truck trips, draw the sample from the DMV registration files and conduct either a telephone or mailout-mailback survey or a combination of both to yield a higher response rate
- For obtaining trip diaries, a combination of fleet-employer samples and truck unit samples should be used. Sub-sampling fleet employers provides better sample control and reduces large fleet oversampling
- Use a larger sample of small or individual truck operators, since it has been shown that they tend to yield lower response rates than large fleet operators
- Soliciting the help of private freight/trucking agencies will facilitate cooperation and assistance with the design of the survey

The author's recommendations for truck travel analysis include the following:

- Examine time-of-day (24 hour), day-of-week and seasonal variations in truck travel
- Analyze trips by facility types used (include question in survey, for each trip)
- The origins and destinations of internal-internal trips should be geocoded to the transportation analysis zones (TAZs) rather than the city or zip code level; this improves the accuracy of truck trip generation models based on zonal socioeconomic attributes.

This paper provided a complete picture of the up to date commercial vehicle surveys undertaken. The overview, comparisons and recommendations are helpful in determining an efficient data collection strategy for the purposes of this research as well as providing insight into key parameters of freight vehicle characteristics developed from past experience in freight vehicle studies and surveys.

The study by Niles (2003) recommends that the Regional Freight Logistics Profile (RFLP) take place due to the exclusion of urban freight transport (primarily by trucks) in Regional Transportation Plans. Basic data such as the fraction of trucks in the daily traffic streams, truck movement data and origin and destination data are not available. The impediments to freight mobility are seldom examined, nor are air pollution from truck diesel engines or accidents caused by trucks. Studies in the San Francisco Bay Area and the Puget Sound Region indicate that most truck trips are intra-urban, or local. This study looks at package service companies, e.g. Federal Express and UPS, and retail delivery trucks e.g. Frito-Lay. The variety of goods demanded by consumers has increased in the last 15 years; express package delivery (especially to housing units) has experienced a higher rate of growth. This express service has lead to the dispatch of more trucks carrying only partial loads instead of waiting for enough cargo to fill a truck, resulting in more trucks on the road. The trucking industry's problems include roadways with truck restrictions, meeting delivery windows, and lack of loading/unloading facilities. Truck movement in urban areas generally avoids peak commuting hours but it can both be hindered by and generate traffic congestion. Traffic congestion can delay a truck trip thus missing the delivery window, whereas inadequate curbside loading zones may force loading and unloading from a street lane, causing traffic congestion. It is proposed that the RFLP for a metropolitan area include the following:

- Regional infrastructure supporting trucks: (a) map of truck routes; (b) table showing travel time averages on major truck routes; (c) table and map showing segments and intersections with frequent traffic congestion involving trucks; (d) table and maps of locations where the road design constrains truck movement or causes accidents resulting in congestion; (e) displays of truck involvement in non-recurrent congestion caused by road work, accidents, special events; (f) table and map showing posted truck restrictions; (g) tables and map showing planned infrastructure improvements.
- Number and proportion of trucks: (a) table showing the universe of urban truck trips (distinguish between intra-urban, entering/leaving and passing through trips); (b) table showing all truck types by size and cargo type (from vehicle registration data); (c) table further classifying these as passing through, outbound, inbound, drayage and local delivery tours; (d) weekday hourly profile of major segments with vehicle counts of cars, buses, or trucks by size (e) regional intra-urban fleet census of truck companies; a map of their base locations/origins of truck tours.
- Major truck origins and destinations: (a) map showing residential, commercial (retail and office), industrial zones, distribution centers, warehouses, truck depots, sports arenas, refuse stations, construction sites, and intermodal terminals all showing daily truck attractions and productions levels (b) case studies of truck movements at sample of pickup/delivery points (c) map of delivery locations consistently demonstrating truck loading or access practices that contribute to arterial congestion.

- Urban delivery patterns: (a) case studies of operating cycles of leading regional fleets e.g. UPS, FedEx, Frito-Lay; can provide an indicator fleet that can be updated annually.
- Safety: (a) truck accident rates compared with auto-only accident rates, with trends over time (b) map of truck accident hot spots to help identify infrastructure deficiencies (c) description of major blocking accidents involving trucks.
- Other environmental impacts: (a) table/map of diesel truck air emissions (b) table of truck noise complaints (c) truck breakdown statistics on major routes.
- Public policy issues: problems in urban trucking that can be addressed by public spending or regulation: (a) growing traffic congestion or truck accidents (b) public outcry (c) key business persons

It is recommended that consistent time series with annual data sets be established to make comparisons and illustrate trends. Iterative incrementalism can be an option i.e. starting out with the data available and expanding in depth and geographical coverage over time. It is suggested that the RFLP be incorporated into MPO Transportation Planning.

The above study recognizes two key urban freight vehicle-trip categories, package and retail delivery. They have flourished in recent years, especially to residential destinations, commanding the investigation of their operations. This research will examine the same types of freight vehicles: package service companies (UPS, FedEx) and retail delivery (Frito-Lay).

Taylor et al. (1998) document the (still ongoing) Freight Activity & Commercial Travel Survey (FACTS) that took place in the Melbourne metropolitan area. Information on vehicle location, timing and speed was collected using a Global Positioning System (GPS) receiver. The tracking data was linked to a GIS system for geographical viewing of the vehicles moving on the road network and mapping of the vehicle location data points overlaying on the network. The GPS receiver was linked to a palmtop computer (with a touchscreen) in the vehicle cabin, which the drivers used to enter the trip information. GPS location data were recorded every 2 seconds in longitudes and latitudes, which were transformed into a sequential list of roads to make a travel route. The GPS system with differential correction claims accuracy within 5 meters.

The Australian experience provides insight into state of the art trip data collection, which can improve accuracy in trip data collection.

Lawson and Riis (2001) document The Oregon DOT's contract with Portland State University to conduct a survey of shippers and motor carriers to gather perceptual information on transportation problems in the state, particularly on the highway system. A series of pilot tests were designed to determine the best performing instrument and survey method and test the hypothesis that there is no difference in response rates across different survey methods. The hypothesis was tested using a sample of 550 firms, separated into 6 groups, each group receiving a different treatment. The first group received a packet containing an introductory letter, a sample survey page, a survey questionnaire, a business reply envelope and e-mail instructions. The second group received the same materials and a map of Oregon's transportation system to reference locations. The third group received an initial postcard asking for participation, followed by the survey questionnaire to the positive respondents. The fourth group received the initial postcard, followed by the questionnaire and also the map. The fifth group was contacted by telephone to obtain permission to send the questionnaire with the map. The sixth group was contacted and surveyed by telephone to obtain perceptions on infrastructure problems. A random sample of firms was obtained from the Oregon Employment Department database and was stratified to understand the responsiveness of the freight companies to the different deployment strategies. The results show the number of completed surveys using the third and fourth approaches to be too low. The sixth survey approach had a 35% completed rate indicating that using the telephone to gather data is acceptable, but its overall completion rate was no better than the others due to the unreliable sampling frame (e.g. no listed phone number). Small, metro carriers were the most responsive (53%). The options of using the website or e-mail were found not to be of interest to the participants.

The Oregon report provided an overview of the various methods available to solicit participation of private companies in commercial vehicle research projects. The response rate of each method was useful in arriving upon an efficient freight vehicle data collection strategy for the proposed research.

A recent report by Cambridge Systematics, Inc. (2003) assesses the recent literature relevant to the treatment of commercial vehicles in urban transportation models. This is the first of three tasks of the first of two phases of an ongoing FHWA research project. The study focuses on intra urban trips, as is the focus of this research, and points out that much of the current literature is focused instead on inter urban commercial trips. It deals with various commercial vehicles, categorized by type (e.g. package and mail delivery), purpose (e.g. movement of goods) and service type (fixed route or on-demand service). Current practice uses three types of models for commercial freight vehicles:

- Vehicle-based models, where truck trip generation rates used in travel demand models are estimated based on land-use and employment by industry.
- Commodity-based models where truck trips generation rates are not developed; instead annual commodity tonnage data are converted into daily truck trips using a payload conversion factor. These models tend to underestimate trips in urban areas because they do not account for trip chaining and local pickup and delivery activities.
- Hybrid models, which are combinations of the above two models.

The paper identifies three primary data sources:

- Travel Surveys: 1995 National Personal Transportation Survey, ITE Trip Generation Manual, regional commercial vehicle surveys etc.
- Other surveys e.g. Vehicle Inventory and Use Survey (does not include truck trip data)
- GIS data e.g. Bureau of Transportation Statistics, National Transportation Atlas Data Shapefiles, Census Bureau TIGER files, Census 2000 Map files, state GIS sources etc.

Freight modeling efforts include the Cambridge Systematics' Quick Response Freight Manual developed for FHWA to estimate truck trip tables and predict truck flows. Other models have been designed for heavy trucks that primarily move goods (vs. parcels). Articles on on-demand urban freight distribution deal with delivery route optimizations and algorithms for the traveling salesman issue for example.

The Cambridge Systematics report recognizes the unique nature of intra-urban freight vehicle trips and stresses the absence of specific trip data for these. Their movements differ from heavy inter-urban freight vehicle trips, and their examination is one of the objectives of this research.

The second task of the first phase of the Cambridge Systematics research project compiles data available from various sources and estimates the magnitude and spatial/temporal distribution of different types of urban commercial vehicles. Twelve categories are identified. The Package, Product and Mail Delivery category includes vehicles of the USPS, FedEx and UPS. The primary data sources include commercial vehicle survey data from Detroit, Atlanta, Denver and the Piedmont-Triad area of North Carolina; California DMV data for Los Angeles, San Francisco, San Diego and Sacramento; and USPS data for Atlanta, Denver, Houston, Greensboro, Orlando and Portland. Table 1 in Appendix A summarizes the findings regarding average VMT and average number of trips per vehicle per day (where available) that were compiled from the three above sources. The Commercial Vehicle Surveys and the California DMV data exclude USPS vehicles. Data for the latter were obtained directly from the USPS and have been added to Table 1. In addition, only the findings for the vehicle classes relevant to this research are presented here, that is, the class termed "Package, Product and Mail Delivery" by the authors. The report states that the average daily VMT per USPS vehicle is about 25 miles, although it is much lower in urbanized areas (about 5-6 miles) and higher in suburban areas. The data from the 4 surveys are further analyzed to review the distribution of vehicle trips by hour of day. In general, it is shown that the majority (range of 50-71%, average of 58%) of commercial vehicle trips tend to occur between 9:00 am and 3:00 pm, that is, in the daylight off-peak period.

The Cambridge Systematics report provides a strong basis for future comparison with the findings of this research study. This is especially true regarding the USPS vehicles (one of the focus commercial vehicle groups in this study), which tend to be excluded from the various surveys and literature sources.

Morris, Kornhauser and Kay (in three papers published in 1998, 1999 and 2000 respectively) discuss their three-part Goods Movement Study in New York City's central business district (CBD), which extends from 59th Street on the north to the southern tip of Manhattan, and spans Manhattan from east to west. The three-part study consists of the following:

- The Industry-Sector Focus Groups: they included transportation and logistics executives to identify barriers to efficient freight movement into and through New York City and identify the strategies employed for coping with these.

- The Freight Mobility Interviews: a survey questionnaire collected information on the last segment of the supply chain.
- The third part is in progress and includes a time and motion study of dock activities and a survey of managers of commercial buildings about the facilities for receipt of goods.

The first part of the Goods Movement study in the New York Metropolitan Area was the industry-sector focus groups. These consisted of senior logistics executives who discussed barriers to goods movement into New York City's CBD and also assisted in developing the Freight Mobility Interview form. The groups consisted of only two to four members; they had already received the Focus Group Moderator's Guide, a series of six questions that dealt with barriers to urban freight mobility, a review of the Interview and how to improve industry access to the local MPO. The major findings of the focus groups were the barriers to transporting goods into the CBD i.e.:

- Congestion,
- Inadequate docking space and curb space for commercial vehicles
- Security
- Excessive ticketing of high-profile companies

All these factors increase the company's vehicle and labor expenses, especially in the metropolitan area, resulting in many national carriers subcontracting the last leg of the trip to carriers with smaller trucks. They were later verified in the second part of the three-part study, the Freight Mobility Interviews. Quantitative data from the 74 Interviews (59 shippers and 15 motor carriers) include:

- Time of dispatch
- Transit time
- Trip length: average 10 to 30 miles
- Truck size: 15 ft to 48 ft, mode=20 ft to 24 ft
- Truck type: vans, step vans, pickup trucks and straight trucks
- Trucks dispatched per week: 1 to 125, mode= 5
- Average duration of CBD round trip: 2 to 14 hours, mode=5 to 8 hrs
- Roadway facility used prior to CBD drop-off
- Most of the deliveries were express small package services

The Freight Mobility Interviews included both shippers and carriers operating on both truck load (TL) and less than truckload (LTL). Major findings on the various characteristics of dispatched truck trips were pooled from the surveys:

- Starting points for the trip into the CBD were Distribution Centers and Warehouses.
- The majority of facilities were 3 to 50 miles from the CBD.
- Truck sizes ranged from 8 to 53 ft but most were less than 30 ft.
- Vehicles used included vans, step vans, pick-up trucks, straight trucks and tractor trailers.
- Drop offs in the CBD ranged from 1 to 200 with most between 1 and 10.
- Number of trucks dispatched per week: Shippers: 1-300, most less than 20. Carriers: TL: 2-15, LTLs: 18-70, Express Carriers: 2000-4000.

- Standard times of dispatch: Shippers: 2-10:30 am, Carriers: 6-9 am
- Average Duration of round trip in and out of CBD: Shippers: most 5-8 hrs, Carriers: highly variable
- Average shipment size per vehicle: Shippers: 4 categories: 5-50 lbs, 100-800 lbs, 1000-8000 lbs, 12,000-43,000 lbs. Carriers: LTL: 600-1200 lbs, TL: 30,000-46,500 lbs. Express Carriers: 1 lb-170 lbs.
- Number of trucks sent to CBD per day: TL: 1-3, LTL: 5-14, Express carriers: 70-800
- Number of Days per week shipments sent to CBD: Express carriers: 6-7, Rest: 5
- Number of pick ups from CBD per day: TL: 0-3, Express: 13,200
- Latest departure time for CBD: 6-10 am
- Latest departure time for return trip: 5-10 pm

Transportation barriers evident from the results include congestion due to time of day and season, security problems, infrastructure limitations on truck size and inadequate docking space.

The third part of the Goods Movement study in the New York Metropolitan Area is documented in a third paper by Morris et. al. in 2000. The goal was to document the physical structure of docks in Commercial Office Buildings (COBs) in the CBD along with dwell times of commercial vehicles in docks or adjacent streets. The data collection process consisted of a survey/interview of managers of COBs regarding dock facilities and the management of pickups and deliveries of goods and services to their tenants; and a time-and-motion study of dock activities, including curbside dwell times. The COB manager surveys solicited information on building characteristics, number and size of freight elevators, dock space description, delivery windows and property managers' suggestions for upgrading docks and freight elevators. Each manager was sent a letter containing the survey, a project summary and a request for participation. They were then contacted by telephone within 1 week to schedule an appointment for the interview. Most interviews were completed by telephone due to time constraints. Findings from the Commercial Office Building Manager Surveys included property managers' suggestions:

- Expanding the dock size to improve functionality
- Installing a leveling device, or
- Increasing the number of freight elevators

Twenty-eight Commercial Office Building Dock Surveys took place and the findings were:

- Number of Deliveries per day ranged from 5 to 60
- Average dock dwell time ranged from 10 to 45 minutes
- Number of freight elevators ranged from 0 to 6
- Number of Platform leveling devices ranged from 0 to 5
- Dock width ranged from 15 to 75 ft; dock depth ranged from 20 to 38 ft
- Delivery windows ranged from 7 am to 7 pm

The time-and-motion study on Vehicular Deliveries to Docks (VDD) followed. It collected information on the dwell time of a vehicle in the dock, the dwell time of a vehicle parked on the street, truck size and product category.

- Most deliveries occurred during the morning whether in-dock or on-street

- Dwell times averaged 33 minutes for both in-dock and on-street. This may be a contributing factor to congestion in the CBD

The authors recommend that incentives be provided for building owners to retrofit docking facilities and increase efficiency of freight deliveries; use passenger elevators to move freight during off-peak daytime hours; and make curbside commercial parking zones more available for commercial vehicles.

Although the quantitative results of the Freight Mobility Interviews are of most interest for the purposes of this research, the Focus Groups and the Time and Motion study provided a more complete understanding of the operations of freight vehicles in urban areas and the problems that they encounter.

Ruiter (1992) documents the Commercial Vehicle Survey conducted for the Arizona Department of Transportation. Travel surveys were conducted of commercial vehicles operating within the Phoenix metropolitan area and the data collected was used to develop commercial vehicle trip generation, distribution and traffic assignment models. The total population of commercial vehicles was obtained from 2 sources: the Department of Motor Vehicles and the US Post Office vehicle listings. The data collection procedure included telephone contacts (to solicit participation in the survey) and a mail out – mail back questionnaire that included a 1-day travel diary. The surveys yielded information on various vehicle characteristics by vehicle weight class:

- Total commercial vehicle population: 159,000 (after expansion factor; before: 4000)
- Total Daily Vehicle Trips: 968,000 (after expansion factor; before: 3402)
- Average trips per vehicle: 6.1
- Average VMT per vehicle: 78.5
- Average Miles per trip: 10.2

The surveys collected information on the following vehicle characteristics:

- Average surveyed vehicle weight per trip
- Vehicle type
- Vehicle usage for home-to-work travel
- Vehicle not used on typical weekday
- Time of first daily trip
- Vehicle trips per day by vehicle type (only first 10 trips documented on trip diary)
- Vehicle mileage per day
- Time-of-day distributions
- Activities at trip ends
- Land uses at trip ends
- Activity and land use linkages at trip ends
- Stop locations (on or off street)
- Trips by time duration
- Trips by travel distance

Household and employment data by land use category were obtained for each zone and were related to the total number of trips to yield truck trip rates for each land use category and each vehicle weight class. The gravity model was calibrated to predict trip times and compare them to the observed trip time distributions, with a percentage error ranging from –2 % to +2.6%.

The Phoenix survey is of special interest to this research because of the inclusion of USPS vehicles as well as privately owned commercial vehicles. The data collection method proves to be effective and leads to the estimation of key urban freight vehicle and trip characteristics, which is one of the objectives of this research.

Schlappi et al. (1993) document the findings and conclusions of a study conducted by Barton-Aschman Associates Inc. to collect truck travel data and produce a truck travel model for Alameda County and adjacent counties in the San Francisco Bay Area, in order to facilitate future estimates of the contribution of trucks to traffic congestion in the study corridor (I-880). Three gaps in the knowledge of truck travel were identified: time-of-day patterns, origin and destination data and goods carried. Four travel surveys were conducted: truck classification counts at 11 freeway locations; truck intercept surveys at weigh stations (8000) and toll bridge crossings (700); employer surveys of the truck trips generated (2700 truck trips); interviews with truck drivers and terminal operators at the Port of Oakland to estimate daily truck trips generated by the port (3800 represented). The study found that:

- The peak period for truck travel is midday, not in either the a.m. or p.m. peak commute periods
- Almost all of the truck trips had origins and destinations in one of the nine Bay Area counties
- Many daily truck trips in the port area are local trips that never access a freeway
- 65% of the employers do not own or lease trucks, whereas 35% do
- Larger employers are more likely to have trucks than smaller employers, with manufacturing or wholesale companies having the highest rates of truck ownership
- Internal-external trips were 14% of total trips
- Internal-external trips had 32% of the total Vehicle Hours Traveled (VHT)
- 3-axle trips had both the smallest percentage of total trips and total VHT
- 4-or-more axle trucks had 1/3 of 2-axle truck trips but had 70% of 2-axle truck VHT

The employer surveys provided a sample of truck travel, the intercept surveys provided a sample of external-internal (one trip end outside of the nine counties) and freeway classification counts provided the diurnal travel patterns and helped calibrate the model. The model was designed to estimate travel for 3 truck trip types (external-external, internal-external and internal-internal) and 3 truck types (two, three and four-or-more axles). For trip generation, equations were formulated for garage-based productions and attractions. Productions were estimated as trip rates using the employer survey. Attractions were estimated by relating trip destinations and socioeconomic data using multiple linear regression. Total employment numbers were found to work the best. Linked trips were estimated similar to non-home-based trip equations. The report also compares the survey data to the model results in tables which cannot be included here: trips by truck type and trip type, trip production and attraction rates by trip type, employment type and truck type, trip length distribution, peak hour truck trip factors.

The Alameda study focused on regional commercial trips as well as special generator trips. Key freight vehicle operational parameters were estimated, and certain facts on urban freight trips were verified, for example, the peak truck travel period being midday.

Barton-Aschman Associates also conducted the Commercial Truck Travel Survey in El Paso in 1994. El Paso County was identified as a non-attainment area for ozone and carbon monoxide, according to the classifications established by the 1990 Clean Air Act Amendments, and commercial vehicles can be major emitters of pollutants. A sample of trucks was selected from the region and each truck owner/driver was interviewed regarding the trips made by the truck within the study area in a 24-hour period. The truck manifests were utilized, along with 'key facility' route information collected for each trip from the driver, which was later used for truck assignment. The survey procedures included the following steps:

- Determination of Data Items- Origin and destination address, arrival and departure times, kind of establishment visited, truck classification and purpose of trip.
- Questionnaire Design
- Truck Owner Contact – Telephone calls were made to identify the truck, determine if it was used commercially in the study area, solicit participation in the survey and determine the use of a truck manifest.
- Mail Out Packages – Included a truck diary, a cover letter, a travel date, a reminder form and instructions for recording trips.
- Interviews With Truck Operators – If a truck manifest was in use, the trips made on the travel day were obtained by telephone interviews. If a manifest was not used, the trips data were obtained from the mailed travel diary and from driver interviews, the latter of which also provided the key facility data.

Information collected from the trip diaries included:

- Trip origin and destination
- Trip time beginning and ending
- Purpose of trip
- Land use at destination
- Travel route data
- Truck class (size and weight)
- Truck year and make
- Odometer readings
- Gasoline or diesel fueled
- Business type of owner/operator

The truck sample was based on commercial trucks with six or more wheels. Texas vehicle registration data provided the owner's name and address, registration class (commercial or apportioned) and the gross vehicle weight (8,500 lbs or heavier). The total population was filtered down to 2,500 trucks. In case of multiple truck ownership, one in five trucks was included in the survey. The survey response rate was 43%. The origins and destinations of all trips were geocoded to the traffic serial zones (TAZ) using GIS automated procedures.

The truck survey's findings consisted of the following:

- Total number of surveyed trucks: 88
- Gross Vehicle Weight: 8500 lbs or greater
- Total number of companies: 441
- Total intra urban truck trips
- Proportion of these trips occurring by time of day
- Average trip length, time and frequency distribution
- Proportion of trucks by type, age and fuel used
- Mileage accumulation rates by type and age of truck
- Truck trip ends by type of land use activity

The El Paso survey was limited to freight vehicles of weight higher than 8500 lbs, thereby excluding many urban freight trips, which are primarily made by smaller trucks and vans. This research hopes to investigate these lighter vehicles' urban freight movements more thoroughly.

Barton-Aschman Associates also conducted a Commercial Vehicle Survey in the Piedmont-Triad Area of North Carolina in 1996. A very similar approach was used to conduct this survey to estimate truck and commercial car trips in the Triad region. These commercial vehicles were classified into 5 categories: single-unit trucks (e.g. panel or UPS trucks), combination trucks (e.g. tractor-trailers), pick-up trucks, vans (delivery and passenger) and autos. About 30% of the sampled vehicles were single-unit trucks and 20% were pickups or vans. The survey methods and data collected resemble closely those of the El Paso study with additional information collected in the trip diaries regarding whether the vehicle was turned off at the destination (cold and hot starts) for air quality purposes. The completed sample consisted of 420 trucks and 86 cars. Geocoding of trip ends using GIS took place here as well. Expansion factors were developed to allow for the estimation of the total amount and type of commercial vehicles in the area. A truck/car trip factor per 1000 employees by industry type was applied to current estimates of employees by industry and to forecasts of employment used to predict future commercial vehicle trips. The findings are included database tables with Company information, Vehicle data, and Trip data. The data tables provide information on:

- Travel day and date
- Odometer readings at beginning of first trip and end of last trip
- Origin and destination addresses
- Engine on or off at stop and duration
- Destination land use e.g. office, retail, residential
- Freight carried e.g. mail, food, apparel
- Activity at destination e.g. pick up, drop off
- Vehicle type e.g. pickup truck, van, car, tractor trailer
- Trip start time, destination arrival time and destination leave time i.e. trip duration and stop duration

The Piedmont-Triad commercial vehicle survey was the only one to collect operating data necessary for air quality analysis, for instance, whether the engine was turned off or left idle at stops and for how long. These data items are of great importance in this research. The dataset was obtained for estimation of travel characteristics and air quality effects of the local freight vehicles, and comparison with a second local fleet dataset, in the Knoxville area.

Table 2 summarizes the major findings from the most recent commercial vehicle surveys or studies around the country, the processes of which are explained in detail above (NYC CBD, Phoenix, Alameda, Piedmont Triad, El Paso). Each study estimated different trip data items and used different commercial vehicles classifications; furthermore the results of some surveys were not always available from the reports.

Air Quality

The Environmental Protection Agency's User's Guide for MOBILE6.0 (2002) and related technical documentations are the primary literature sources. The program estimates Volatile Organic Compound (HC), carbon monoxide (CO) and nitrogen oxide (NOx) emission factors for gasoline and diesel-fueled highway motor vehicles. MOBILE6 calculates emission factors for 28 vehicle types in low and high altitude regions of the U.S. based on various conditions such as ambient temperatures, travel speeds, operating modes, fuel volatility and mileage accrual rates. MOBILE6 includes default values for a wide range of input variables that affect emissions, based on national fleet data. The user can substitute information that reflects local conditions. At a minimum, users must provide input data for calendar year, minimum and maximum daily temperature and fuel volatility. MOBILE6 is the latest model and incorporates updated information on basic emission rates, more realistic driving patterns, separation of start and running emissions, improved correction factors, changing fleet composition, new regulations and also provides more options for input of specific times and geographic locations. The output from MOBILE6 can report emission rates in grams of pollutant per vehicle mile traveled (g/mi) or grams per vehicle per unit time (day or hour).

Chatterjee et. al. (1997) discuss the 1993 Conformity Rule and document the air quality modeling procedures used in relation to EPA's MOBILE5a model. The report identifies the most important variables required for air quality analysis and describes the data requirements in detail, e.g. data type and description, geographic detail, use of each data item, current practices for the data development, data sources and level of accuracy. The problems surrounding the data items and the variables not available from the transportation planning process are also identified. The CAAA classifications for Ozone, CO, and Particulate Matter pollutants are discussed along with the procedural requirements of the conformity rule. The following procedures must be followed:

- Determine level of spatial and temporal detail
- Determine total base-year VMT by functional class of roadway (use HPMS or travel demand model data)

- Develop growth factors and future year VMT (use historical trends from HPMS data or socioeconomic predictions from travel demand models)
- Develop pollutant emission factors per VMT by various vehicles in various operating modes
- Multiply these factors by the calculated VMT to determine total mobile source emissions for non-attainment region
- Determine point source emissions to calculate total emissions for the non-attainment region
- Input meteorological, boundary and terrain data required for dispersion models
- Determine ambient pollutant concentrations

The key transportation variables required for air quality modeling (MOBILE5a) include:

- Average vehicle speeds by functional class (including delays)
- Current and projected VMT by vehicle and functional classes
- Vehicle mix
- Age distribution
- Mileage accumulation
- Fuel type
- % VMT by operating mode (cold start, hot start, hot stabilized)
- Trip-end data (number and length)
- Parking time
- Number of hot and cold starts
- Capacity (for calculation of speeds and delay)
- Queuing (idle vehicle time)
- Travel characteristics (e.g. vehicle occupancy rates to distinguish between person trips and vehicle trips)

This paper provided a complete picture of the transportation data required and data sources available for use in mobile emissions modeling. Although MOBILE6 is different in many ways than MOBILE5a, the key transportation data needs remain similar.

Chatterjee et. al. (1997) perform a sensitivity analysis that reveals the change in emission factors due to different levels of specific input parameters. Multiple runs of MOBILE5A were made increasing speed from 2.5 to 65 mph at 5mph intervals. Emissions of CO, VOCs and NOx in grams per minute are lowest when the engine is idle, and they increase with speed. The rate of increase is greatest for NOx and lowest for CO. The highest speeds produce the highest emission rates (highest RPMs). When operating mode percentages are tested, it is found that VOCs are most sensitive in 32 F when a 4.4% change in cold starts yields a 10% change in the VOC emission factor. At 32 F a 6.6% change in cold starts causes a 10% change in CO emissions. NOx is not very sensitive to operating mode (requires a 36% change to produce a 10% change in emission factor). Hot starts show less sensitivity; 30% or greater change in hot starts is required to produce a 10% change in the average emission factor. Vehicle type analysis shows that HDGVs emit the most CO and VOCs of all vehicle types. HDGV CO emission factors are 4-6 times higher and VOC emissions are 2-3 times higher than LDGV emissions, depending on temperature. HDDVs are highest in NOx emissions, 6-7 times higher than LDGVs; the HDDV effect on NOx emissions is also found to be the most sensitive parameter. Variations in the vehicle age mix yield an increase of 11.7% in CO for LDGV for a 1-year increase in the median vehicle age; the CO emission factor decrease by 12.9% for a 1-year decrease in median vehicle age. VOC and NOx emission factors for LDGV vary from +8.8% to +11.4% per year for a 1-year increase in median vehicle age. Since emissions are estimated by multiplying VMT by the emission factors in grams per mile, and daily VMT on a highway segment is equal to the segment's ADT multiplied by the length in miles, there is a strong error propagation possibility. The latter can be due to errors in vehicle counts, counting stations, not accounting for VMT on local streets in travel demand models etc. It is concluded that an error of 5 mph in input speed can cause a 42% difference in the CO emission factor; a 4.4% difference in the HDDV input can cause an 18% difference in NOx emission factor; a 10% difference in cold starts can cause a 23% difference in the VOC emission factor.

Although MOBILE6 does not use operating mode per se, the most sensitive input parameters identified in this paper will be given due consideration in developing the model inputs for this research.

Granell et al. (2002) surveyed DOTs and MPOs around the country to find out the extent to which local data are used for vehicle fleet characterization in air quality analyses. The result was that only 41.5% use local data whereas more than half the agencies use the MOBILE defaults. The programs that allocate vehicles into vehicle classes are not tailored for the new MOBILE6 classes yet. The effort to use a VIN decoder to classify vehicles from vehicle registration data into the EPA's MOBILE6 model vehicle classes is documented along with the problems encountered. MOBILE6 uses 4 parameters to classify vehicles into classes: model year, weight, fuel type and body type. This study also demonstrated the possibility of using GIS for geocoding (address matching of Vehicle Identification Numbers to a street network) and data aggregation to any desired level.

This source indicates the extend to which agencies rely on the default input parameters for air quality analyses and the need for the development of these based on local vehicle fleets, which is one of the objectives of this research.

Miller et. al. (1991) describe the methodology used by researchers at the University of Tennessee to prepare a mobile source emissions inventory for use as input to EPA's MOBILE4 emissions model. The non-attainment areas of Nashville, Memphis and Knoxville, Tennessee were investigated to estimate and evaluate the traffic parameters required. Each area was subdivided into 5 km x 5 km grids, each designated as one of three settings: rural, urban fringe or urban core. Five roadway classifications were designated for each grid: interstates, major arterials, minor arterials, collectors and local streets. The vehicle miles traveled each hour on each of the five roadway types were determined for each grid. MOBILE4 was used to calculate an emission factor (HC, NOx and CO) for each hour of the day (average weekday in July) for each of the 15 highway classification/geographic setting combinations, taking into account hourly traffic profiles of vehicle speed, vehicle mix and cold start fraction developed for each. The ADT data was obtained from the Tennessee Roadway Information Management System (TRIMS) and multiplied by the road segment length to obtain VMT. Other required inputs included (a)VMT (i.e. % ADT) by hour on different road classes, (b)vehicle mix, (c)travel speed by hour of the day on different road classes and (d)vehicle operating mode mix, i.e. % cold start, % hot start and % hot stabilized. VMT/ADT by Hour of Day was estimated using data from TDOT and the '187 Manual'. The Vehicle Mix recognized two classes of vehicles (trucks with gross weight greater than 8500 lbs) and other vehicles due to lack of more detailed data. The percent trucks by hour was developed as: % Daily Trucks*Hourly Distribution of Trucks/Hourly Distribution of Total Traffic. The % Daily Trucks was available from TDOT, as was the hourly travel speed for urban fringe and rural areas by road functional class. The urban core speed profile was developed from original data collected in the city of Knoxville. Operating Mode profiles were summarized from other surveys and provide percent of vehicles in the cold start mode, hot start mode and hot stabilized mode by geographic setting, functional road class and by hour. MOBILE4 was run using the developed operating mode profiles and using the default values for Rutherford County TN.

The findings suggested that:

- On a countywide basis the daily total HC and CO emissions estimated using the developed operating mode profiles varied less than 2% from the emission values calculated using the default operating modes
- Greater variations in emission rates were obtained when the developed vehicle speed and HDDV truck mix were used in combination in a single run. On a countywide basis, CO emissions averaged –41%, HC emissions averaged –25% and NOx emissions averaged +34%.

This source outlines the air quality analysis based on MOBILE4, which has a less detailed vehicle classification scheme than MOBILE6. Only freight vehicles of 8500 lbs and heavier are recognized in this study, which may lead to exclusion of many urban freight trips that are made by lighter vehicles. The latter group is the target group of vehicles for this research.

Davis and Truett (2002) in their study at ORNL investigate the class 2b truck population in the United States, i.e. trucks between 8,500 and 10,000 lbs GVWR. Data sources included NHTSA, The Polk Company, Ward's Communications and the Census Bureau. None of these included weight data to separate class 2 trucks (6,001-10,000 lbs GVWR) into class 2b trucks from class 2a trucks (6,001-8500 lbs GVWR), thus individual truck models were researched to determine which models were class 2b trucks. Four methodologies were used to derive sales of class 2b trucks over the 10-year period from 1989-1999. Method 3, using model year sales data from Ward's Automotive Reports and Polk data to subdivide some truck model data, was the preferred method for model year sales. Method 4, using calendar year sales data from Ward's Facts & Figures and Polk data to find the share of class 2b trucks was the preferred method for calendar year sales. The characteristics of class 2b trucks were investigated by body styles, fuel types, exterior dimensions, engine sizes and prices. Pickup sales were 82% of all class 2b sales in 1999; two thirds of class 2b trucks were gasoline fueled and one third was diesel fueled. The population of class 2b trucks in 2000 was 5.8 million, or 8% of all trucks under 10,000 lbs (74.7 million). 24% of class 2b trucks were diesel, while only 2.5% of class 2a and 0.3% of class 1 trucks were diesel. Class 2b trucks had a higher average age (8.6 years) than class 2a and class 1 trucks (7.4 and 7.3 years respectively). The annual miles of class 2b trucks were estimated to be 76.7 billion, and the annual miles for class 2a and class 1 trucks were 251.9 and 672.7 billion respectively. Next the report looks at the new EPA Tier 2 motor vehicle emissions standards, which begin in 2004. These apply to class 2b trucks designed for passenger use, which fall into the new Medium Duty Passenger Vehicle class. Class 2b trucks designed for commercial uses will be subject to the existing heavy-duty vehicle standards. The available EPA data show that the smog forming pollution emitted by class 2b trucks ranges from 27 to 121 lbs per 15,000 miles of operation.

This report provided valuable data and knowledge on class 2b trucks, to which a large number of urban pickup and delivery vehicles belong.

The Environmental Protection Agency's MOBILE6 Model

The EPA MOBILE6 model classifies vehicles into 28 categories (Table 3): 6 categories comprise of passenger cars (LDGV, LDDV), buses (HDGB, HDDBT, HDDBS) and motorcycles (MC), all of which are outside the scope of this research. The remaining 22 categories classify trucks and other types of vehicles by gross vehicle weight and fuel type. These 22 classes are of potential interest to this study, as they partially or solely consist of vehicles used for commercial purposes.

For generating emission factors, an analyst has to specify values for several parameters of MOBILE6. These input parameters can be classified into 5 general categories:

1. External Conditions: the inputs required are calendar year and month of evaluation, altitude, temperature, humidity and average percent cloud cover.
2. Vehicle Fleet Characteristics: profile of a given fleet by vehicle age, power source and activity level.
3. Vehicle Activity: vehicle travel is allocated by time of day, day of week, type of road, speed and other factors that affect emissions.
4. Vehicle Gasoline Specifications: gasoline volatility, oxygen content, sulfur content and whether the area is part of the Federal Reformulated Gasoline Program. The Knoxville area is not.
5. Inspection and Maintenance Programs and Anti-Tampering Programs: An I/M program is not currently enforced in Knox County, Tennessee.

This research focuses on the Vehicle Fleet Characteristics and the Vehicle Activity, which are described in detail below.

Values for input parameters that are in the form of fractions are estimated for this research based on sample data. Although the sample does not represent the entire local vehicle fleet it shows how different the freight vehicle fleet may be from the default fractions. The default values have been developed from national fleet data and are provided by the model for all inputs. The required input parameters for EPA's MOBILE6 model are developed for each Vehicle Class and by Age, where applicable.

The Vehicle Fleet Inputs required by MOBILE6 are:

- Age Distribution of Vehicles.

MOBILE6 provides default values for the vehicle age distribution, although it is recommended that local registration data be used to estimate this input. Gasoline and diesel fueled vehicles are combined for this purpose and a 25 year range of vehicle ages is covered, with vehicles 25 years and older grouped together. A total of 400 values need to be entered, representing the fraction of vehicles in each age group in each of 16 composite vehicle classes (Table 4).

- Diesel Fractions.

Vehicles within a vehicle class can be separated according to the fuel used, gasoline or diesel. Fractions for each of 14 composite classes for each of the 25 model years, a total of 350 values, need to be entered.

The development of the Age Distribution and Diesel Fractions inputs is based on vehicle registration data and is beyond the scope of this research.

- Annual Mileage Accumulation Rates.

Gasoline and diesel vehicles are treated separately. A total of 700 values need to be entered representing the annual VMT (divided by 100,000) in each of the 28 vehicle classes in each of 25 age groups. In this research, the daily VMT per vehicle was obtained in the data collection process. The annual mileage accumulation rate for the vehicle classes and ages present in the commercial vehicle sample is then estimated based on the daily VMT multiplied by the number of days of annual operation. For the North Carolina vehicles and for the Knox County PUD Companies' vehicles, these are assumed to be 250 days of operation per year (5 days/week * 50 weeks/year), whereas for the Knox County USPS vehicles these are 300 days per year (6 days/week * 50 weeks/year).

The Vehicle Activity Inputs required by MOBILE6 are:

- Vehicle Miles Traveled (VMT) Fraction by Vehicle Class.

This specifies the fraction of total highway VMT that is accumulated by each of the 16 composite vehicle classes, gasoline and diesel vehicles combined. The VMT Mix (as otherwise called) is used only in determining the composite emission factors. It does not affect the estimation of vehicle class specific emission factors. The default VMT Mix is based on the calendar year for which the model is run, which is one of the required inputs into the model. The investigation of all vehicle classes and hence the development of the VMT fraction for each is beyond the scope of this research.

- Vehicle Miles Traveled Fraction by Highway Functional System.

MOBILE6 makes available 4 'driving cycles': Freeway, Arterial/Collector, Local Roadway and Freeway Ramp. A total of 2688 fractions need to be entered, representing the fraction of VMT by each of the 28 classes, on 4 roadway types over 24 hours. The development of this input is beyond the scope of this research.

- Vehicle Miles Traveled Fraction by Hour of the Day.

This distribution is the fraction of all daily VMT that occurs in each hour of a 24-hour day independent of facility type. Daily mileage, hours of operation and timing of trips obtained from the collected data are used to estimate the VMT fraction by each of the 24 hours of the weekday.

- Vehicle Miles Traveled Fraction by Average Speed.

In MOBILE6, average speed is defined as the distance traveled (miles) divided by the time (hours), including intersections and other travel obstacles. The average speed distributions have 14 ranges, which represent the fraction of all VMT (all vehicle classes combined), which occurs at 2.5 mph and 5 to 65 mph in 5 mph increments. There are 2 separate speed distributions, one for freeways and one for arterial/collectors. A total of 672 fractions need to be entered (14*24*2).
The data collection process provided information on trip length and travel time allowing the estimation of an average travel speed. The fraction of the daily VMT traveled within that hour, under that travel speed is then allocated to the appropriate speed bin. Collection of data on freeway or arterial/collector travel is beyond the scope of this research. The input values from both default distributions are compared to the developed distribution.

- Vehicle Engine Starts Per Day.

The number of starts per day affects engine exhaust start emissions for light duty gasoline and diesel trucks. The evaporative hot soak losses occurring at trip ends of all gasoline vehicles (including heavy duty) are also affected. The user must provide an average number of engine starts per day for each of 10 vehicle classes (HDDVs are not affected), for weekdays and weekends (latter not applicable for the vehicles under this study). Gasoline and diesel vehicles are treated separately. The number of trips per day and trip ends per day is calculated by MOBILE6 from the number of starts per day. The North Carolina data provided data on whether the engine was turned off or not at each stop. The Knox County USPS and PUD Companies have policies in place regarding turning the engine off at stops where the driver dismounts. The number of dismounts per day was obtained from the data collection and allows for the estimation of this input, at least for some vehicle classes.

- Vehicle Engine Starts by Hour of the Day.

The user must provide the fraction of engine starts that occur in each hour of a 24-hour day for weekdays or weekend days, a total of 48 fractions. Data on number of dismounts and hours of operation permit the estimation of this input, for weekdays.

- Vehicle Soak Time between Engine Starts.

Soak time is defined as the time between when the engine is turned off and the next time it is started. The user is required to supply 3360 values, which represent the fraction of engine starts by time since last engine running (70 soak time ranges) for each of 24 hours of the day for average weekdays and weekend days. The soak time affects exhaust start and exhaust running emissions. Information from the data collection on number of dismounts per day, hours of operation and duration of stops are used in estimating this input, for weekdays.

- Vehicle Trip Length (Duration) Distribution.

During trips, fuel evaporation occurs and the longer the trip the higher the evaporative running loss emissions. Only Light Duty Gasoline Vehicles and Trucks are required to be analyzed to develop the Trip Length Distribution. The user must supply 6 values, which represent the percentage of daily VMT occurring within each of 6 trip length range durations throughout the day. In this input, a 'trip' is defined as 'engine on time to engine off time'. The collected data provide the necessary VMT/trip and duration of trip to estimate this input, for weekdays.

MOBILE6 input parameters are developed for the North Carolina and then for the Knox County commercial vehicle sample. Both are then compared to the default values the model provides. The research develops as many input parameters for as many vehicle classes and ages as permitted by the datasets.

MOBILE6 model simulations are performed using the default values of parameters, and then again using this study's two sets of values for the same input parameters. The resulting emission rates, in grams of pollutant per vehicle mile traveled (VMT) are then analyzed and compared.

Chapter 3

DESCRIPTION OF DATASETS

North Carolina Data

The data from the *Piedmont Triad Area: Commercial Vehicle Survey*, which was collected by Barton-Aschman Associates, Inc., in early 1995, was obtained from the North Carolina Department of Transportation to provide one of the two commercial vehicle datasets examined and analyzed in this research study. The Piedmont Triad Area consists of the area between the cities of Greensboro, High Point and Winston-Salem in North Carolina.

The North Carolina companies surveyed represent a broad spectrum of industries, although hardly any operate in the package PUD sector. In addition, the data include internal-external trips as well as purely internal trips. The focus of the Knox County data, on the other hand, is internal trips. In a way, the North Carolina data and the Knox County data complement each other. The vehicle and trip data supplied by 258 companies in the Piedmont-Triad area are used in this analysis, 254 of which had only one vehicle sampled. Three companies each had 2 vehicles sampled and one company had 6 vehicles sampled. Figure 6 shows the breakdown of the company sample by broad Standard Industrial Classification Category. Figure 7 shows the breakdown of the company sample by Standard Industrial Classification Code. Table 5 shows the description of each SIC Code and Category and the number of companies classified in each.

The original vehicle sample consists of 420 trucks and 86 cars, a total of 506 vehicles, consisting of the following vehicle types:

- 121 Single Unit Trucks (24%)
- 46 Combination Trucks (9%)
- 152 Pickup Trucks (30%)
- 101 Vans (20%)
- 86 Commercial Cars (17%)

The sample size was determined by NCDOT and the sample consists of commercial vehicles garaged at a total of 424 sites within the study area. The method for choosing the sampled vehicles at the selected location was carried out by matching a random number with the last digit of the license plate number. Out of the 506 total vehicles identified to participate in the survey, data were gathered for 353 vehicles. The remaining 153 vehicles were not driven on the study day. Furthermore, out of the 353 vehicles, 19 were passenger vans and 56 were passenger cars used for commercial purposes. The two latter categories are outside the scope of this research. In addition, 6 vehicles made only long haul trips, and 6 more vehicles failed to provide mileage data. As a result, the refined sample size consists of 266 vehicles (owned by a total of 258 companies) of the following vehicle types:

- 82 Single Unit Trucks (31%)
- 33 Combination Trucks (12%)
- 100 Pickup Trucks (38%)
- 51 Vans (19%)

Table 6 shows the composition of the refined North Carolina data sample by MOBILE6 vehicle class.

On the study day for each vehicle the driver was asked to log the vehicle's movements on a trip diary. The trip diary data were then transferred into Microsoft Access Database files. The database files contain the following information, useful for specific analysis purposes:

- Company Data: Name, address, number of vehicles owned, number of employees, Standard Industrial Classification Code, Industry Type, Traffic Analysis Zone of garage etc.
- Vehicle Characteristics: Make and Model, Model Year, Body Type, Fuel used, Empty Weight, Loaded Weight
- Trip Data (one-day trip diary per vehicle): Travel Day & Date, Passenger or Freight Vehicle, Odometer Readings at begin and end of travel day, Trip Number, Destination Land Use, type of Freight Carried, Activity at destination, Trip Departure Time, Trip End Time, Stop duration, Engine off/on at stop, Trip duration, Destination address and Destination Traffic Analysis Zone.

Barton-Aschman Associates prepared their report for NCDOT consisting of the pooled results of the survey. This study goes to greater depth to develop an array of travel parameters typically used in transportation engineering research.

Knox County Data

A considerable and lengthy data collection process took place for this research study. The vehicle and trip data required for both the travel characteristics analysis and the emission analysis were collected in Knox County, Tennessee. Data on the local operations of the United States Postal Service and two major package pickup and delivery companies were obtained. The data collected from all participants include:

- Vehicle Characteristics: make/model, model year, body type, fuel used, Gross Vehicle Weight Rating (GVWR).
- Trip Data: daily mileage, typical number of stops per day, typical stop duration.

The area USPS operations are of two distinct types. The residential and business daily mail delivery routes are operated mostly by the small, standard USPS trucks, called "Long Life Vehicles", or a few small SUVs (owned and operated by subcontractors). The "blue-box" collection routes are operated by slightly larger trucks, but their operation is very similar to a large number of residential/business mail delivery routes, so it is feasible for them to be combined into one category.
Mail pickup and delivery between the main facility and the various post office stations in Knoxville, TN and surrounding areas is operated by single unit big trucks or tractor trailers and is distinctly different from residential/business mail routes.
The two package pickup and delivery companies use single unit big trucks or step vans and a few tractor trailers. Both companies' vehicles and trips share common operational characteristics though, so their data can be feasibly pooled into one category.

The classification scheme according to ownership of vehicles is used in the travel characteristics analysis, whereas in the emission analysis the vehicles are classified according to MOBILE6 specifications.

Table 7 shows the cross classification of the entire data sample of the Knox County data. The number of vehicles and number of trips are classified by owner and by MOBILE6 class.

Chapter 4

TRAVEL CHARACTERISTICS ANALYSIS

North Carolina Data

The commercial vehicle dataset from North Carolina is analyzed to obtain key travel parameters commonly used in transportation engineering research. The most feasible vehicle classification scheme for purposes of this particular analysis proves to be the Vehicle Body Type, as specified in the original dataset. Average values and standard deviations for each parameter are developed for each of 4 vehicle classes/body types and for the entire vehicle sample (Table 8).

A trip here is defined to be the traveling from point A to point B. Only the odometer readings at the start and end of the entire day are provided by the data, not the odometer readings at each stop. Therefore, the average trip length in miles is calculated based on each trip's travel time and the average daily speed. The latter is calculated based on the vehicle's daily VMT and the total travel time.

Overall, there are high standard deviations, pointing perhaps to the variability in vehicle characteristics and travel patterns of different types of vehicles in different industries. Examples would include plumbers' vans versus food product distributors' single unit trucks; or construction pickup trucks versus general retail combination trucks. The combination big trucks vehicle class is shown to have the highest average daily VMT, trip length and trip travel time. This may be due to the fact that the combination trucks' trips generally tend to be more of the longer haul, inter urban type than the shorter haul, intra urban one. This may warrant more frequent use of highways or interstates, which allow for higher speeds and easier maneuvering than local arterials for example. Combination trucks are shown to have the highest speeds among the 4 classes, although the class with the second highest average speed is not far behind. The high number of daily trips made by combination trucks may be explained by overnight driving with a shift change in drivers through the day.

For better conception of the vehicle characteristics and travel patterns between the 4 vehicle classes as well as within each class, frequency distributions are also developed (Figures 8 through 14). The corresponding frequency distribution tables can be found in Tables 9 through 15.

The Daily VMT Distribution (Figure 8) shows that the vast majority (45-65%) of vans, pickups and single unit big trucks have a daily VMT of 50 miles or less, whereas the daily VMT of combination trucks is more evenly spread among the intervals, with only 15% having a daily VMT of 50 miles or less. About 15% of combination trucks have a daily VMT of 300-700 miles.

The Number of Trips Per Day Distribution (Figure 9) shows that the vast majority (around 75-85%) of vehicles in all 4 classes make 10 trips per day or less. This is more pronounced for vans, with 47% making 4 trips per day or less. This could be explained by the fact that they tend to be the vehicles of choice for trades people e.g. plumbers.

The Average Daily Speed Distribution (Figure 10) is based on vehicle speed, which is calculated by dividing the daily VMT by the total travel time of each vehicle. The reason, as noted above, is that only the odometer readings at the start and end of the day are provided by the collected data; not the odometer readings at each stop. Hence an average value for each vehicle's speed throughout the day can only be developed. Overall though, the majority of vehicles of all 4 classes show speeds in the 15-50 mph range. The speed intervals are based on the speed 'bins' specified by the MOBILE6 model.

The Trip Length Distribution (Figure 11) clearly shows that the vast majority (70% or more) of trips made by vehicles in all 4 classes are 20 miles or less. A few combination truck trips go up to 320 miles, but these trips are of the internal-external kind, not strictly intra urban.

The pattern is repeated in the Trip Travel Time Distribution (Figure 12). The vast majority (about 70-90%) of trips made by vehicles in all 4 classes are 30 minutes long or less. The longer haul trips last up to 385 minutes or about 6 ½ hours.

The Stop Duration Distribution (Figure 13) shows that the vast majority (65% or more) of stops made by vehicles of all 4 classes were 30 minutes or less. The maximum stop time of 495 minutes (8:15 hours) can be attributed to a trip(s) made in the early am hours of the day, followed by a long 'down time' throughout the data collection day, followed by a late pm trip(s). Combination trucks have fewer short duration stops; they are more evenly distributed along the stop duration intervals whereas vans, pickups and single unit trucks tend to peak more at stops of shorter durations.

The Engine Starts Per Vehicle Per Day Distribution (Figure 14) shows a slightly gentler curve as compared to the Number of Trips Per Day Distribution. This can be explained by the fact that not all trips were associated with an engine start, since the engine may had been left running for the duration of the stop. Nevertheless, in general, the majority (around 90%) of vehicles in all 4 classes are shown to have 10 engine starts per day or less.

Knox County Data

The commercial vehicle dataset from Knox County, TN is analyzed to develop a second set of values for key travel parameters commonly used in transportation planning, and also to compare the results to the ones obtained from the analysis of the North Carolina dataset. The vehicles are classified according to ownership for this particular analysis.

The most feasible definition of a 'trip' in the analysis of the Knox County Data has been found to be the travel from an engine-on to an engine-off event. The following discussion elaborates on this definition as it relates to the movements of the vehicles in each of the three ownership classes.

- USPS Home/Business Mail Delivery

The USPS Home/Business Mail Delivery route vehicles have their engines turned off in cases where the driver dismounts the vehicle, for example in neighborhoods where the mailboxes are on the front door, at apartment or business complexes or at public mail-drop box locations. In neighborhoods where mailboxes are located on curbside, the driver does not dismount the vehicle and keeps the engine running. So according to the engine-on to engine-off definition of a trip, there is a large number of these 'stops' included in a single trip. The number of daily engine starts for the USPS Home/Business Mail Delivery route vehicles is equal to the number of dismounts, which (other than the public mail-drop boxes) varies according to the area each particular vehicle-route serves.
Hence, each trip made by vehicles in this class is associated with more than one stop, but with a single engine start.
More detailed examination of USPS Home/Business Mail Delivery Routes is beyond the scope of this research as additional data in a different form would be required.

- USPS Station Delivery

The USPS Station Delivery vehicles have their engines turned off at each destination or stop, for example post office stations, and the driver dismounts to unload and load mailbags. The number of daily engine starts for these vehicles is equal to the number of destinations or stops. Each trip made by this class of vehicles is associated with a single stop and a single engine start.

- Package PUD Companies

The drivers of Package PUD Companies are required to turn their vehicles' engines off at every address they visit. The number of daily engine starts for these vehicles is equal to the number of destinations or stops. Each trip made by these vehicles is associated with a single stop and a single engine start.

Average values and standard deviations for each parameter are developed for each ownership class and for the entire vehicle sample and are presented in Appendix A, Table 16. USPS Home/Business Delivery vehicles have the lowest daily VMT and daily speed because typically they travel slowly along neighborhood curbs where the driver reaches over and puts mail in curbside mailboxes. The number of trips implies the number of locations where the driver dismounts and turns the engine off, for example at apartment/business complexes or mail-drop boxes. The Average Stop Duration implies the engine off time at such stops. The Trip Length and the Trip Travel Time imply the distance and time lapses respectively between dismounts, i.e. engine on to engine off events. During these lapses, there may or there may not be curbside mailbox mail delivery, depending on whether there is curbside mail delivery or not between mail delivery locations where dismounting takes place.

USPS Station Delivery vehicles have the highest daily VMT, due to trips between the central USPS facility in Knoxville and Post Office stations in Knox and surrounding counties as well as stations as far as Johnson City, TN. The number of daily trips is the lowest and implies the number of engine starts and trip destinations i.e. PO stations visited. The daily speed is the highest, implying direct origin to destination trips. The USPS Station Delivery vehicles are comparable to the Combination Big Trucks of the North Carolina Data in their travel characteristics.

The vehicles belonging to Package PUD Companies typically load up in the morning and are on the road throughout the business day making deliveries or pickups. Usually each vehicle is assigned to a specific area of town for maximum efficiency. Therefore, their daily VMT is high, the number of trips is high, trips and stops are short and the speed is in between the other two classes' speeds. The number of trips implies the number of engine starts as well as destinations/addresses visited, since there is always a dismount, an engine off event and an engine on event at every destination.

As is the case with the North Carolina data, only the daily mileage was available, therefore the speed is based on the vehicle's total daily travel time and the miles traveled. The total daily travel time was estimated based on the collected raw data on the typical number of stops/dismounts and their typical duration.

For better conception of the vehicle characteristics and travel patterns between the 3 classes as well as within each class, frequency distributions are also developed (Figures 15 through 20). The corresponding frequency distribution tables can be found in Tables 17 through 22.

As seen from the Daily VMT Distribution (Figure 15), more than 90% of USPS Home/Business vehicles travel 50 miles/day or less. The daily VMT of the USPS Stations vehicles has a broad range from 50 to 200 or greater. About 75% of Package PUD Companies vehicles have their VMT in the 40-140 mile range.

In Figure 16, almost 80% of USPS Home/Business vehicles are shown to make about 20 trips per day or less. About 80% of USPS Stations' vehicles make 5-20 daily trips. The distribution is populated almost exclusively by the Package PUD Companies' vehicles starting with the 40-45 interval and spreads smoothly through to the maximum of 155 daily trips.

The Daily Speed Distribution (Figure 17) shows almost 100% of USPS Home/Business vehicle speeds at 22.5 mph or less; almost 100% of Package PUD Companies' vehicle speeds lie in the 5 to 35 mph range. About 85% of USPS Stations' vehicle speeds are in the 15 to 45 mph range, with about 15% around 50 mph.

Both the Trip Length and the Trip Travel Time Distributions show similar patterns (Figures 18 and 19). The vast majority of vehicles of both USPS Home/Business and Package PUD Companies tend to make short trips, and the frequency diminishes sharply after the 5 mile and 10 minute intervals. The USPS Stations vehicles curve is more temperate ranging from 1 to 20 miles and 5 to 30 minutes respectively.

The Stop Duration Distribution (Figure 20) shows almost 80% of stops made by Package PUD vehicles to be 2 minutes or less. USPS Home/Business stops are mostly 25 minutes or less. USPS Stations stops are more widely distributed, mostly in the 10 to 40 minute range.

Statistical Tests and Aggregation of Vehicle Classes by Usage

Statistical tests were conducted to investigate the goodness of fit of the 6 travel characteristics (Daily VMT, Daily Number of Trips, Daily Speed, Trip Length, Trip Travel Time and Stop Duration) of all 7 vehicle classes contained in the North Carolina and Knox County commercial vehicle datasets to the normal or the log-normal distribution. The statistical software JMP version 5.1 was used to conduct the KSL (Kolmogorov-Smirnoff-Lillifors) goodness of fit test. None of the travel parameters of any vehicle class fitted the normal distribution. However, several parameters of several vehicle classes showed a good fit to the log-normal distribution. Table 23 shows the travel parameters and vehicle classes which were found to fit the log-normal distribution, as well as the KSL D-Value and Critical Value.

The Travel Characteristics analyses classify the North Carolina commercial vehicles into 4 classes according to the vehicle body type. The Knox County vehicles are grouped into 3 classes according to ownership (which also distinguishes between vehicle body types). The statistical software JMP 5.1 was used to conduct the Tukey-Kramer test in order to explore the significant differences for all possible pairs of means. The means of each of the 6 Travel Characteristics (Daily VMT, Daily Number of Trips, Daily Speed, Trip Length, Trip Travel Time and Stop Duration) of all 7 classes were compared to each other, in order to investigate the possibility of further aggregation of the 7 classes based on similarities in the key travel characteristics. The means comparisons overall supported the aggregation of the 7 original vehicle classes into 4 new classes, according to the vehicles' primary use. The North Carolina Vans, Pickups and Single Unit Trucks showed little significant overall difference in means in the 6 travel characteristics and were combined into one new Vehicle Usage Class named 'North Carolina Service Vehicles'. The North Carolina Combination Trucks and the Knox County USPS Station Delivery Vehicles again showed little significant overall difference in means in the 6 travel characteristics and were combined into a second new Vehicle Usage Class called

‘North Carolina and Knox County Long Haul Vehicles’. The means comparisons of the Knox County USPS Home/Business Mail Delivery Vehicles and the Package Pickup and Delivery vehicles in did not warrant combining them with any other vehicle class. Table 24 shows the basic statistics, that is, the average values and standard deviations calculated, when applicable, for each of the aggregated Vehicle Usage Classes.

Chapter 5

EMISSION ANALYSIS

North Carolina Data

Not all MOBILE6 model input parameters require the entry of distinct values for each vehicle class. Some parameters require values developed from the data of all vehicle classes pooled together; others require distinct values only for some vehicle classes whereas others do require distinct values for each vehicle class and age. This section presents the results of the analysis of the North Carolina dataset to develop the MOBILE6 model input parameters, as required for entry in order to run the model. Obviously, the development of all parameters is dependent on availability of data. The dataset does not include vehicles of all the vehicle classes and vehicle ages present in the MOBILE6 model, therefore the inputs are developed where applicable.

The MOBILE6 model primarily classifies vehicles based on the fuel used and the Gross Vehicle Weight Rating (GVWR). The survey did not collect data on the GVWR per se; rather it collected data on the 'Loaded Weight' and 'Empty Weight' for the vehicles. It did collect data though on the fuel used, make, model and model year for each vehicle in the survey. A search for the GVWR of the vehicles based on these 4 variables concludes that for some vehicles the GVWR is reported as the 'Loaded Weight', whereas for others the case is not so. Therefore in order to best classify the 266 vehicles into the appropriate MOBILE6 vehicle classes a combination of all the above variables is used, leading to the vehicle classification shown in Table 6.

The Annual Mileage Accumulation Rate is the first input parameter developed for the North Carolina vehicle data. The average daily mileage for each class and age of vehicles is multiplied by 250 (assuming 5 days/week, 50 weeks/year operation) and then divided by 100,000 for entry into the model files. For presentation purposes, an average annual mileage accumulation rate per vehicle for each vehicle class over all age groups (in that class that exist in the dataset) is presented in Figure 21. It can be seen from the figure that the annual rate for almost all vehicle classes in the dataset exceeds the corresponding default value provided by the model. The annual rates for the heavy diesel classes (HDDV8a and HDDV8b) are the only ones that are lower than the defaults, probably due to the fact that the dataset mainly focuses on intra urban vehicle trips, whereas typically these heavier vehicles tend to be used more for long haul travel than intra urban travel. In general, commercial vehicles are shown to have a much higher annual mileage than the one implied by the default rates. Appendix A, Table 25 shows the actual rates for each class and age of vehicles developed from the data; Table 26 shows the average annual rate by class of vehicles, that is, the data table for Figure 21. The average annual class rates developed from the default rates only include the rates for those vehicle ages present in the North Carolina dataset for a more equalized comparison. The annual default rates are based on a 365 days/year operation.

In the VMT By Hour input parameter, the total daily VMT is allocated to each of the 24 hours of the day (Figure 22). Whereas the plotted default values clearly show an am and a pm peak (rush hours), the plotted fractions for the North Carolina commercial vehicle dataset show only one, much higher peak occurring in between the 2 default peaks, that is from about 9 am to about 3 pm, with a sharper drop in the overnight period. This indicates that the bulk of commercial vehicle travel takes place largely in the midday period, avoiding the am and pm rush hour periods and operating within the day’s business hours. The data table is provided as Table 27 and also shows the designated Hour Index for each hour of the day. MOBILE6 nomenclature dictates the use of 24 Hour Indices for the 24 hours of the day, with the first Hour Index being the 6:00-6:59 am hour.

The Vehicle Miles Traveled Fraction by Average Speed (or Speed VMT) actually distributes the total hourly VMT into 14 'speed bins', shown in Table 28. This is nominally done for each of the 24 hours of the day (or 24 Hour Indices), in two sets, one for freeways and one for arterials/collectors. The North Carolina data do not distinguish between roadway classes, so only one distribution can be developed. The fractions developed from the data are substituted for the arterial/collector fractions in the model run, as most of the traveling of these commercial vehicles is thought to occur on these roadway classes rather than on freeways. Since the distribution is basically a 3-D matrix, the most feasible visual comparison is plotting the average of the developed fractions and the 2 sets of default fractions over 4 sets of hours (Figures 23 through 26). The chosen grouping scheme is: AM Peak Period (7:00-8:59 am), Midday Off Peak Period (9:00 am – 3:59 pm), PM Peak Period (4:00-5:59 pm) and Overnight Off Peak Period (6:00 pm – 6:59 am). The term 'Peak' refers to the conventional/default 'rush hour' commuting period. As seen in the plots, the plotted values developed from the North Carolina dataset have a smoother pattern than both default values with less extreme points, and tend to lie in between the two default curves. This may mean that commercial vehicles tend to travel more on arterial/collectors or even local streets than highways or interstates, which allow for higher speeds. Table 29 shows the complete set of Speed VMT fractions developed from the NC data. Tables 30 and 31 show the default Speed VMT fractions for Freeways and Arterials, respectively.

The MOBILE6 model requires the entry of the number of engine Starts per Day per vehicle only for certain vehicle classes, not all 28. The required classes also present in the North Carolina dataset are shown in Figure 27, along with the corresponding developed and default value for the class. The commercial vehicles are shown to have a smaller number of starts per day than the national average (default values). This may be due to the fact that commercial vehicles do not always turn their engines off at destinations. No deduction can be made for the LDDT12 class since there is only one vehicle in this class. Table 32 shows the data table for the chart.

The Start Distribution (Figure 28) shows the bulk of engine starts for the North Carolina commercial vehicles to occur between the hours of 8 am and 3 pm, consistent with their VMT By Hour pattern. They show a sharper drop in the overnight off peak hours as compared to the defaults. The latter are generally shown to rise (though not as dramatically) starting in the morning hours, throughout the midday off peak hours and peaking between 3:00-4:00 pm when the pm rush hour starts. The distribution table is included as Table 33.

The Soak Distribution (Figures 29 to 32) portrays the fraction of all engine starts in each hour of the day by time since the engine was turned off last (soak time). The average values developed for the North Carolina commercial vehicles are plotted along the average default values for the same 4 sets of hourly periods used for the Speed VMT distribution. Each Soak Index corresponds to a preset soak time in minutes. Soak Index 68 corresponds to the overnight engine off soak time (maximum), while Soak Index 1 corresponds to a soak time of 1 minute and so on. Naturally the soak index 68 is at its highest in the AM Peak Period when most vehicles make their first start for the day, dropping through the day. Soak times are distributed over the remaining soak indices in the Midday Off Peak and the PM peak periods. Overnight they diminish, while the high fraction for soak index 68 points out that many vehicles may make their first start for the day just before 7 am when the AM Peak Period starts.

The Weekday Trip Length Distribution (Figure 33) shows the distribution of all daily VMT by trip duration. Only Light Duty Gasoline Vehicles are required to be analyzed in the development of this distribution. The term 'trip duration' here, refers to the time lapse between an engine on and an engine off event. The North Carolina commercial vehicle values show about double the percent daily VMT being traveled in 10 minutes or less, as compared to the defaults. This may be explained by the operational efficiency gained by commercial vehicles in minimizing travel time between destinations. The remaining trip duration categories show that the percent daily VMT being traveled by commercial vehicles is comparable to the defaults, with the highest percent VMT in the 51 minutes or longer trip duration. Table 34 shows the data table for the distribution.

Knox County Data

This section presents the results of the analysis of the Knox County data in order to develop a second set of input parameters for the MOBILE6 model. The MOBILE6 vehicle classification for the Knox County vehicles is included in Table 7. The model specifications are followed in the development of this second set of input parameters. The procedures and assumptions used in this analysis are similar to the ones followed in the emission analysis of the North Carolina Data, unless any deviations are noted.

Figure 34 shows the average annual VMT (divided by 100,000) for the classes and ages of vehicles within those classes present in the Knox County vehicle data sample against the respective default values derived from the Annual Mileage Accumulation Rates MOBILE6 provides. It is clear that the trends are similar to the ones shown by the analogous North Carolina data analysis. The only class showing a somewhat lower annual VMT than the default is the LDGT1, which consists of the small USPS Home/Business delivery trucks. The annual VMT of almost all vehicle classes is found to exceed the default values of the model. A note must be made here that USPS vehicles operate 6 days/week whereas PUD companies' vehicles operate 5 days/week, and this fact was taken into account when calculating the annual (50 weeks/year in both cases) VMT. Table 35 shows all Annual Mileage Accumulation Rates for the Knox County vehicles against the respective default rates and the percent difference between the two. Table 36 shows the data table for Figure 34; the average annual VMT of all vehicle ages in each class in the Knox County vehicle sample against the respective default values as well as the percent difference between them.

Figure 35 shows the distribution of VMT by Hour of the day. The Knox County distribution agrees with the North Carolina distribution, which suggests that urban commercial vehicles do most of their traveling within the day's business hours avoiding the morning and evening rush hour periods. The 'scoop' around 12:00-13:00 indicates lunch breaks, which are more of an institution for the Knox County commercial vehicle sample than for the North Carolina one. The hourly fractions can be found in Table 37.

Figures 36 through 39 show the distribution of VMT by Speed for the same 4 combinations of hourly period as in the North Carolina data emission analysis. The Midday Off Peak and the PM Peak charts show the VMT to be distributed by en large between 5 and 35 mph; the AM Peak shows a concentration of the VMT between 15 and 40 mph. These three distributions are very different than the defaults. The Overnight chart shows less of a difference, perhaps due to the fact that the sample's VMT during these hours is primarily traveled by the USPS Station delivery vehicles, which make the longest trips and in many cases internal-external ones, warranting use of freeways, hence higher speeds. The complete set of Speed VMT fractions developed from the Knox County data are shown in Table 38.

Figure 40 shows the number of Starts per Day per vehicle for the vehicle classes present in the Knox County data and also required by MOBILE6. The HDGV2b vehicles show a vast difference with the default value, due to the fact that they belong to the Package PUD Companies and turn the engine off (and on) at every single destination/address they visit. The starts per day for LDGT1 and LDGT2 again exceed the defaults, although these vehicles are primarily composed of USPS Home/Business Mail Delivery vehicles, which only have the engines turned off at dismount locations. The starts per day for the Knox County vehicles are higher than the defaults, in contrast to the starts per day of the North Carolina vehicles, which are shown to be somewhat lower. Table 39 shows the values for Figure 40.

Figure 41 shows the Distribution of engine Starts throughout the day. A similar pattern to the one obtained for the VMT distribution by hour of the day is shown, as is the case with the North Carolina vehicles. In addition, the Start Distribution of the Knox County vehicles shows the same lunch break 'scoop' around 12:00-13:00 shown in the VMT by Hour distribution. The hourly fractions can be found in Table 40.

Figures 42 to 45 show the Soak Distributions (fraction of hourly starts by time since last engine off event) for the same 4 hourly periods used in the Speed VMT Distribution as well as in the respective analysis for the North Carolina vehicles. In general, soak times for the Knox County vehicles are concentrated at the lower end of the scale, signaling their short stops and time dependent operation. Naturally, the AM Peak distribution shows a high fraction of starts occurring after an overnight soak time (index 68), as is the case with the North Carolina Vehicles, although here, the fraction is lower than the default. As several Knox County vehicles start their day around 8:00 am, fractions for soak indices 1 to 4 are higher than defaults in the AM Peak period, and continue to rise throughout the workday (Midday Off Peak and PM Peak). In the Overnight Off Peak period commercial vehicle activity decreases sharply, with some vehicles starting their day before 7:00 am, hence the high fraction of engine starts occurring after an overnight soak (index 68).

Figure 46 shows that the Knox County Light Duty Gasoline vehicles have most of their daily VMT in the 10 minutes or less and the 11 to 20 minutes ranges; the percent daily VMT in these 2 ranges is much higher than the default values. The remaining trip durations show a lower percent VMT than the default values. The Knox County LDGTs in the sample are primarily USPS Home/Business Mail Delivery vehicles, which only have their engines turned off at dismount locations. They are shown to make more trips of short durations. In contrast, the North Carolina data trip length distribution is not very different than the default distribution. The data for the Weekday Trip Length Distribution can be found in Table 41.

Input Parameter Summary

Table 42 summarizes the findings of the North Carolina data and the Knox County data analyses for the development of the MOBILE6 input parameters as they compare with the default values the model provides.

Emission Factor Results

North Carolina and Knox County Runs

The emission factor results from several runs of the MOBILE6 model are presented and discussed in this section. The first run uses the model's default values for all input parameters and serves as a benchmark for all subsequent runs. All subsequent runs show the percent change in each emission factor compared with the respective emission factor obtained from the default run. All runs use the same values for the minimum input requirements of the model, for better comparison of results:

- Calendar Year of Evaluation: 2004
- Minimum Temperature: 60.0 F
- Maximum Temperature: 90.0 F
- Nominal Fuel Reid Vapor Pressure (RVP): 9.0 psi

The second run substitutes some of the input parameters with the developed values from the North Carolina dataset analysis. The third run substitutes some of the input parameters with the developed values from the Knox County dataset analysis. Both of these runs use the respective developed values or distributions in place of the defaults for the following 7 input parameters:

- Annual Mileage Accumulation Rates
- VMT Distribution by Hour of Day
- VMT Distribution by Average Speed (developed distribution substituted for the default arterial distribution)
- Starts Per Day (developed values substituted for the default weekday values)
- Start Distribution by Hour of Day (developed distribution substituted for the default weekday distribution)
- Soak Distribution (developed distribution substituted for the default weekday distribution)
- Trip Length Distribution (developed distribution substituted for the default weekday distribution)

Tables 43 to 45 show the emission factors resulting from the Default Run, the North Carolina Run and the Knox County Run for the applicable vehicle classes, as well as the percent change as compared to the respective emission factor obtained from the Default Run. The EPA considers emission factor changes of 20% or higher to be 'major' and 5% to 20% to be 'intermediate'. The discussion of changes in the emission factors resulting from the various runs will concentrate on changes of around 20% or higher. Of all the input parameters changed in the North Carolina and Knox County runs, EPA sensitivity analyses show that changing the speed distribution (or average speed) has a major effect on emissions. Changing the mileage accumulation rates and starts per day has been found to have an intermediate effect on emissions. Therefore, additional runs are conducted, each run using only one of these 3 non-default input parameters to investigate whether the change in the emission factor in the North Carolina and Knox County runs is due to using non-default Speed VMT arterial distribution, Mileage Accumulation Rates, or Starts per Day, or the combined effect of using non-default values for all the 7 inputs listed above. The results of these single non-default input runs are shown in Table 46.

The most notable change in the emission factors obtained from the North Carolina Run is the 17% higher CO factor for Heavy Duty Gasoline Vehicles (HDGV) compared to the Default Run. The single non-default input run using only the North Carolina Mileage Accumulation Rates yields a 12% CO increase for HDGVs. The single non-default input run using only the North Carolina Speed VMT distribution yields a 7% CO increase. The single non-default input run using only the North Carolina Starts per Day input values shows no change in the CO of HDGVs. Therefore the 17% CO increase for HDGVs in the North Carolina run can be attributed primarily to the use of the North Carolina Annual Mileage Accumulation Rates of HDGVs, which are shown to be higher than the defaults (Figure 21), and secondarily to the use of the North Carolina non-default Speed VMT distribution.

The Knox County Run yields 79% higher VOC and 46% higher CO for HDGVs; 26% higher VOC and 32% higher CO for HDDVs; and 23% lower CO for LDGTs.

The single input run using only the non-default Knox County Starts per Day yields a 96% increase in the VOC of HDGVs, due to the much higher than default value of Starts per Day for class HDGV2b (Figure 40). The number of Starts per Day affects the evaporative hot soak losses of HDGVs (primarily hydrocarbons), which occur at trip ends. It does not affect the emissions from HDDVs and MOBILE6 does not allow user substitution of the defaults for the Starts per Day for HDDVs. The single input run using only the Knox County Speed VMT distribution shows a 24% increase in the CO factor of HDGVs so it is the most likely input parameter that causes the 46% higher CO in the Knox County run.

The single input run using only the Knox County Speed VMT distribution also shows a 20% increase in VOC and a 24% increase in CO of HDDVs. Thus, the 26% VOC increase and the 32% CO increase for HDDVs resulting from the Knox County run can be primarily attributed to the use of the non-default Speed VMT distribution.

None of the results of the single input runs can explain the 23% lower CO for LDGTs, so it has to be assumed to be due to the combined effect of using all 7 non-default input parameters in the Knox County Run.

Vehicle Usage Class Runs

The results from four additional runs of the MOBILE6 model are presented next. The purpose of each run is to investigate the effects of each Vehicle Usage Class on the emission factors. As already mentioned, the use of a non-default Average Speed value has a major effect on the emission factors and the use of non-default Mileage Accumulation Rates and Starts per Day has an intermediate effect. The mileage data of the North Carolina and the Knox County vehicles were combined into a single Annual Mileage Accumulation Rate file, to substitute the default in all 4 runs. An Average Speed value and an average number of Starts per Day were calculated for each of the 4 Vehicle Usage Classes. The number of Starts per Day substituted the default value only for the MOBILE6 classes present in the Vehicle Usage Class, if permitted by the model. Table 47 summarizes the non-default input values used in each run of the MOBILE6 model by Vehicle Usage Class.

The default Areawide VMT distribution by facility is used in all 4 runs: 34.2% Freeways, 49.8% Arterials/Collectors, 13.0% Local and 3.0% Freeway Ramps. The default daily Average Speed for these 4 roadway types is 36.5 mph, 31.2 mph, 12.9 mph and 34.6 mph respectively. The VMT distribution and the default Average Speed values apply to all vehicle classes. The user cannot substitute the default speed for Local roadways and Freeway Ramps. Therefore the user input of an Average Speed value only applies to the Freeway and Arterial/Collector Average Speeds only. Also, MOBILE6 does not allow for user input of Starts per Day for HDDVs or for any HDGV class except HDGV2b. Thus the average number of Starts per Day in runs where the Vehicle Usage Class includes HDGVs was substituted for the HDGV2b default value.

Table 48 shows the emission factor results of the 4 Vehicle Usage Class Runs for the primary MOBILE6 vehicle classes in each Vehicle Usage Class. The percent change compared to the Default Run is also shown and the benchmark value of 20% will be used to discuss major changes in the emission factors. In runs where major changes in the emission factors result, additional runs were conducted to determine whether the change is due to the use of a non-default Average Speed or the use of non-default Starts per Day. In each of these additional runs, the combined Mileage Accumulation Rates were used, so some of the percent change, calculated in relation to the Default Run, is due to the change in this input. The discussion will concentrate on comparing the percent changes between the use of a non-default Average Speed and non-default Starts per Day, however, since it has already been made evident from the North Carolina and Knox County runs that the non-default Annual Mileage Accumulation Rates did not make a major contribution to any changes in the emission factors. The results of these single non-default input runs are shown in Table 49.

Run 1 (which consists of the Knox Co. USPS Home/Business Mail Delivery Vehicles) shows increases of 67% in VOC, 32% in CO and 31% in NOx for all LDGTs. When only the Average Speed is changed and the default Starts per Day values are used, the results show a 45% VOC increase, an 8% CO increase and a 20% NOx increase for

LDGTs. Therefore, it is safe to say that the primary reason for the 67% VOC increase and the 31% NOx increase in Run 1 is the use of the 12.1 Average Speed. The 32% CO increase is primarily due to the use of 14.3 as the number of Starts per Day of LDGTs since the single input run for Starts per Day only shows a 27% CO increase. EPA sensitivity analyses have shown all 3 emission factor to increase at average speed values below 20 mph.

Run 2 (the Knox County Package PUD Vehicles) shows increases of 105% in VOC and 53% in CO for HDGVs. The single input run that only used 19.4 mph for the Average Speed value and the default values for Starts per Day yields a 30% VOC increase and an equal (53%) CO increase for HDGVs. The single input run that only changed the Starts per Day shows a 76% VOC increase and a 16% CO increase for HDGVs. Thus the 105% VOC increase is primarily due to the change of the Starts per Day for class HDGV2b (81.8 versus the default of 6.88) and secondarily due to the change in the Average Speed value (19.4 mph versus 36.5 mph for freeways and 31.2 mph for arterials). The reverse is true for the 53% CO increase.

Run 2 also shows a 45% increase in both VOC and CO for HDDVs. Their emissions are not affected by the number of Starts per Day hence the same increases are observed in the single run that only changes the Average Speed. Thus, the 45% VOC and CO increases for HDDVs are due to the use of 19.4 mph as the Average Speed value.

Run 3 (North Carolina Service Vehicles) and Run 4 (North Carolina and Knox County Long Haul Vehicles) do not yield any dramatic changes in any of the emission factors for any of the included MOBILE6 classes. The minimal changes shown can hence be attributed to the combination of the moderate changes in Average Speed and the Starts per Day, and of course the non-default Annual Mileage Accumulation Rates. As already mentioned, the number of Starts per Day is not an issue for HDDVs. Any changes in the HDDV emission factors are due to changes in Average Speed and Mileage Accumulation Rates. The results are not surprising because both Average Speed values used in Runs 3 and 4 (29.0 mph and 34.3 mph respectively) are not very different than the default MOBILE6 average speeds of 36.5 mph for freeways and 31.2 mph for arterials.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Similarities and differences in travel characteristics between various types of commercial vehicles are attributed to an array of independent or intertwined factors, mainly the industry they operate in, which affects the vehicle size and type and the manner in which the vehicles are used. In general, different industries have different needs and operate the type(s) of vehicles that will best meet them. This research demonstrates that similarities do exist between vehicles operating in different industries. Thus, any similarities or differences in travel characteristics between commercial vehicles depend on the manner in which they are used, which may or may not vary between different industries.

The North Carolina commercial vehicle dataset originally contained 4 vehicle classes (Vans, Pickups, Single Unit Trucks and Combination Trucks) and the Knox County commercial vehicle dataset originally contained 3 vehicle classes (USPS Home/Business Mail Delivery Vehicles, USPS Station Delivery Vehicles and Package PUD Vehicles). Statistical tests to compare all pairs of means for each of 6 Travel Characteristics (Daily VMT, Daily Number of Trips, Daily Speed, Trip Length, Trip Travel Time and Stop Duration) between the 7 vehicle classes were conducted. The means comparisons overall supported the aggregation of the 7 original vehicle classes into 4 new classes, according to the vehicles' primary use.

The statistical tests of the travel characteristics demonstrated that the North Carolina Combination Trucks could be aggregated with the Knox County USPS Station Delivery Vehicles into one 'Long Haul' Usage Class. The tests also demonstrated that aggregation of the North Carolina Vans, Pickups and Single Unit Trucks into a second 'Service Vehicle' Usage Class was also possible. The travel characteristics of the USPS Home/Business Mail Delivery Vehicles and of the Package PUD Vehicles proved to be distinctly different so their aggregation with any other vehicle class was not warranted.

General conclusions from the Emission Analysis, supported by both the development of MOBILE6 input parameters from the North Carolina data and the Knox County data include:

The two commercial vehicle datasets show higher Annual Mileage Accumulation Rates compared to the default values for the respective vehicle classes and ages. Vehicles of almost all ages are shown to have a higher annual mileage than the default values, leading to the conclusion that the amount of usage of commercial vehicles may be more prolonged than suggested by the defaults.

In addition, MOBILE6 in its calculations translates the annual VMT rate to a daily VMT rate by dividing by 365. Most commercial vehicles though, operate 5 days/week with some operating 6 days/week (e.g. USPS vehicles). This fact needs to be taken into account in future versions of the MOBILE model, at least for the heavier vehicle classes (gasoline and diesel) since they are exclusively composed of commercial vehicles. Medium to light vehicle classes include privately owned as well as commercially used vehicles. Two sets of Annual Mileage Accumulation Rates would need to be developed for each of these vehicle classes, one for the privately owned vehicles and one for the commercial vehicles. The current set of default Rates are based on the 1992 Vehicle Inventory and Use Survey, which did not make a distinction between private and commercial vehicles. There is a need to update these defaults based on data from the 1997 version of the Survey or, when available, from the 2002 Survey.

The two distributions of VMT by Hour of Day (further supported by the distributions of Engine Starts by Hour of Day) indicate that commercial vehicle travel patterns are very different compared to the default curves. It is shown that urban commercial vehicle travel primarily occurs within the two daily peak (am and pm) travel periods shown by the defaults. Future versions of the MOBILE model may need to include two VMT by Hour and two Starts by Hour distributions, one for privately owned vehicles and one for commercially used vehicles.

The Starts Per Day values and the Trip Length Distribution for the North Carolina dataset support the default values whereas the Knox County data analysis results do not. The VMT by Speed curves are also different than the defaults and from each other.

The following conclusions can be drawn from the Emission Factor Results of the various MOBILE6 runs that were conducted:

The first run used all non-default inputs developed from the North Carolina commercial vehicle data. The only notable emission factor change was a 17% increase in CO for Heavy Duty Gasoline Vehicles, compared to the initial run which used default values for all inputs. It was determined from single non-default input runs that the primary reason for the CO increase is the higher than default Annual Mileage Accumulation Rates for the North Carolina commercial vehicles.

The second run used all non-default inputs developed from the Knox County commercial vehicle data. This run produced increases of 79% in VOC and 46% in CO for HDGVs. The single non-default input runs determined that the VOC increase is primarily due to the much higher Starts per Day of HDGVs and that the CO increase is primarily due to the different Speed VMT distribution, in comparison to the defaults. The run also produced a 26% VOC increase and a 32% CO increase for Heavy Duty Diesel Vehicles (HDDVs). The single non-default input runs determined both the VOC and the CO increase to be due to the different Speed VMT distribution of the Knox County commercial vehicles in comparison to the default.

The first Vehicle Usage Class Run (USPS Home/Business Mail Delivery Vehicles) produced increases of 67% in VOC, 32% in CO and 31% in NOx for Light Duty Gasoline Trucks (LDGTs - the primary MOBILE6 vehicle class present in this Vehicle Usage Class). The single non-default input runs determined that the use of these vehicles' Average Speed of 12.1 mph is the main reason for the VOC and NOx increases, while the CO increase is due to their 14.3 average Starts per Day. By comparison, the default Average Speed is 36.5 mph for Freeways and 31.2 mph for Arterials. The default number of Starts per Day is 8.06 for LDGTs and 6.88 for HDGV2b.

The second Vehicle Usage Class Run (Package PUD Vehicles) produced increases of 105% in VOC and 53% in CO for HDGVs (which together with HDDVs are the primary MOBILE6 vehicle classes present in this Vehicle Usage Class). The single non-default input runs determined that the VOC increase is due mainly to these vehicles' 81.8 average Starts per Day, while the CO increase is due to their Average Speed of 19.4 mph. This run also produced increases of 45% in both VOC and CO for HDDVs. The single non-default input runs determined both to be due to their 19.4 mph Average Speed.

The third and fourth Vehicle Usage Class Runs, one for Service Vehicles and one for Long Haul Vehicles did not produce any major changes in any emission factors. Their Average Speeds are 29.0 mph and 34.3 mph respectively are not very different than the default values, as is the case with their 5.7 average Starts per Day (Starts per Day only affect HDGVs not HDDVs). Hence their operations do not cause any major changes in the emission factors produced by the Default Run.

This study is by no means all inclusive, but it may help demonstrate the need for future research on the specific travel characteristics of various types of urban commercial vehicles and each type's effect on air quality in terms of the MOBILE6 model.

Recommendations for Future Research

The growth trends in urban freight transportation, particularly package pickup and delivery are likely to continue in the future, both in periods of booming economy and in periods of sluggish economy. Rising demand for timely transport of goods will lead to additional growth in truck pickups, deliveries and VMT. Ultimately, the effects of this growth will become more obvious on the already strained urban transportation system.

The anticipation of the growth in urban freight transport activities necessitates that the research community is in possession of the essential knowledge on the operations of urban freight vehicles, in order to remedy or possibly prevent the adverse effects of this unavoidable growth. Therefore, additional research is required in order to further analyze the travel characteristics of urban commercial vehicles. Investigation on the existence of any similarities in travel characteristics or lack thereof among the various types and sizes of vehicles operating in various industries will greatly enhance the research community's comprehension.

It has already been stated that there exists a need for an update of the default Annual Mileage Accumulation Rates included in the MOBILE6 model. The current defaults are based on the 1992 Vehicle Inventory and Use Survey (VIUS) and are in need of an update. At the time of this writing the 2002 VIUS results are not yet available to the public, only the 1997 VIUS results are available. The 1992 VIUS did not distinguish between private and commercial vehicles, hence there is a need to do in future VIUS in order to investigate the differences in annual mileage and other characteristics between the two, on a fleet scale basis. The need and the ability to produce two sets of Annual Mileage Accumulation Rates for use with the MOBILE6 model may then arise.

Based on the conclusions of this research on the hourly operational pattern of commercial vehicles compared to the defaults, there also is a need to investigate the possibility of developing two distributions for VMT by Hour and two for Engine Starts by Hour of Day, one for private vehicles and one for commercial vehicles for each parameter. In addition, there is a need for revision of the model's assumption that all vehicles, regardless of whether they are private or commercial, operate 365 days per year.

There is also a need to measure the fraction of VMT by road type represented by the various commercial vehicle classes, for example Package PUD vehicles. This would required detailed vehicle classification counts of representative roadways, either through manual or automated means.

Clearly, in order for any type of future research to be facilitated, data collection efforts need to be periodical, thorough, more spatially and temporally consistent, and take place through the appropriate government agencies. At the moment, the necessary data are not widely available or are deemed proprietary by the corporate sector.

The data collection efforts need to ensure that the vehicle samples adequately represent the urban commercial vehicle population both in quality and quantity. A variety of urban areas and commercial vehicles employed by a variety of industries need to be sampled, periodically if possible. The most effective method for data collection has been found to be the one-day trip diary, provided that it is properly conducted by the participants. Another drawback of the one-day trip diary method is that it is time and effort consuming, both for the researchers and the participants. In any case, it is likely that data requests in any form from the private sector will be greeted with mistrust and reluctance. Therefore, the data collection may be more effective if it is conducted under the auspices of a related government agency either at the local, state or federal level.

It is beneficial for government at all levels to be aware of the travel characteristics of urban commercial vehicles in order to better include them in city planning analyses, traffic control and air quality analyses, among others.

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APPENDICES

APPENDIX A

Table 1. Findings of Cambridge Systematics Report

Data Source	Avg VMT/Veh/Day	Avg # Trips/Veh/Day
Atlanta CV Survey	33.16	2.70
Denver CV Survey	9.65	2.05
Detroit CV Survey	85.77	7.18
Triad CV Survey	27.43	3.86
California DMV Data	76.1	Not Reported
Atlanta USPS Data	24.6	Not Reported
Denver USPS Data	17.1	Not Reported
Detroit USPS Data	17.1	Not Reported
Greensboro USPS Data	23.8	Not Reported
Houston USPS Data	18.8	Not Reported
Orlando USPS Data	19.6	Not Reported
Portland USPS Data	16.1	Not Reported

Table 2. Findings from Commercial Vehicle Surveys/Studies

DATA ITEM	NYC CBD	PHOENIX	ALAMEDA	PIEDMONT TRIAD	EL PASO
Companies/Industry Types	59 Shippers (S), 15 Motor Carriers I; Carriers include Truck Load (TL) and Less Than TruckLoad (LTL)	DMV Registered Vehicles and USPS Vehicles		Industrial, Retail, Special Retail, Service, Office, Other	
# Commercial Vehicles Sampled		527 + 62 USPS		420 Trucks + 86 Cars	88 Trucks Registered in El Paso County
Vehicle Types or Weight Categories	S:Vans, Step Vans, Pickup Trucks, Straight Trucks, Tractor Trailers C: Vans, Straight Trucks, Tractor Trailers	0-8,000 lbs 8,000-28,000 lbs 28,000-64,000 lbs 64,000 lbs+	2 Axle 3 Axle 4+ Axles	24% Single Unit Trucks (SUT), 9% Combination Trucks (CT), 30% Pickup Trucks (PUT), 20% Vans (V), 17% Cars	
Vehicle Size (ft) or Weight (lbs)	Shippers: 8-53' (most <9') Carriers: 14-53'	11,870 lbs/trip			Vehicles of Gross Vehicle Weight 8,500 lbs and up
Trip Characteristics		4777 Total Vehicle Trips	3800 Port trips + 2700 other trips	2751 Total Commercial Vehicle Trips	
Average Number of Daily Trips Per Commercial Vehicle, by Vehicle Type where applicable	Intra CBD Trips: Shippers: 4/day Carriers: TL 1/day LTL: 14/day Add 2 for to and from CBD trips	0-8K lbs: 5.6 8K-28K lbs: 9.6 28K-64K lbs: 6.8 64K lbs+: 4.0 Overall avg: 6.1 Light:12.1 Heavy: 4.7; 96.6% of trips made by 2 lightest weight categories	2 Axle: 69% of Total Trips 3 Axle: 8% 4+ Axle: 23% of Total Trips Large trucks: 75% of truck travel except pickups	Cars=7.1 Vans=6.5, Pickups=7.2 Single Unit Trucks=8.6 Comb. Trucks=7.3 Overall=7.4	
Regional/Local vs Through Trips	Last Link Into Manhattan, usually from New Jersey	Vehicles operating within Phoenix Metropolitan Area	35% Regional Garage Based, 59% Regional Linked, 6% External	Regional/Local Origin of 97% of first trips was Base	Regional/Local
Avg Trip Length (miles)	Shippers: 27 miles Carriers: 45 miles	Overall: 10.2 miles 0-8K lbs: 11 8K-28K lbs: 4.7 28K-64K lbs: 9.2 64K lbs+: 33.4			
Avg Trip Duration	Shippers: 6.5 hrs Carriers: 5.5 hrs	Overall: 28.1 min 0-8K lbs: 16.4 min 8K-28K: 11.9 min 28K+: 18.8 min	Internal trips only: 2 Axle: 19 min 3 Axle: 21 min 4+ Axle: 34 min	SUT:19 min CT: 38 min PUT: 18 min V:38 min C:19 min	
Average VMT/day-vehicle	Shippers: 60 Carriers:100	Overall: 78.5 0-8K lbs: 79 8K-28K lbs: 56 28K-64K lbs: 74 64K lbs+: 157		SUT:98, CT: 181, PUT:58, V: 69, C=77 Overall=85	

Table 2. Continued.

DATA ITEM	NYC CBD	PHOENIX	ALAMEDA	PIEDMONT TRIAD	EL PASO
Time of first trip	S:2-1030 am C: 6-9 am	Light Vehicles: 6-9 am Heavy Vehicles: before 6am			
Time-of-day Distribution		Peak: 9am-2pm	Midday		
Truck Travel during Peak Periods		13% of heavy truck travel from 11am-2pm		Truck Trips AM Peak: 15% Truck Trips Off-Peak: 18% Truck Trips PM Peak: 67%	
Truck Traffic % Volume during Peak Periods			Heavy trucks: 10%+ of traffic		
Day-of-Week Distribution	Carriers: 5 days/wk Express Carriers: 6-7 days/week			5 days/week	
Truck Travel by Road Facility Type			5000 daily port truck trips are local, non FWY		Key Facility Route Data Collected
Stop Characteristics					
Avg Stops Per Day Per Vehicle	Shippers: 5 Carriers: TL 2, LTL 15				
On-Street Stops		All trucks: 33%+ of all stops were on street; Light trucks: 50% of stops were on-street			
Avg Time at Stops	23 min on street 36 min on dock				Results not available
Engine Off				Yes: 79% No: 21% of all trucks	
Trips & Land Use					
Trips by Land Use		Medium Truck Trips: residential (trash) Heavy Truck Trips: 27% residential (construction mtls) 42% work trips (Company vehicle)	25% of trips=Retail (Retail Trucks: 5.3 trips/day) 20% Manufacturing 20% Terminals/Warehouses Overall Avg: 12.6 truck trips/100 Employees	23% Office, 23% Retail, 28% Manufacturing, 12% Residential, 2% Port, .6% Utilities, 4% Construction Trips	
Activities at Trip Ends		Light trucks: largely services & personal Heavy trucks: cargo load/unload		35% Trips: Unload 20% Trips: Return to Base 16%: Load 11%: Other business 4%: Personal 3%: Fuel	

Table 3. MOBILE6 Vehicle Classes

Class Number	Abbreviation	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, >5,750 lbs. ALVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)
ALVW=Alternative Loaded Vehicle Weight: The adjusted loaded vehicle weight is the numerical average of the vehicle curb weight (empty weight) and the gross vehicle weight rating (GVWR), which is the empty weight + maximum load).		

Table 4. MOBILE6 Composite Vehicle Classes

Class Number	Abbreviation	Description
1	LDV	Light-Duty Vehicles (Passenger Cars)
2	LDT1	Light-Duty Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDT2	Light-Duty Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDT3	Light-Duty Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
5	LDT4	Light-Duty Trucks 4 (6,001-8,500 lbs. GVWR, > 5,750 lbs. ALVW)
6	HDV2b	Class 2b Heavy-Duty Vehicles (8,501-10,000 lbs. GVWR)
7	HDV3	Class 3 Heavy-Duty Vehicles (10,001-14,000 lbs. GVWR)
8	HDV4	Class 4 Heavy-Duty Vehicles (14,001-16,000 lbs. GVWR)
9	HDV5	Class 5 Heavy-Duty Vehicles (16,001-19,500 lbs. GVWR)
10	HDV6	Class 6 Heavy-Duty Vehicles (19,501-26,000 lbs. GVWR)
11	HDV7	Class 7 Heavy-Duty Vehicles (26,001-33,000 lbs. GVWR)
12	HDV8a	Class 8a Heavy-Duty Vehicles (33,001-60,000 lbs. GVWR)
13	HDV8b	Class 8b Heavy-Duty Vehicles (>60,000 lbs. GVWR)
14	HDBS	School Buses
15	HDBT	Transit and Urban Buses
16	MC	Motorcycles (Gasoline)
ALVW=Alternative Loaded Vehicle Weight: The adjusted loaded vehicle weight is the numerical average of the vehicle curb weight (empty weight) and the gross vehicle weight rating (GVWR), which is the empty weight + maximum load).		

Table 5. NC Data Companies - SIC Codes and Categories

SIC	Number of Companies	Standard Industrial Classification Code Description	Broad SIC Category	Number of Companies
3	2	No Description Provided	A. Agriculture, Forestry, & Fishing	3
8	1	Forestry		
13	1	Oil & Gas Extraction	B. Mining	2
14	1	Nonmetallic Minerals, except Fuels		
15	8	General Building Contractors	C. Construction	26
16	3	Heavy Construction, except Building		
17	14	Special Trade Contractors		
18	1	No Description Provided		
20	5	Food & Kindred Products	D. Manufacturing	74
22	3	Textile Mill Products		
23	2	Apparel & Other Textile Products		
24	5	Lumber & Wood Products		
25	7	Furniture & Fixtures		
26	4	Paper & Allied Products		
27	6	Printing & Publishing		
28	5	Chemical & Allied Products		
29	2	Petroleum & Coal Products		
30	7	Rubber & Miscellaneous Plastics Products		
31	1	Leather & Leather Products		
32	5	Stone, Clay, & Glass Products		
33	4	Primary Metal Industries		
34	3	Fabricated Metal Products		
35	6	Industrial Machinery & Equipment		
36	2	Electronic & Other Electric Equipment		
37	1	Transportation Equipment		
38	1	Instruments & Related Products		
39	5	Misc. Manuf. Industries		
42	17	Trucking & Warehousing	E. Transportation & Public Utilities	31
45	2	Transportation by Air		
46	1	Pipelines, Except Natural Gas		
47	3	Transportation Services		
48	5	Communications		
49	3	Electric, Gas, & Sanitary Services		
50	20	Wholesale Trade- Durable Goods	F. Wholesale Trade	29
51	9	Wholesale Trade- Nondurable Goods		
52	6	Building Materials& Gardening Supplies	G. Retail Trade	45
53	2	General Merchandise Stores		
54	1	Food Stores		
55	9	Automative Dealers & Service Stations		
56	1	Apparel & Accessory Stores		
57	13	Furniture & Homefurnishings Stores		
58	2	Eating & Drinking Places		
59	11	Miscellaneous Retail		
62	1	Security & Commodity Brokers	H. Finance, Insurance, & Real Estate	5
65	4	Real Estate		
72	1	Personal Services	I. Services	36
73	12	Business Services		
75	9	Auto Repair, Services, & Parking		
76	3	Miscellaneous Repair Services		
79	2	Amusement & Recreation Services		
80	2	Health Services		
82	1	Educational Services		
83	3	Social Services		
87	3	Engineering & Management Services		

Table 5. Continued.

SIC	Number of Companies	Standard Industrial Classification Code Description	Broad SIC Category	Number of Companies
91	2	Executive, Legislative, & General	J. Public Administration	7
95	2	Environmental Quality & Housing		
96	2	Administration of Economic Programs		
99	1	Non classifiable Establishments		
	258			258

Table 6. NC Data - MOBILE6 Vehicle and Trip Classification

MOBILE6 Class	MOBILE6 Class Number	Number of Vehicles	Number of Trips
LDGT2	3	73	530
LDGT4	5	37	233
HDGV2b	6	23	131
HDGV3	7	17	97
HDGV4	8	9	51
HDGV6	10	8	50
HDGV7	11	5	40
HDGV8a	12	2	48
LDDT12	15	1	4
HDDV2b	16	5	56
HDDV3	17	1	9
HDDV5	19	6	60
HDDV6	20	13	77
HDDV7	21	18	193
HDDV8a	22	28	204
HDDV8b	23	20	149
Total		266	1932

Table 7. Knox Co. Data – Vehicle and Trip Cross Classification

MOBILE6 Class	MOBILE6 Class Number	Owner			MOBILE6 Class Total	
		USPS Home/Business Mail Delivery	USPS Station Delivery	Package PUD Companies	Total Vehicles	Total Trips
LDGT1	2	193			193	2673
LDGT2	3	13		6	19	371
LDGT4	5	39		3	42	383
HDGV2b	6			19	19	1480
HDGV3	7			24	24	1536
HDGV5	9			12	12	1154
HDGV6	10			20	20	1848
HDDV2b	16	9		6	15	813
HDDV3	17			17	17	1490
HDDV4	18			36	36	3429
HDDV5	19			9	9	780
HDDV6	20			69	69	5893
HDDV7	21		8	3	11	233
HDDV8b	23		7		7	56
Total Vehicles		254	15	224	493	22139
Total Trips		3627	192	18320	22139	

Table 8. NC Data - Travel Parameters

Travel Characteristic	Statistic	Vehicle Body Type				Overall
		Vans	Pickups	Single Unit Big Trucks	Combination Big Trucks	
Number of Vehicles		51	100	82	33	266
Number of Trips		297	689	696	250	1932
Loaded Weight Per Vehicle (lbs)	Average	6021	10060	27070	53580	
	Standard Deviation	2400	8678	17047	23176	
VMT Per Vehicle Per Day	Average	79.3	59.1	92.6	176.3	87.8
	Standard Deviation	82.8	66.0	90.9	142.2	95.9
Number of Trips Per Vehicle Per Day	Average	5.8	6.9	8.5	7.6	7.3
	Standard Deviation	4.1	5.1	7.4	4.8	5.8
Daily Speed Per Vehicle (mph)	Average	32.2	26.4	30.3	35.6	29.9
	Standard Deviation	15.6	13.8	17.9	12.6	15.6
Trip Length (miles)	Average	13.6	8.6	10.9	23.3	12.1
	Standard Deviation	20.4	14.3	21.6	37.0	22.4
Trip Travel Time (minutes)	Average	23.1	17.9	20.1	35.8	21.8
	Standard Deviation	28.0	25.6	30.0	44.3	31.0
Stop Duration Per Trip (minutes)	Average	38.2	34.9	28.0	33.5	32.7
	Standard Deviation	66.0	56.3	45.3	48.8	53.3
Number of Engine Starts Per Vehicle Per Day	Average	5.4	5.9	5.5	5.6	5.7
	Standard Deviation	3.7	4.1	4.6	4.1	4.2

Table 9. NC Data - Daily VMT Distribution Table

Daily VMT Per Vehicle	Vans		Pickups		Single Unit Big Trucks		Combination Big Trucks	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=10	7	13.7	16	16.0	8	9.8	0	0.0
>10, <=20	5	9.8	20	20.0	8	9.8	1	3.0
>20, <=30	4	7.8	14	14.0	7	8.5	1	3.0
>30, <=40	6	11.8	4	4.0	10	12.2	1	3.0
>40, <=50	6	11.8	9	9.0	4	4.9	2	6.1
>50, <=60	1	2.0	1	1.0	4	4.9	2	6.1
>60, <=70	1	2.0	6	6.0	3	3.7	1	3.0
>70, <=80	4	7.8	6	6.0	4	4.9	0	0.0
>80, <=90	1	2.0	3	3.0	2	2.4	1	3.0
>90, <=100	3	5.9	2	2.0	3	3.7	2	6.1
>100, <=110	1	2.0	3	3.0	1	1.2	2	6.1
>110, <=120	1	2.0	3	3.0	3	3.7	1	3.0
>120, <=130	0	0.0	1	1.0	2	2.4	1	3.0
>130, <=140	1	2.0	3	3.0	1	1.2	1	3.0
>140, <=150	0	0.0	0	0.0	1	1.2	0	0.0
>150, <=160	1	2.0	2	2.0	5	6.1	2	6.1
>160, <=170	1	2.0	1	1.0	1	1.2	3	9.1
>170, <=180	2	3.9	0	0.0	2	2.4	0	0.0
>180, <=190	2	3.9	0	0.0	3	3.7	0	0.0
>190, <=200	0	0.0	0	0.0	0	0.0	0	0.0
>200, <=210	0	0.0	0	0.0	0	0.0	2	6.1
>210, <=220	2	3.9	1	1.0	2	2.4	1	3.0
>220, <=230	0	0.0	0	0.0	1	1.2	1	3.0
>230, <=240	0	0.0	0	0.0	2	2.4	1	3.0
>240, <=250	0	0.0	0	0.0	0	0.0	0	0.0
>250, <=260	0	0.0	1	1.0	3	3.7	0	0.0
>260, <=270	0	0.0	1	1.0	1	1.2	1	3.0
>270, <=280	0	0.0	2	2.0	0	0.0	0	0.0
>280, <=290	0	0.0	0	0.0	0	0.0	1	3.0
>290, <=300	0	0.0	1	1.0	0	0.0	0	0.0
>300, <=700	2	3.9	0	0.0	1	1.2	5	15.2
Total	51	100.0	100	100.0	82	100.0	33	100.0

Table 10. NC Data - Number of Trips Per Day Distribution Table

# Trips Per Veh/day	**Vans**		**Pickups**		**Single Unit Big Trucks**		**Combination Big Trucks**	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	12	23.5	13	13.0	10	12.2	2	6.1
>2,<=4	12	23.5	28	28.0	21	25.6	6	18.2
>4,<=6	11	21.6	20	20.0	13	15.9	9	27.3
>6,<=8	5	9.8	16	16.0	9	11.0	8	24.2
>8,<=10	4	7.8	9	9.0	10	12.2	2	6.1
>10,<=12	3	5.9	3	3.0	6	7.3	0	0.0
>12,<=14	2	3.9	2	2.0	1	1.2	2	6.1
>14,<=16	1	2.0	4	4.0	3	3.7	3	9.1
>16,<=18	0	0.0	1	1.0	0	0.0	0	0.0
>18,<=20	1	2.0	0	0.0	1	1.2	0	0.0
>20,<=22	0	0.0	1	1.0	1	1.2	0	0.0
>22,<=24	0	0.0	2	2.0	3	3.7	1	3.0
>24,<=26	0	0.0	0	0.0	1	1.2	0	0.0
>26,<=28	0	0.0	0	0.0	1	1.2	0	0.0
>28,<=30	0	0.0	0	0.0	1	1.2	0	0.0
>30,<=45	0	0.0	1	1.0	1	1.2	0	0.0
Total	51	100.0	100	100.0	82	100.0	33	100.0

Table 11. NC Data - Daily Speed Distribution Table

Speed (mph) M6 Bins	**Vans**		**Pickups**		**Single Unit Big Trucks**		**Combination Big Trucks**	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2.5	0	0.0	0	0.0	1	1.2	0	0.0
>2.5,<=7.5	1	2.0	6	6.0	2	2.4	1	3.0
>7.5,<=12.5	5	9.8	8	8.0	7	8.5	1	3.0
>12.5,<=17.5	5	9.8	15	15.0	8	9.8	0	0.0
>17.5,<=22.5	7	13.7	12	12.0	15	18.3	2	6.1
>22.5,<=27.5	4	7.8	18	18.0	13	15.9	5	15.2
>27.5,<=32.5	2	3.9	9	9.0	9	11.0	5	15.2
>32.5,<=37.5	3	5.9	13	13.0	6	7.3	4	12.1
>37.5,<=42.5	9	17.6	8	8.0	3	3.7	6	18.2
>42.5,<=47.5	8	15.7	6	6.0	6	7.3	2	6.1
>47.5,<=52.5	2	3.9	0	0.0	1	1.2	4	12.1
>52.5,<=57.5	3	5.9	1	1.0	3	3.7	2	6.1
>57.5,<=62.5	1	2.0	2	2.0	2	2.4	1	3.0
>62.5,<=67.5	1	2.0	1	1.0	2	2.4	0	0.0
>67.5,<=72.5	0	0.0	0	0.0	2	2.4	0	0.0
>72.5,<=77.5	0	0.0	0	0.0	0	0.0	0	0.0
>77.5,<=82.5	0	0.0	1	1.0	1	1.2	0	0.0
>82.5,<=87.5	0	0.0	0	0.0	1	1.2	0	0.0
Total	51	100.0	100	100.0	82	100.0	33	100.0

Table 12. NC Data - Trip Length Distribution Table

Trip Length (miles)	Vans		Pickups		Single Unit Big Trucks		Combination Big Trucks	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	55	18.5	169	24.5	153	22.0	16	6.4
>2,<=4	47	15.8	167	24.2	141	20.3	30	12.0
>4,<=6	42	14.1	101	14.7	111	15.9	23	9.2
>6,<=8	30	10.1	53	7.7	66	9.5	21	8.4
>8,<=10	17	5.7	42	6.1	33	4.7	29	11.6
>10,<=12	12	4.0	34	4.9	39	5.6	10	4.0
>12,<=14	9	3.0	14	2.0	20	2.9	18	7.2
>14,<=16	10	3.4	15	2.2	24	3.4	16	6.4
>16,<=18	4	1.3	18	2.6	20	2.9	7	2.8
>18,<=20	12	4.0	17	2.5	11	1.6	8	3.2
>20,<=22	8	2.7	6	0.9	6	0.9	6	2.4
>22,<=24	7	2.4	8	1.2	11	1.6	2	0.8
>24,<=26	3	1.0	4	0.6	4	0.6	4	1.6
>26,<=28	8	2.7	5	0.7	5	0.7	0	0.0
>28,<=30	2	0.7	4	0.6	4	0.6	4	1.6
>30,<=32	2	0.7	4	0.6	4	0.6	3	1.2
>32,<=34	1	0.3	6	0.9	7	1.0	4	1.6
>34,<=36	4	1.3	2	0.3	5	0.7	5	2.0
>36,<=38	0	0.0	0	0.0	2	0.3	1	0.4
>38,<=40	3	1.0	0	0.0	2	0.3	2	0.8
>40,<=42	0	0.0	0	0.0	0	0.0	2	0.8
>42,<=44	2	0.7	3	0.4	1	0.1	3	1.2
>44,<=46	0	0.0	0	0.0	2	0.3	2	0.8
>46,<=48	3	1.0	1	0.1	3	0.4	1	0.4
>48,<=50	0	0.0	1	0.1	1	0.1	4	1.6
>50,<=52	1	0.3	0	0.0	1	0.1	2	0.8
>52,<=54	1	0.3	0	0.0	0	0.0	0	0.0
>54,<=56	3	1.0	1	0.1	1	0.1	0	0.0
>56,<=58	2	0.7	1	0.1	1	0.1	3	1.2
>58,<=60	1	0.3	1	0.1	1	0.1	1	0.4
>60,<=62	0	0.0	0	0.0	0	0.0	2	0.8
>62,<=64	0	0.0	1	0.1	0	0.0	2	0.8
>64,<=66	0	0.0	0	0.0	0	0.0	0	0.0
>66,<=68	0	0.0	0	0.0	0	0.0	2	0.8
>68,<=70	0	0.0	1	0.1	0	0.0	0	0.0
>70,<=320	8	2.7	10	1.5	17	2.4	17	6.8
Total	297	100.0	689	100.0	696	100.0	250	100.0

Table 13. NC Data - Trip Travel Time Distribution Table

Trip Travel Time (minutes)	Vans		Pickups		Single Unit Big Trucks		Combination Big Trucks	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	7	2.4	21	3.0	25	3.6	5	2.0
>2,<=4	10	3.4	34	4.9	43	6.2	3	1.2
>4,<=6	47	15.8	131	19.0	137	19.7	27	10.8
>6,<=8	10	3.4	45	6.5	18	2.6	6	2.4
>8,<=10	43	14.5	109	15.8	116	16.7	27	10.8
>10,<=12	7	2.4	15	2.2	28	4.0	0	0.0
>12,<=14	9	3.0	18	2.6	19	2.7	6	2.4
>14,<=16	46	15.5	99	14.4	81	11.6	34	13.6
>16,<=18	5	1.7	14	2.0	15	2.2	4	1.6
>18,<=20	20	6.7	44	6.4	29	4.2	16	6.4
>20,<=22	3	1.0	7	1.0	9	1.3	4	1.6
>22,<=24	2	0.7	7	1.0	12	1.7	2	0.8
>24,<=26	12	4.0	27	3.9	29	4.2	17	6.8
>26,<=28	4	1.3	8	1.2	6	0.9	3	1.2
>28,<=30	20	6.7	29	4.2	33	4.7	19	7.6
>30,<=32	0	0.0	7	1.0	5	0.7	0	0.0
>32,<=34	1	0.3	4	0.6	3	0.4	1	0.4
>34,<=36	5	1.7	8	1.2	8	1.1	7	2.8
>36,<=38	1	0.3	2	0.3	4	0.6	2	0.8
>38,<=40	7	2.4	10	1.5	12	1.7	5	2.0
>40,<=42	0	0.0	0	0.0	2	0.3	2	0.8
>42,<=44	1	0.3	3	0.4	1	0.1	1	0.4
>44,<=46	8	2.7	10	1.5	12	1.7	5	2.0
>46,<=48	0	0.0	1	0.1	0	0.0	0	0.0
>48,<=50	2	0.7	8	1.2	1	0.1	4	1.6
>50,<=52	0	0.0	2	0.3	0	0.0	1	0.4
>52,<=54	1	0.3	0	0.0	1	0.1	0	0.0
>54,<=56	1	0.3	4	0.6	3	0.4	4	1.6
>56,<=58	0	0.0	2	0.3	0	0.0	0	0.0
>58,<=60	5	1.7	4	0.6	7	1.0	6	2.4
>60,<=385	20	6.7	16	2.3	37	5.3	39	15.6
Total	297	100.0	689	100.0	696	100.0	250	100.0

Table 14. NC Data - Stop Duration Distribution Table

Stop Duration (minutes)	Vans		Pickups		Single Unit Big Trucks		Combination Big Trucks	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	17	6.9	43	7.3	34	5.5	4	1.8
>2,<=4	10	4.0	41	7.0	36	5.9	5	2.3
>4,<=6	49	19.8	75	12.7	91	14.8	20	9.2
>6,<=8	9	3.6	36	6.1	34	5.5	4	1.8
>8,<=10	17	6.9	58	9.8	52	8.5	21	9.7
>10,<=12	7	2.8	29	4.9	41	6.7	10	4.6
>12,<=14	5	2.0	8	1.4	16	2.6	4	1.8
>14,<=16	20	8.1	45	7.6	56	9.1	29	13.4
>16,<=18	6	2.4	5	0.8	13	2.1	4	1.8
>18,<=20	1	0.4	16	2.7	22	3.6	4	1.8
>20,<=22	8	3.2	23	3.9	25	4.1	10	4.6
>22,<=24	2	0.8	3	0.5	5	0.8	4	1.8
>24,<=26	10	4.0	23	3.9	17	2.8	7	3.2
>26,<=28	1	0.4	6	1.0	4	0.7	1	0.5
>28,<=30	9	3.6	10	1.7	15	2.4	12	5.5
>30,<=32	6	2.4	16	2.7	21	3.4	17	7.8
>32,<=34	2	0.8	1	0.2	4	0.7	0	0.0
>34,<=36	3	1.2	15	2.5	11	1.8	7	3.2
>36,<=38	1	0.4	2	0.3	5	0.8	2	0.9
>38,<=40	1	0.4	3	0.5	6	1.0	1	0.5
>40,<=42	3	1.2	6	1.0	6	1.0	2	0.9
>42,<=44	0	0.0	1	0.2	0	0.0	0	0.0
>44,<=46	8	3.2	9	1.5	13	2.1	11	5.1
>46,<=48	1	0.4	2	0.3	1	0.2	2	0.9
>48,<=50	6	2.4	8	1.4	9	1.5	0	0.0
>50,<=52	0	0.0	4	0.7	4	0.7	0	0.0
>52,<=54	0	0.0	0	0.0	0	0.0	1	0.5
>54,<=56	2	0.8	3	0.5	4	0.7	1	0.5
>56,<=58	0	0.0	0	0.0	0	0.0	0	0.0
>58,<=60	2	0.8	3	0.5	4	0.7	5	2.3
>60,<=495	41	16.6	95	16.1	65	10.6	29	13.4
Total	247	100.0	589	100.0	614	100.0	217	100.0

Table 15. NC Data - Engine Starts Per Vehicle Per Day Distribution Table

Engine Starts Per Vehicle Per Day	Vans		Pickups		Single Unit Big Trucks		Combination Big Trucks	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	13	25.5	16	16.0	18	22.0	9	27.3
>2,<=4	12	23.5	32	32.0	28	34.1	6	18.2
>4,<=6	12	23.5	21	21.0	15	18.3	7	21.2
>6,<=8	5	9.8	13	13.0	4	4.9	6	18.2
>8,<=10	3	5.9	8	8.0	8	9.8	1	3.0
>10,<=12	4	7.8	3	3.0	4	4.9	1	3.0
>12,<=14	1	2.0	1	1.0	1	1.2	0	0.0
>14,<=16	0	0.0	2	2.0	2	2.4	3	9.1
>16,<=18	0	0.0	2	2.0	0	0.0	0	0.0
>18,<=20	1	2.0	1	1.0	1	1.2	0	0.0
>20,<=22	0	0.0	0	0.0	0	0.0	0	0.0
>22,<=24	0	0.0	1	1.0	0	0.0	0	0.0
>24,<=26	0	0.0	0	0.0	0	0.0	0	0.0
>26,<=28	0	0.0	0	0.0	0	0.0	0	0.0
>28,<=30	0	0.0	0	0.0	1	1.2	0	0.0
Total	51	100.0	100	100.0	82	100.0	33	100.0

Table 16. Knox Co. Data – Travel Parameters

Travel Characteristic	Statistic	Owner			Overall
		USPS Home/Business Mail Delivery	USPS Station Delivery	Package PUD Companies	
Number of Vehicles		254	15	224	493
Number of Trips		3627	192	18320	22139
VMT Per Vehicle Per Day	Average	22.8	172.3	94.6	60.0
	Standard Deviation	12.5	125.8	47.1	56.4
Number of Trips Per Vehicle Per Day *	Average	14.3	12.8	81.8	44.9
	Standard Deviation	14.1	7.0	28.2	40.0
Daily Speed Per Vehicle (mph)	Average	12.1	31.5	19.4	16.0
	Standard Deviation	4.2	10.1	6.5	7.2
Trip Length (miles)	Average	1.6	13.5	1.2	1.3
	Standard Deviation	2.4	18.4	1.5	2.7
Trip Travel Time (minutes)	Average	8.8	23.9	3.6	4.6
	Standard Deviation	19.3	21.1	4.0	9.2
Stop Duration Per Trip (minutes)	Average	15.7	53.9	2.9	5.3
	Standard Deviation	15.6	70.7	9.8	14.1

* Average Number of Trips Per Vehicle Per day = Average Number of Engine Starts Per Vehicle Per Day, according to the definition of 'trip' in the Knox Co. dataset

Table 17. Knox Co. Data – Daily VMT Distribution Table

Daily VMT Per Vehicle	USPS Home/Business		USPS Stations		Package PUD Companies	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=5	6	2.4	0	0.0	0	0.0
>5,<=10	17	6.7	0	0.0	0	0.0
>10,<=15	42	16.5	0	0.0	0	0.0
>15,<=20	70	27.6	0	0.0	1	0.4
>20,<=25	47	18.5	0	0.0	6	2.7
>25,<=30	23	9.1	0	0.0	1	0.4
>30,<=35	17	6.7	0	0.0	2	0.9
>35,<=40	13	5.1	0	0.0	9	4.0
>40,<=45	7	2.8	0	0.0	9	4.0
>45,<=50	3	1.2	1	6.7	9	4.0
>50,<=55	2	0.8	0	0.0	12	5.4
>55,<=60	3	1.2	0	0.0	16	7.1
>60,<=65	1	0.4	0	0.0	7	3.1
>65,<=70	2	0.8	1	6.7	15	6.7
>70,<=75	0	0.0	0	0.0	7	3.1
>75,<=80	0	0.0	1	6.7	13	5.8
>80,<=85	0	0.0	0	0.0	9	4.0
>85,<=90	0	0.0	0	0.0	11	4.9
>90,<=95	0	0.0	0	0.0	5	2.2
>95,<=100	1	0.4	1	6.7	2	0.9
>100,<=105	0	0.0	0	0.0	10	4.5
>105,<=110	0	0.0	2	13.3	6	2.7
>110,<=115	0	0.0	0	0.0	5	2.2
>115,<=120	0	0.0	0	0.0	8	3.6
>120,<=125	0	0.0	0	0.0	7	3.1
>125,<=130	0	0.0	0	0.0	6	2.7
>130,<=135	0	0.0	0	0.0	8	3.6
>135,<=140	0	0.0	1	6.7	2	0.9
>140,<=145	0	0.0	2	13.3	3	1.3
>145,<=150	0	0.0	0	0.0	3	1.3
>150,<=155	0	0.0	1	6.7	3	1.3
>155,<=160	0	0.0	0	0.0	2	0.9
>160,<=165	0	0.0	0	0.0	1	0.4
>165,<=170	0	0.0	1	6.7	3	1.3
>170,<=175	0	0.0	0	0.0	4	1.8
>175,<=180	0	0.0	1	6.7	4	1.8
>180,<=185	0	0.0	0	0.0	1	0.4
>185,<=190	0	0.0	0	0.0	3	1.3
>190,<=195	0	0.0	0	0.0	4	1.8
>195,<=200	0	0.0	0	0.0	1	0.4
>200, <=480	0	0.0	3	20.0	6	2.7
Total	254	100.0	15	100.0	224	100.0

Table 18. Knox Co. Data – Number of Trips Per Day Distribution Table

# Trips Per Veh/day	**USPS Home/Business**		**USPS Stations**		**Package PUD Companies**	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=5	60	23.6	1	6.7	0	0.0
>5,<=10	80	31.5	6	40.0	1	0.4
>10,<=15	38	15.0	4	26.7	2	0.9
>15,<=20	18	7.1	2	13.3	7	3.1
>20,<=25	13	5.1	1	6.7	5	2.2
>25,<=30	10	3.9	0	0.0	3	1.3
>30,<=35	13	5.1	1	6.7	2	0.9
>35,<=40	6	2.4	0	0.0	2	0.9
>40,<=45	5	2.0	0	0.0	5	2.2
>45,<=50	3	1.2	0	0.0	2	0.9
>50,<=55	2	0.8	0	0.0	8	3.6
>55,<=60	3	1.2	0	0.0	7	3.1
>60,<=65	2	0.8	0	0.0	9	4.0
>65,<=70	0	0.0	0	0.0	10	4.5
>70,<=75	0	0.0	0	0.0	13	5.8
>75,<=80	0	0.0	0	0.0	14	6.3
>80,<=85	0	0.0	0	0.0	22	9.8
>85,<=90	0	0.0	0	0.0	19	8.5
>90,<=95	0	0.0	0	0.0	22	9.8
>95,<=100	1	0.4	0	0.0	13	5.8
>100,<=105	0	0.0	0	0.0	16	7.1
>105,<=110	0	0.0	0	0.0	11	4.9
>110,<=115	0	0.0	0	0.0	11	4.9
>115,<=120	0	0.0	0	0.0	7	3.1
>120,<=125	0	0.0	0	0.0	4	1.8
>125,<=130	0	0.0	0	0.0	5	2.2
>130,<=155	0	0.0	0	0.0	4	1.8
Total	254	100.0	15	100.0	224	100.0

Table 19. Knox Co. Data – Daily Speed Distribution Table

Speed (mph) M6 Bins	USPS Home/Business		USPS Stations		Package PUD Companies	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2.5	2	0.8	0	0.0	0	0.0
>2.5,<=7.5	29	11.4	0	0.0	2	0.9
>7.5,<=12.5	120	47.2	0	0.0	39	17.4
>12.5,<=17.5	81	31.9	0	0.0	55	24.6
>17.5,<=22.5	18	7.1	3	20.0	54	24.1
>22.5,<=27.5	4	1.6	3	20.0	46	20.5
>27.5,<=32.5	0	0.0	3	20.0	25	11.2
>32.5,<=37.5	0	0.0	2	13.3	1	0.4
>37.5,<=42.5	0	0.0	2	13.3	2	0.9
>42.5,<=47.5	0	0.0	0	0.0	0	0.0
>47.5,<=52.5	0	0.0	2	13.3	0	0.0
Total	254	100.0	15	100.0	224	100.0

Table 20. Knox Co. Data – Trip Length Distribution Table

Trip Length (miles)	USPS Home/Business		USPS Stations		Package PUD Companies	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	2842	78.4	19	9.9	15586	85.1
>2,<=4	531	14.6	26	13.5	2117	11.6
>4,<=6	108	3.0	14	7.3	359	2.0
>6,<=8	55	1.5	21	10.9	164	0.9
>8,<=10	23	0.6	46	24.0	41	0.2
>10,<=12	24	0.7	15	7.8	16	0.1
>12,<=14	17	0.5	6	3.1	12	0.1
>14,<=16	15	0.4	0	0.0	7	0.0
>16,<=18	4	0.1	8	4.2	3	0.0
>18,<=20	2	0.1	8	4.2	2	0.0
>20,<=22	2	0.1	16	8.3	0	0.0
>22,<=24	2	0.1	0	0.0	4	0.0
>24,<=26	0	0.0	0	0.0	2	0.0
>26,<=28	0	0.0	0	0.0	1	0.0
>28,<=30	0	0.0	3	1.6	3	0.0
>30,<=115	2	0.1	10	5.2	3	0.0
Total	3627	100.0	192	100.0	18320	100.0

Table 21. Knox Co. Data – Trip Travel Time Distribution Table

Trip Travel Time (minutes)	**USPS Home/Business**		**USPS Stations**		**Package PUD Companies**	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	982	27.1	0	0.0	8015	43.8
>2,<=4	1149	31.7	0	0.0	5058	27.6
>4,<=6	354	9.8	14	7.3	2764	15.1
>6,<=8	318	8.8	0	0.0	1093	6.0
>8,<=10	91	2.5	23	12.0	534	2.9
>10,<=12	70	1.9	4	2.1	255	1.4
>12,<=14	163	4.5	0	0.0	170	0.9
>14,<=16	65	1.8	29	15.1	142	0.8
>16,<=18	82	2.3	0	0.0	76	0.4
>18,<=20	100	2.8	43	22.4	63	0.3
>20,<=22	30	0.8	9	4.7	38	0.2
>22,<=24	32	0.9	0	0.0	45	0.2
>24,<=26	24	0.7	31	16.1	26	0.1
>26,<=28	8	0.2	0	0.0	6	0.0
>28,<=30	14	0.4	12	6.3	7	0.0
>30,<=32	13	0.4	7	3.6	5	0.0
>32,<=34	6	0.2	0	0.0	3	0.0
>34,<=36	11	0.3	1	0.5	1	0.0
>36,<=38	4	0.1	0	0.0	2	0.0
>38,<=40	10	0.3	4	2.1	1	0.0
>40,<=42	8	0.2	0	0.0	1	0.0
>42,<=44	0	0.0	0	0.0	1	0.0
>44,<=46	3	0.1	4	2.1	0	0.0
>46,<=48	0	0.0	0	0.0	0	0.0
>48,<=50	0	0.0	1	0.5	2	0.0
>50,<=52	0	0.0	0	0.0	0	0.0
>52,<=54	0	0.0	0	0.0	2	0.0
>54,<=56	0	0.0	0	0.0	0	0.0
>56,<=58	5	0.1	0	0.0	1	0.0
>58,<=60	6	0.2	3	1.6	2	0.0
>60,<=180	79	2.2	7	3.6	7	0.0
Total	3627	100.0	192	100.0	18320	100.0

Table 22. Knox Co. Data – Stop Duration Distribution Table

Stop Duration (minutes)	USPS Home/Business		USPS Stations		Package PUD Companies	
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency
<=2	123	3.6	0	0.0	14205	77.8
>2,<=4	554	16.4	0	0.0	2650	14.5
>4,<=6	426	12.6	1	0.6	495	2.7
>6,<=8	352	10.4	0	0.0	163	0.9
>8,<=10	463	13.7	12	6.8	110	0.6
>10,<=12	68	2.0	1	0.6	106	0.6
>12,<=14	42	1.2	0	0.0	107	0.6
>14,<=16	250	7.4	22	12.4	30	0.2
>16,<=18	31	0.9	0	0.0	24	0.1
>18,<=20	188	5.6	32	18.1	19	0.1
>20,<=22	0	0.0	7	4.0	19	0.1
>22,<=24	0	0.0	0	0.0	18	0.1
>24,<=26	132	3.9	17	9.6	18	0.1
>26,<=28	13	0.4	0	0.0	13	0.1
>28,<=30	391	11.6	10	5.6	19	0.1
>30,<=32	0	0.0	7	4.0	12	0.1
>32,<=34	0	0.0	0	0.0	12	0.1
>34,<=36	54	1.6	8	4.5	8	0.0
>36,<=38	0	0.0	0	0.0	14	0.1
>38,<=40	81	2.4	9	5.1	9	0.0
>40,<=42	0	0.0	1	0.6	7	0.0
>42,<=44	0	0.0	0	0.0	9	0.0
>44,<=46	92	2.7	4	2.3	8	0.0
>46,<=48	0	0.0	0	0.0	6	0.0
>48,<=50	61	1.8	1	0.6	7	0.0
>50,<=52	0	0.0	0	0.0	1	0.0
>52,<=54	0	0.0	0	0.0	6	0.0
>54,<=56	5	0.1	1	0.6	2	0.0
>56,<=58	0	0.0	0	0.0	5	0.0
>58,<=60	16	0.5	2	1.1	47	0.3
>60,<=545	31	0.9	42	23.7	98	0.5
Total	3373	100.0	177	100.0	18247	100.0

Table 23. Goodness of Fit Test Results

Dataset	Vehicle Class	Travel Parameter	KSL D-Value	KSL Critical Value	Distribution Fitted
NC	Vans	Daily VMT	0.105795	0.1500	Log-Normal
NC	Vans	Trip Length	0.035661	0.1500	Log-Normal
NC	Pickups	Daily VMT	0.075041	0.1500	Log-Normal
NC	Pickups	Trip Length	0.033174	0.0654	Log-Normal
NC	Single Unit Trucks	Daily VMT	0.077941	0.1500	Log-Normal
NC	Single Unit Trucks	Daily Speed	0.089286	0.1034	Log-Normal
NC	Combination Trucks	Daily VMT	0.090588	0.1500	Log-Normal
NC	Combination Trucks	Trip Length	0.045323	0.1500	Log-Normal
NC	Combination Trucks	No. Trips/Day	0.119572	0.1500	Log-Normal
Knox Co.	USPS Station Deliv. Vehicles	Daily Speed	0.108071	0.1500	Log-Normal
Knox Co.	Package PUD Vehicles	Daily VMT	0.046775	0.1500	Log-Normal

Table 24. Vehicle Usage Classes – Travel Parameters

Travel Characteristic	Statistic	Vehicle Usage Class			
		Knox USPS Home/Business Mail Delivery Vehicles	Knox Package PUD Vehicles	NC Service Vehicles	NC & Knox Long Haul Vehicles
Number of Vehicles		254	224	233	48
Number of Trips		3627	18320	1682	442
VMT Per Vehicle Per Day	Average	22.8	94.6	75.3	175.0
	Standard Deviation	12.5	47.1	80.3	135.9
Number of Trips Per Vehicle Per Day	Average	14.3	81.8	7.2	9.2
	Standard Deviation	14.1	28.2	5.9	6.0
Daily Speed Per Vehicle (mph)	Average	12.1	19.4	29.0	34.3
	Standard Deviation	4.2	6.5	15.8	11.9
Trip Length (miles)	Average	1.6	1.2	10.4	19.0
	Standard Deviation	2.4	1.5	18.8	30.7
Trip Travel Time (minutes)	Average	8.8	3.6	19.8	30.6
	Standard Deviation	19.3	4.0	28.0	36.6
Stop Duration Per Trip (minutes)	Average	15.7	2.9	32.5	42.7
	Standard Deviation	15.6	9.8	54.0	60.4
Number of Engine Starts Per Vehicle Per Day	Average	14.3	81.8	5.7	7.9
	Standard Deviation	14.1	28.2	4.2	6.1

Table 25. NC Data - Annual Mileage Accumulation Rates

M6Class	M6 Age	Annual VMT/100000	Default	Number of Vehicles	Percent Change
LDGT2	1	0.19667	0.19496	3	0.9
LDGT2	2	0.13417	0.18384	6	-27.0
LDGT2	3	0.16458	0.17308	6	-4.9
LDGT2	4	0.23750	0.16267	3	46.0
LDGT2	5	0.16500	0.15260	5	8.1
LDGT2	6	0.22200	0.14289	5	55.4
LDGT2	7	0.17806	0.13352	9	33.4
LDGT2	8	0.14188	0.12451	8	13.9
LDGT2	9	0.17100	0.11584	5	47.6
LDGT2	10	0.03333	0.10752	3	-69.0
LDGT2	11	0.08214	0.09955	7	-17.5
LDGT2	12	0.03750	0.09194	3	-59.2
LDGT2	13	0.22083	0.08467	3	160.8
LDGT2	16	0.01250	0.06496	1	-80.8
LDGT2	17	0.05375	0.05909	2	-9.0
LDGT2	22	0.22125	0.03497	2	532.7
LDGT2	23	0.07750	0.03120	1	148.4
LDGT2	27	0.06000	0.02470	1	142.9
LDGT4	2	0.22050	0.19865	5	11.0
LDGT4	3	0.08667	0.18500	3	-53.2
LDGT4	4	0.13500	0.17228	2	-21.6
LDGT4	5	0.15250	0.16044	2	-4.9
LDGT4	6	0.44333	0.14942	3	196.7
LDGT4	7	0.13700	0.13915	5	-1.5
LDGT4	8	0.08250	0.12959	2	-36.3
LDGT4	9	0.17750	0.12068	3	47.1
LDGT4	10	0.11000	0.11239	3	-2.1
LDGT4	11	0.15250	0.10466	3	45.7
LDGT4	12	0.01250	0.09747	1	-87.2
LDGT4	14	0.03250	0.08453	1	-61.6
LDGT4	15	0.02750	0.07872	1	-65.1
LDGT4	17	0.30583	0.06827	3	348.0
HDGV2b	2	0.22500	0.18779	2	19.8
HDGV2b	3	0.10750	0.17654	4	-39.1
HDGV2b	4	0.15875	0.16596	2	-4.3
HDGV2b	5	0.02125	0.15601	2	-86.4
HDGV2b	6	0.10125	0.14666	2	-31.0
HDGV2b	7	0.09500	0.13787	2	-31.1
HDGV2b	8	0.11000	0.12961	1	-15.1
HDGV2b	9	0.02500	0.12184	2	-79.5
HDGV2b	10	0.18250	0.11454	3	59.3
HDGV2b	12	0.98500	0.10122	1	873.1
HDGV2b	22	0.14750	0.05456	1	170.3
HDGV2b	25	0.02750	0.04533	1	-39.3

Table 25. Continued.

M6Class	M6 Age	Annual VMT/100000	Default	Number of Vehicles	Percent Change
HDGV3	2	0.26125	0.18779	2	39.1
HDGV3	3	0.02750	0.17654	1	-84.4
HDGV3	5	0.17833	0.15601	3	14.3
HDGV3	6	0.41500	0.14666	1	183.0
HDGV3	7	0.23750	0.13787	2	72.3
HDGV3	8	0.07125	0.12961	2	-45.0
HDGV3	9	0.05250	0.12184	1	-56.9
HDGV3	10	0.04750	0.11454	1	-58.5
HDGV3	11	0.02500	0.10768	1	-76.8
HDGV3	14	0.18750	0.08946	1	109.6
HDGV3	20	0.13750	0.06174	2	122.7
HDGV4	1	0.02000	0.21394	1	-90.7
HDGV4	2	0.22333	0.19692	3	13.4
HDGV4	3	0.34000	0.14400	1	136.1
HDGV4	8	0.06250	0.11975	1	-47.8
HDGV4	10	0.37750	0.10145	1	272.1
HDGV4	11	0.37750	0.09338	1	304.3
HDGV4	12	0.01000	0.08595	1	-88.4
HDGV6	7	0.09375	0.13010	2	-27.9
HDGV6	8	0.04500	0.11975	1	-62.4
HDGV6	9	0.06250	0.11022	1	-43.3
HDGV6	14	0.03500	0.07282	1	-51.9
HDGV6	16	0.14750	0.06169	1	139.1
HDGV6	20	0.18000	0.04428	1	306.5
HDGV6	23	0.01750	0.03453	1	-49.3
HDGV7	3	0.16250	0.14400	1	12.8
HDGV7	7	0.07000	0.13010	1	-46.2
HDGV7	10	0.10000	0.10145	2	-1.4
HDGV7	11	0.23750	0.09338	1	154.3
HDGV8a	2	0.28000	0.19692	1	42.2
HDGV8a	7	0.11250	0.13010	1	-13.5
LDDT12	6	0.30000	0.16079	1	86.6
HDDV2b	3	0.13250	0.22721	1	-41.7
HDDV2b	4	0.89250	0.20791	1	329.3
HDDV2b	5	0.02250	0.19024	1	-88.2
HDDV2b	7	0.44000	0.15928	1	176.2
HDDV2b	14	0.08250	0.08555	1	-3.6
HDDV3	9	0.29750	0.12321	1	141.5
HDDV5	1	0.22000	0.30563	1	-28.0
HDDV5	3	0.07500	0.26805	1	-72.0
HDDV5	7	0.12125	0.20618	2	-41.2
HDDV5	8	0.75000	0.19309	1	288.4
HDDV5	10	0.17500	0.16935	1	3.3

Table 25. Continued.

M6Class	M6 Age	Annual VMT/100000	Default	Number of Vehicles	Percent Change
HDDV6	2	0.12750	0.36872	2	-65.4
HDDV6	4	0.38250	0.30291	1	26.3
HDDV6	6	0.19750	0.24885	1	-20.6
HDDV6	7	0.21000	0.22555	2	-6.9
HDDV6	9	0.36000	0.18529	2	94.3
HDDV6	11	0.17875	0.15222	2	17.4
HDDV6	15	0.01750	0.10273	1	-83.0
HDDV6	16	0.07750	0.09312	1	-16.8
HDDV6	18	0.25500	0.07650	1	233.3
HDDV7	1	0.36625	0.40681	2	-10.0
HDDV7	2	0.28083	0.36872	3	-23.8
HDDV7	4	0.03250	0.30291	1	-89.3
HDDV7	5	0.39500	0.27455	1	43.9
HDDV7	6	0.10500	0.24885	1	-57.8
HDDV7	7	0.35167	0.22555	3	55.9
HDDV7	8	0.28500	0.20443	2	39.4
HDDV7	9	0.39000	0.18529	1	110.5
HDDV7	10	0.22750	0.16795	1	35.5
HDDV7	11	0.10000	0.15222	1	-34.3
HDDV7	12	0.16625	0.13797	2	20.5
HDDV8a	1	0.46250	0.87821	2	-47.3
HDDV8a	2	0.53875	0.78257	2	-31.2
HDDV8a	3	0.53375	0.69735	2	-23.5
HDDV8a	4	0.05250	0.62141	1	-91.6
HDDV8a	6	0.56625	0.49343	2	14.8
HDDV8a	8	0.33813	0.39181	4	-13.7
HDDV8a	9	0.08250	0.34915	4	-76.4
HDDV8a	11	0.15900	0.27724	5	-42.6
HDDV8a	12	0.56167	0.24705	3	127.3
HDDV8a	16	0.09500	0.15577	1	-39.0
HDDV8a	24	0.63750	0.06193	1	929.4
HDDV8a	25	0.15500	0.05518	1	180.9
HDDV8b	2	0.81875	1.12590	2	-27.3
HDDV8b	3	0.49750	1.02060	2	-51.3
HDDV8b	4	0.59250	0.92514	3	-36.0
HDDV8b	5	0.65750	0.83861	1	-21.6
HDDV8b	6	0.75875	0.76017	2	-0.2
HDDV8b	7	0.29000	0.68907	1	-57.9
HDDV8b	8	0.44688	0.62462	4	-28.5
HDDV8b	12	1.74250	0.42172	1	313.2
HDDV8b	13	0.07000	0.38228	1	-81.7
HDDV8b	18	0.14250	0.23396	2	-39.1
HDDV8b	22	0.24000	0.15796	1	51.9

Standard Error: 0.207

Table 26. NC Data - Annual Mileage Accumulation Rates – Class Average

M6 Class	NC Data	Default	Number of Vehicles	Percent Change
LDGT2	0.13387	0.11014	73	21.5
LDGT4	0.14827	0.12866	37	15.2
HDGV2b	0.18219	0.12816	23	42.2
HDGV3	0.14917	0.12998	17	14.8
HDGV4	0.20155	0.13648	9	47.7
HDGV6	0.08304	0.08191	8	1.4
HDGV7	0.14250	0.11723	5	21.6
HDGV8a	0.19625	0.16351	2	20.0
LDDT12	0.30000	0.16079	1	86.6
HDDV2b	0.31400	0.17404	5	80.4
HDDV3	0.29750	0.12321	1	141.5
HDDV5	0.26825	0.22846	6	17.4
HDDV6	0.20069	0.19510	13	2.9
HDDV7	0.24545	0.24320	18	0.9
HDDV8a	0.34855	0.41759	28	-16.5
HDDV8b	0.56881	0.65273	20	-12.9

Table 27. NC Data - VMT By Hour Table

Hour	Hour Index	VMT	NC Data	Default
6:00-6:59	1	543	0.0232	0.0569
7:00-7:59	2	837	0.0358	0.074
8:00-8:59	3	1733	0.0742	0.0655
9:00-9:59	4	2457	0.1052	0.0555
10:00-10:59	5	2490	0.1066	0.054
11:00-11:59	6	2571	0.1100	0.0582
12:00-12:59	7	2447	0.1047	0.0608
13:00-13:59	8	2328	0.0996	0.0571
14:00-14:59	9	2237	0.0957	0.0598
15:00-15:59	10	2188	0.0936	0.0636
16:00-16:59	11	1571	0.0672	0.0777
17:00-17:59	12	820	0.0351	0.073
18:00-18:59	13	297	0.0127	0.0501
19:00-19:59	14	101	0.0043	0.0389
20:00-20:59	15	16	0.0007	0.0308
21:00-21:59	16	4	0.0002	0.0264
22:00-22:59	17	1	0.0001	0.0194
23:00-23:59	18	2	0.0001	0.0144
0:00-0:59	19	23	0.0010	0.0108
1:00-1:59	20	65	0.0028	0.0086
2:00-2:59	21	46	0.0020	0.0081
3:00-3:59	22	121	0.0052	0.008
4:00-4:59	23	150	0.0064	0.0098
5:00-5:59	24	319	0.0137	0.0186
Total		23366	1.0000	1.0000

Standard Error: 0.031

Table 28. MOBILE6 Speed Bins

Speed Index	Speed Range (mph)
1	0-2.5
2	2.5-7.5
3	7.5-12.5
4	12.5-17.5
5	17.5-22.5
6	22.5-27.5
7	27.5-32.5
8	32.5-37.5
9	37.5-42.5
10	42.5-47.5
11	47.5-52.5
12	52.5-57.5
13	57.5-62.5
14	>62.5

Table 29. NC Data – Speed VMT Fractions

Hour Index	Speed Index 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.0000	0.0000	0.0186	0.0000	0.0395	0.0338	0.0847	0.1024	0.1457	0.0503	0.0946	0.1738	0.1093	0.1474
2	0.0000	0.0017	0.0283	0.0469	0.0362	0.1138	0.0420	0.0315	0.1250	0.0592	0.1444	0.1534	0.0938	0.1239
3	0.0000	0.0010	0.0144	0.0351	0.0625	0.1378	0.0871	0.1102	0.1793	0.0896	0.0474	0.1040	0.0543	0.0773
4	0.0000	0.0059	0.0207	0.0517	0.0476	0.1061	0.0991	0.0835	0.1623	0.1360	0.0554	0.0736	0.0500	0.1082
5	0.0001	0.0034	0.0228	0.0365	0.0721	0.1185	0.0966	0.1037	0.1168	0.1695	0.0566	0.0789	0.0568	0.0678
6	0.0003	0.0037	0.0177	0.0360	0.0657	0.1064	0.0996	0.0849	0.1719	0.1493	0.0445	0.0903	0.0634	0.0665
7	0.0000	0.0040	0.0157	0.0390	0.0777	0.1118	0.0725	0.0799	0.0834	0.2106	0.1007	0.1144	0.0602	0.0301
8	0.0000	0.0051	0.0174	0.0402	0.0616	0.1229	0.0727	0.1592	0.1354	0.1948	0.0638	0.0367	0.0597	0.0305
9	0.0000	0.0065	0.0148	0.0301	0.0706	0.1410	0.1045	0.1073	0.1490	0.1480	0.0539	0.0729	0.0330	0.0685
10	0.0000	0.0080	0.0060	0.0196	0.0697	0.1302	0.1105	0.1191	0.1583	0.1395	0.0554	0.0834	0.0401	0.0601
11	0.0000	0.0026	0.0103	0.0157	0.0752	0.1066	0.0737	0.1329	0.0784	0.1747	0.0860	0.1034	0.0650	0.0756
12	0.0000	0.0025	0.0017	0.0080	0.0475	0.1137	0.0866	0.1832	0.0793	0.0743	0.0626	0.1589	0.0954	0.0861
13	0.0000	0.0042	0.0000	0.0000	0.0122	0.1487	0.2020	0.1409	0.0598	0.0000	0.0422	0.3037	0.0499	0.0364
14	0.0000	0.0041	0.0000	0.0000	0.0782	0.1164	0.1810	0.0886	0.0000	0.0000	0.0000	0.5318	0.0000	0.0000
15	0.0000	0.0262	0.0000	0.0000	0.5797	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3941	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0734	0.0000	0.0000	0.0000	0.0000	0.0000	0.9266	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0414	0.0000	0.0000	0.0000	0.0000	0.0000	0.9586	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1078	0.0000	0.8922	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.1019	0.0000	0.0000	0.0000	0.2446	0.0000	0.6534	0.0000	0.0000	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0533	0.0000	0.0000	0.0000	0.0230	0.1192	0.3686	0.0000	0.2386	0.0000	0.1974	0.0000
24	0.0000	0.0000	0.0167	0.0115	0.0311	0.0000	0.0965	0.1121	0.1322	0.0924	0.1496	0.1723	0.1857	0.0000

Standard Error: With Freeway Defaults: 0.146 With Arterial Defaults: 0.141

Table 30. MOBILE6 Speed VMT Freeway Default Fractions

Hour	Speed Index													
Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	0.0083	0.0272	0.0210	0.0224	0.0217	0.0381	0.0344	0.0536	0.0614	0.0700	0.2507	0.1150	0.2550	0.0212
2	0.0260	0.0066	0.0076	0.0156	0.0282	0.0326	0.0344	0.0361	0.0360	0.0435	0.2453	0.1729	0.3023	0.0129
3	0.0259	0.0033	0.0064	0.0057	0.0126	0.0281	0.0342	0.0349	0.0407	0.0369	0.2181	0.1066	0.4399	0.0127
4	0.0145	0.0096	0.0021	0.0022	0.0041	0.0166	0.0232	0.0373	0.0418	0.0449	0.2248	0.1190	0.4422	0.0177
5	0.0083	0.0086	0.0052	0.0032	0.0040	0.0163	0.0232	0.0364	0.0375	0.0420	0.2352	0.1170	0.4454	0.0177
6	0.0072	0.0034	0.0042	0.0098	0.0121	0.0244	0.0289	0.0327	0.0401	0.0392	0.2294	0.1011	0.4538	0.0137
7	0.0103	0.0023	0.0064	0.0087	0.0147	0.0281	0.0335	0.0328	0.0345	0.0354	0.2294	0.0964	0.4547	0.0128
8	0.0083	0.0075	0.0052	0.0043	0.0054	0.0182	0.0257	0.0381	0.0380	0.0421	0.2258	0.1118	0.4512	0.0184
9	0.0113	0.0065	0.0052	0.0023	0.0039	0.0206	0.0279	0.0358	0.0383	0.0517	0.2147	0.1151	0.4484	0.0183
10	0.0155	0.0075	0.0034	0.0042	0.0081	0.0272	0.0324	0.0363	0.0315	0.0390	0.2124	0.0644	0.5000	0.0181
11	0.0156	0.0411	0.0225	0.0199	0.0284	0.0316	0.0500	0.0488	0.0446	0.0555	0.2223	0.1092	0.2957	0.0148
12	0.0186	0.0113	0.0046	0.0110	0.0183	0.0261	0.0488	0.0383	0.0314	0.0534	0.2235	0.1237	0.3736	0.0174
13	0.0176	0.0064	0.0010	0.0024	0.0034	0.0155	0.0191	0.0315	0.0357	0.0515	0.2134	0.0674	0.5178	0.0173
14	0.0135	0.0043	0.0031	0.0010	0.0012	0.0094	0.0177	0.0258	0.0264	0.0550	0.2060	0.0980	0.5209	0.0177
15	0.0094	0.0031	0.0025	0.0007	0.0012	0.0069	0.0166	0.0216	0.0257	0.0476	0.2169	0.1048	0.5228	0.0202
16	0.0054	0.0018	0.0018	0.0004	0.0011	0.0045	0.0155	0.0175	0.0250	0.0401	0.2277	0.1117	0.5246	0.0229
17	0.0027	0.0010	0.0014	0.0002	0.0011	0.0028	0.0147	0.0147	0.0245	0.0352	0.2350	0.1162	0.5259	0.0246
18	0.0013	0.0006	0.0012	0.0001	0.0011	0.0020	0.0144	0.0133	0.0242	0.0327	0.2386	0.1185	0.5265	0.0255
19	0.0000	0.0001	0.0010	0.0000	0.0011	0.0012	0.0140	0.0119	0.0240	0.0302	0.2422	0.1208	0.5271	0.0264
20	0.0000	0.0013	0.0000	0.0000	0.0000	0.0010	0.0115	0.0097	0.0200	0.0241	0.2450	0.1285	0.5271	0.0318
21	0.0000	0.0003	0.0010	0.0000	0.0000	0.0008	0.0103	0.0086	0.0181	0.0206	0.2464	0.1321	0.5271	0.0347
22	0.0000	0.0013	0.0000	0.0000	0.0000	0.0008	0.0107	0.0081	0.0170	0.0199	0.2451	0.1341	0.5271	0.0359
23	0.0021	0.0003	0.0000	0.0010	0.0000	0.0010	0.0118	0.0100	0.0205	0.0224	0.2452	0.1274	0.5271	0.0312
24	0.0031	0.0003	0.0000	0.0010	0.0001	0.0011	0.0134	0.0124	0.0240	0.0267	0.2404	0.1226	0.5271	0.0278

Table 31. MOBILE6 Speed VMT Arterial Default Fractions

Hour	Speed Index													
Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.0004	0.0052	0.0061	0.0053	0.0158	0.0854	0.3210	0.1382	0.2804	0.0595	0.0628	0.0103	0.0095	0.0001
2	0.0036	0.0029	0.0059	0.0234	0.0735	0.1114	0.2842	0.0950	0.2633	0.0396	0.0698	0.0107	0.0169	0.0000
3	0.0033	0.0021	0.0032	0.0085	0.0436	0.1130	0.2914	0.1076	0.2835	0.0424	0.0719	0.0091	0.0204	0.0000
4	0.0030	0.0015	0.0011	0.0015	0.0183	0.1001	0.2910	0.1246	0.3013	0.0535	0.0743	0.0094	0.0204	0.0000
5	0.0030	0.0014	0.0005	0.0017	0.0181	0.1008	0.2898	0.1246	0.3015	0.0537	0.0751	0.0094	0.0204	0.0000
6	0.0034	0.0017	0.0021	0.0049	0.0344	0.1091	0.2894	0.1125	0.2932	0.0460	0.0735	0.0093	0.0205	0.0000
7	0.0040	0.0021	0.0027	0.0078	0.0427	0.1134	0.2857	0.1083	0.2886	0.0427	0.0724	0.0091	0.0205	0.0000
8	0.0038	0.0025	0.0020	0.0022	0.0216	0.1034	0.2834	0.1243	0.3020	0.0515	0.0736	0.0094	0.0203	0.0000
9	0.0041	0.0024	0.0020	0.0034	0.0249	0.1049	0.2844	0.1215	0.2986	0.0489	0.0751	0.0093	0.0205	0.0000
10	0.0052	0.0027	0.0032	0.0085	0.0450	0.1151	0.2822	0.1024	0.2835	0.0419	0.0777	0.0096	0.0230	0.0000
11	0.0049	0.0165	0.0087	0.0224	0.0652	0.1222	0.2809	0.0959	0.2557	0.0405	0.0651	0.0095	0.0125	0.0000
12	0.0055	0.0071	0.0082	0.0219	0.0675	0.1169	0.2771	0.0915	0.2637	0.0394	0.0712	0.0106	0.0194	0.0000
13	0.0043	0.0024	0.0016	0.0038	0.0255	0.1005	0.2849	0.1205	0.2996	0.0497	0.0761	0.0100	0.0211	0.0000
14	0.0038	0.0021	0.0018	0.0015	0.0115	0.0734	0.2923	0.1219	0.3170	0.0641	0.0794	0.0100	0.0211	0.0001
15	0.0037	0.0017	0.0012	0.0019	0.0103	0.0558	0.3040	0.1067	0.3309	0.0702	0.0824	0.0100	0.0211	0.0001
16	0.0036	0.0018	0.0009	0.0012	0.0109	0.0530	0.3056	0.1064	0.3320	0.0707	0.0827	0.0100	0.0211	0.0001
17	0.0034	0.0009	0.0007	0.0015	0.0104	0.0531	0.3065	0.1064	0.3325	0.0706	0.0829	0.0100	0.0211	0.0000
18	0.0030	0.0013	0.0016	0.0018	0.0103	0.0528	0.3057	0.1061	0.3327	0.0704	0.0831	0.0100	0.0211	0.0001
19	0.0000	0.0000	0.0000	0.0003	0.0087	0.0502	0.3303	0.1054	0.3306	0.0699	0.0733	0.0100	0.0211	0.0002
20	0.0001	0.0000	0.0000	0.0000	0.0082	0.0496	0.3302	0.1057	0.3293	0.0696	0.0757	0.0101	0.0211	0.0004
21	0.0000	0.0000	0.0000	0.0000	0.0081	0.0491	0.3306	0.1060	0.3298	0.0693	0.0755	0.0101	0.0211	0.0004
22	0.0000	0.0000	0.0000	0.0000	0.0077	0.0489	0.3291	0.1060	0.3316	0.0692	0.0758	0.0101	0.0211	0.0005
23	0.0000	0.0000	0.0000	0.0000	0.0082	0.0497	0.3286	0.1056	0.3311	0.0697	0.0756	0.0101	0.0211	0.0003
24	0.0000	0.0000	0.0000	0.0000	0.0085	0.0502	0.3271	0.1054	0.3324	0.0699	0.0752	0.0100	0.0211	0.0002

Table 32. NC Data - Starts Per Day Table

Class	NC Data	Defaults
LDGT2	6.23	8.06
LDGT4	5.97	8.06
HDGV2b	5.48	6.88
LDDT12	4.00	8.06

Standard Error: 1.22

Table 33. NC Data - Start Distribution Table

Hour Begin	Hour Index	NC Data	Defaults
6:00	1	0.013262599	0.02040816327
7:00	2	0.038461538	0.05541601256
8:00	3	0.098806366	0.06028257457
9:00	4	0.103448276	0.04725274725
10:00	5	0.124668435	0.05164835165
11:00	6	0.125331565	0.06718995290
12:00	7	0.102122016	0.08069073783
13:00	8	0.096816976	0.07299843014
14:00	9	0.099469496	0.08037676609
15:00	10	0.086870027	0.08979591837
16:00	11	0.053050398	0.08414442700
17:00	12	0.025862069	0.07723704867
18:00	13	0.007957560	0.06012558870
19:00	14	0.003978780	0.01385757100
20:00	15	0.001989390	0.01385757100
21:00	16	0.001326260	0.01385757100
22:00	17	0.001326260	0.01385757100
23:00	18	0.001989390	0.01385757100
0:00	19	0.001326260	0.01385757100
1:00	20	0.000663130	0.01385757100
2:00	21	0.000663130	0.01385757100
3:00	22	0.003978780	0.01385757100
4:00	23	0.001989390	0.01385757100
5:00	24	0.004641910	0.01385757100
Total		1.000000000	1.000000000

Standard Error: 0.031

Table 34. NC Data - Weekday Trip Length Distribution Table

Trip Duration	**Percent Daily VMT**	
minutes	NC Data	Defaults
<=10	11.87	6.74
11-20	20.32	18.51
21-30	15.88	16.78
31-40	10.01	13.11
41-50	8.69	8.33
51+	33.24	36.53
Total	100.00	100.00

Standard Error: 2.82

Table 35. Knox Co. Data – Annual Mileage Accumulation Rates

M6 Class	M6 Age	Annual VMT/100000	Defaults	Number of Vehicles	Percent Difference
LDGT1	3	0.05829	0.17308	79	-66.3
LDGT1	8	0.06013	0.12451	102	-51.7
LDGT1	10	0.06925	0.10752	12	-35.6
LDGT2	3	0.02600	0.17308	12	-85.0
LDGT2	7	0.17417	0.13352	6	30.4
LDGT2	10	0.11700	0.10752	1	8.8
LDGT4	3	0.09879	0.18500	8	-46.6
LDGT4	5	0.38333	0.16044	3	138.9
LDGT4	8	0.09937	0.12959	25	-23.3
LDGT4	10	0.08700	0.11239	6	-22.6
HDGV2b	1	0.44438	0.19977	4	122.4
HDGV2b	3	0.38875	0.17654	2	120.2
HDGV2b	5	0.34125	0.15601	2	118.7
HDGV2b	7	0.28250	0.13787	3	104.9
HDGV2b	10	0.21333	0.11454	3	86.3
HDGV2b	12	0.28333	0.10122	3	179.9
HDGV2b	14	0.27250	0.08946	1	204.6
HDGV2b	19	0.43500	0.06568	1	562.3
HDGV3	1	0.35500	0.19977	1	77.7
HDGV3	7	0.36000	0.13787	1	161.1
HDGV3	10	0.30250	0.11454	6	164.1
HDGV3	11	0.22000	0.10768	3	104.3
HDGV3	12	0.16417	0.10122	3	62.2
HDGV3	13	0.13250	0.09516	1	39.2
HDGV3	15	0.25500	0.08409	1	203.2
HDGV3	17	0.33000	0.07432	3	344.0
HDGV3	19	0.25250	0.06568	1	284.4
HDGV3	20	0.19250	0.06174	4	211.8
HDGV5	14	0.20750	0.07282	3	184.9
HDGV5	15	0.21036	0.06169	7	241.0
HDGV5	17	0.18125	0.05679	2	219.2
HDGV6	14	0.05750	0.07282	1	-21.0
HDGV6	15	0.14500	0.06169	3	135.0
HDGV6	17	0.16833	0.05679	3	196.4
HDGV6	18	0.14750	0.05227	4	182.2
HDGV6	19	0.14125	0.04811	2	193.6
HDGV6	20	0.17250	0.04428	1	289.6
HDGV6	21	0.13750	0.04076	2	237.3
HDGV6	22	0.18313	0.03752	4	388.1
HDDV2b	1	0.48750	0.27137	6	79.6
HDDV2b	10	0.17500	0.12203	9	43.4
HDDV3	4	0.26950	0.22699	5	18.7
HDDV3	5	0.33250	0.20088	1	65.5
HDDV3	6	0.32333	0.17778	3	81.9
HDDV3	7	0.33750	0.15733	3	114.5
HDDV3	8	0.21900	0.13923	5	57.3

Table 35. Continued.

M6 Class	M6 Age	Annual VMT/100000	Defaults	Number of Vehicles	Percent Difference
HDDV4	3	0.32458	0.26805	6	21.1
HDDV4	7	0.27882	0.20618	19	35.2
HDDV4	8	0.28364	0.19309	11	46.9
HDDV5	13	0.18250	0.13910	1	31.2
HDDV5	14	0.17700	0.13026	5	35.9
HDDV5	15	0.13000	0.12199	3	6.6
HDDV6	3	0.14167	0.33420	3	-57.6
HDDV6	4	0.11625	0.30291	2	-61.6
HDDV6	5	0.18667	0.27455	3	-32.0
HDDV6	6	0.26439	0.24885	18	6.2
HDDV6	7	0.18250	0.22555	13	-19.1
HDDV6	8	0.10679	0.20443	7	-47.8
HDDV6	9	0.17417	0.18529	9	-6.0
HDDV6	11	0.16813	0.15222	4	10.4
HDDV6	13	0.16200	0.12505	5	29.5
HDDV6	14	0.17000	0.11335	3	50.0
HDDV6	15	0.12875	0.10273	2	25.3
HDDV7	4	0.16167	0.30291	3	-46.6
HDDV7	8	0.52800	0.20443	1	158.3
HDDV7	13	0.37843	0.12505	7	202.6
HDDV8b	8	0.65400	0.62462	7	4.7

Standard Error: 0.112

Table 36. Knox Co. Data – Annual Mileage Accumulation Rates – Class Average

M6 Class	Knox Data	Defaults	Number of Vehicles	Percent Difference
LDGT1	0.06256	0.13504	193	-53.7
LDGT2	0.10572	0.13804	19	-23.4
LDGT4	0.16712	0.14686	42	13.8
HDGV2b	0.33263	0.13014	19	155.6
HDGV3	0.25642	0.10421	24	146.1
HDGV5	0.19970	0.06377	12	213.2
HDGV6	0.14409	0.05178	20	178.3
HDDV2b	0.33125	0.19670	15	68.4
HDDV3	0.29637	0.18044	17	64.2
HDDV4	0.29568	0.22244	36	32.9
HDDV5	0.16317	0.13045	9	25.1
HDDV6	0.16375	0.20628	69	-20.6
HDDV7	0.35603	0.21080	11	68.9
HDDV8b	0.65400	0.62462	7	4.7

Table 37. Knox Co. Data – VMT By Hour Table

Hour	Hour Index	VMT	Knox Data	Default
6:00-6:59	1	253.7	0.0086	0.0569
7:00-7:59	2	298.5	0.0101	0.074
8:00-8:59	3	1200.6	0.0406	0.0655
9:00-9:59	4	2766.5	0.0936	0.0555
10:00-10:59	5	3043.0	0.1029	0.054
11:00-11:59	6	3189.7	0.1079	0.0582
12:00-12:59	7	2515.7	0.0851	0.0608
13:00-13:59	8	2859.4	0.0967	0.0571
14:00-14:59	9	3231.7	0.1093	0.0598
15:00-15:59	10	3283.0	0.1110	0.0636
16:00-16:59	11	2621.5	0.0887	0.0777
17:00-17:59	12	1699.5	0.0575	0.073
18:00-18:59	13	947.1	0.0320	0.0501
19:00-19:59	14	592.1	0.0200	0.0389
20:00-20:59	15	160.5	0.0054	0.0308
21:00-21:59	16	48.5	0.0016	0.0264
22:00-22:59	17	70.1	0.0024	0.0194
23:00-23:59	18	47.6	0.0016	0.0144
0:00-0:59	19	28.9	0.0010	0.0108
1:00-1:59	20	157.9	0.0053	0.0086
2:00-2:59	21	175.8	0.0059	0.0081
3:00-3:59	22	152.0	0.0051	0.008
4:00-4:59	23	105.1	0.0036	0.0098
5:00-5:59	24	120.7	0.0041	0.0186
Total		29569	1.0000	1.0000

Standard Error: 0.032

Table 38. Knox Co. Data – Speed VMT Fractions

Hour	Speed Index													
Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.0000	0.0000	0.0438	0.0000	0.0999	0.1073	0.3093	0.1419	0.2071	0.0434	0.0473	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0216	0.0318	0.1280	0.1197	0.2423	0.2311	0.2254	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0004	0.0261	0.0956	0.2276	0.3234	0.2568	0.0337	0.0362	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0004	0.0057	0.1015	0.2008	0.2441	0.2568	0.1543	0.0120	0.0242	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0014	0.0190	0.1675	0.2310	0.2297	0.2154	0.1214	0.0079	0.0023	0.0000	0.0000	0.0044	0.0000	0.0000
6	0.0010	0.0289	0.2119	0.2167	0.2095	0.2000	0.1113	0.0082	0.0000	0.0000	0.0000	0.0125	0.0000	0.0000
7	0.0015	0.0346	0.2628	0.2771	0.1685	0.1327	0.0844	0.0085	0.0119	0.0000	0.0180	0.0000	0.0000	0.0000
8	0.0006	0.0272	0.2346	0.2122	0.1846	0.1758	0.1168	0.0164	0.0000	0.0000	0.0320	0.0000	0.0000	0.0000
9	0.0006	0.0327	0.2210	0.2032	0.2011	0.2032	0.1090	0.0137	0.0000	0.0000	0.0155	0.0000	0.0000	0.0000
10	0.0006	0.0272	0.1911	0.2358	0.2124	0.1947	0.1176	0.0140	0.0000	0.0000	0.0000	0.0067	0.0000	0.0000
11	0.0000	0.0065	0.1580	0.2170	0.2391	0.2251	0.1230	0.0117	0.0080	0.0000	0.0000	0.0118	0.0000	0.0000
12	0.0000	0.0069	0.1075	0.1697	0.3002	0.2333	0.1220	0.0000	0.0409	0.0000	0.0194	0.0000	0.0000	0.0000
13	0.0000	0.0043	0.0704	0.1184	0.3503	0.2364	0.0682	0.0306	0.0203	0.0000	0.1011	0.0000	0.0000	0.0000
14	0.0000	0.0011	0.0251	0.0607	0.3432	0.2934	0.1056	0.0152	0.0572	0.0000	0.0985	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.5033	0.3233	0.1031	0.0000	0.0703	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.3000	0.1858	0.0000	0.0000	0.4326	0.0000	0.0817	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0214	0.0000	0.0000	0.2997	0.0000	0.6789	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5884	0.0000	0.4116	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0443	0.0000	0.0000	0.0760	0.3206	0.1626	0.3125	0.0839	0.0000	0.0000
21	0.0000	0.0000	0.0057	0.0000	0.0569	0.0683	0.0000	0.0341	0.2241	0.1043	0.2806	0.2261	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000	0.1118	0.0987	0.0493	0.1579	0.5012	0.0000	0.0811	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0380	0.1902	0.0761	0.1189	0.1712	0.0948	0.0698	0.2410	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0000	0.0000	0.0000	0.0497	0.1077	0.0000	0.2099	0.2127	0.4199	0.0000	0.0000	0.0000

Standard Error: With Freeway Defaults: 0.122 With Arterial Defaults: 0.119

Table 39. Knox Co. Data – Starts Per Day Table

Class	Knox Data	Defaults
LDGT1	13.85	8.06
LDGT2	19.53	8.06
LDGT4	9.12	8.06
HDGV2b	77.89	6.88

Standard Error: 5.21

Table 40. Knox Co. Data – Start Distribution Table

Hour	Hour Index	Knox Data	Defaults
6:00-6:59	1	0.00198744297	0.02040816327
7:00-7:59	2	0.00221328877	0.05541601256
8:00-8:59	3	0.03057952030	0.06028257457
9:00-9:59	4	0.08058177876	0.04725274725
10:00-10:59	5	0.10944487104	0.05164835165
11:00-11:59	6	0.11685261304	0.06718995290
12:00-12:59	7	0.09693301414	0.08069073783
13:00-13:59	8	0.10461177108	0.07299843014
14:00-14:59	9	0.11897556349	0.08037676609
15:00-15:59	10	0.13306834094	0.08979591837
16:00-16:59	11	0.09770088983	0.08414442700
17:00-17:59	12	0.05935227427	0.07723704867
18:00-18:59	13	0.02859207733	0.06012558870
19:00-19:59	14	0.01337007092	0.01385757100
20:00-20:59	15	0.00275531867	0.01385757100
21:00-21:59	16	0.00063236822	0.01385757100
22:00-22:59	17	0.00009033832	0.01385757100
23:00-23:59	18	0.00000000000	0.01385757100
0:00-0:59	19	0.00004516916	0.01385757100
1:00-1:59	20	0.00049686074	0.01385757100
2:00-2:59	21	0.00040652243	0.01385757100
3:00-3:59	22	0.00058719906	0.01385757100
4:00-4:59	23	0.00054202990	0.01385757100
5:00-5:59	24	0.00018067663	0.01385757100
Total		1.00000000000	1.00000000000

Standard Error: 0.026

Table 41. Knox Co. Data – Weekday Trip Length Distribution Table

Trip Duration	**Percent Daily VMT**	
minutes	Knox Data	Defaults
<=10	34.18	6.74
11-20	30.92	18.51
21-30	9.72	16.78
31-40	3.93	13.11
41-50	1.45	8.33
51+	19.80	36.53
Total	100.00	100.00

Standard Error: 15.40

Table 42. Summary of Input Parameter Findings

MOBILE6 Input Parameter	North Carolina Data		Knox County Data	
	Supports Defaults	Inconclusive	Supports Defaults	Inconclusive
Mileage Accumulation Rates	No		No	
Hour VMT	No		No	
Speed VMT	No		No	
Starts Per Day	Yes		No	
Start Distribution	No		No	
Soak Distribution		Yes		Yes
Trip Length Distribution	Yes		No	

Table 43. Emission Factor Results – Default Run

Vehicle Class	Composite Emission Factors (grams/mile)		
	VOC	CO	NOX
LDGT12	1.630	18.64	1.229
LDGT34	2.629	25.05	1.609
LDGT (All)	1.884	20.27	1.325
HDGV	2.313	20.07	4.660
LDDT	0.983	1.696	1.642
HDDV	0.600	3.274	13.09
ALL VEHICLES	1.619	16.609	2.303

VOC=Volatile Organic Compounds (a MOBILE6 Hydrocarbon category)
CO=Carbon Monoxide
NOX=Nitrogen Oxides

Table 44. Emission Factor Results – North Carolina Run

Vehicle Class	Composite Emission Factors (grams/mile)					
	VOC	% Change	CO	% Change	NOX	% Change
LDGT12	1.553	-4.7	18.35	-1.6	1.272	+3.5
LDGT34	2.518	-4.2	24.33	-2.9	1.610	+0.1
LDGT (All)	1.788	-5.1	19.81	-2.3	1.355	+2.3
HDGV	2.468	+6.7	23.47	+16.9	4.926	+5.7
LDDT	0.849	-13.6	1.412	-16.7	1.706	+3.9
HDDV	0.616	+2.7	3.506	+7.1	13.987	+6.9
ALL VEHICLES	1.586	-2.0	16.856	+1.5	2.331	+1.2

Table 45. Emission Factor Results – Knox County Run

Vehicle Class	Composite Emission Factors (grams/mile)					
	VOC	% Change	CO	% Change	NOX	% Change
LDGT12	1.900	+16.6	15.00	-19.5	1.246	+1.4
LDGT34	2.332	-11.3	17.48	-30.2	1.536	-4.5
LDGT (All)	2.018	+7.1	15.68	-22.6	1.325	0.0
HDGV	4.144	+79.2	29.39	+46.4	4.526	-2.9
LDDT	1.022	+4.0	1.902	+12.1	1.716	+4.5
HDDV	0.755	+25.8	4.326	+32.1	13.581	+3.8
ALL VEHICLES	1.764	+9.0	14.178	-14.6	2.428	+5.4

Table 46. NC and Knox Co. Emission Factor Results – Single Non-Default Input Runs

Run	Non-Default Input	Vehicle Class	Composite Emission Factors (grams/mile)			
			VOC	% Change	CO	% Change
NC	Speed VMT Only	HDGV	2.36	+2.0	21.47	+7.0
	Mile Accumulation Only		2.523	+9.1	22.45	+11.9
	Starts per Day Only		2.269	-1.9	20.07	0.0
Knox County	Speed VMT Only	HDGV	2.705	+16.9	24.85	+23.8
		HDDV	0.718	+19.7	4.061	+24.0
		LDGT (All)	2.04	+8.3	20.47	+1.0
	Mile Accumulation Only	HDGV	2.151	-7.0	21.60	+7.6
		HDDV	0.593	-1.2	3.24	-1.0
		LDGT (All)	1.943	+3.1	20.27	0.0
	Starts Per Day Only	HDGV	4.54	+96.3	20.07	0.0
		HDDV	0.60	0.0	3.274	0.0
		LDGT (All)	2.454	+30.3	27.07	+33.5

Table 47. Input Parameters - Vehicle Usage Class Runs

Run	Primary M6 Vehicle Class(es) in Vehicle Usage Class	Average Speed (mph)	Starts Per Day (Defaults in brackets)
1. Knox Co. USPS Home/Business Mail Delivery Vehicles	LDGT1	12.1 (36.5 FWY, 31.2 ART)	14.3 (8.06)
	LDGT2		14.3 (8.06)
	LDGT4		14.3 (8.06)
2. Knox Co. Package PUD Vehicles	HDGV	19.4 (36.5 FWY, 31.2 ART)	81.8 (HDGV2b=6.88)
	HDDV		N/A
3. NC Service Vehicles (Vans, Pickups, Single Unit Trucks)	LDGT2	29.0 (36.5 FWY, 31.2 ART)	5.7 (8.06)
	LDGT4		5.7 (8.06)
	HDGV		5.7 (HDGV2b=6.88)
	HDDV		N/A
4. NC & Knox Co. Long Haul Trucks	HDDV	34.3 (36.5 FWY, 31.2 ART)	N/A

Table 48. Emission Factor Results – Vehicle Usage Class Runs

Run	Vehicle Class	Composite Emission Factors (grams/mile)					
		VOC	% Change	CO	% Change	NOX	% Change
1. Knox Co. USPS Home/Business Mail Delivery Vehicles	LDGT12	2.888	+77.2	25.65	+37.6	1.651	+34.3
	LDGT34	3.847	+46.3	29.72	+18.6	1.991	+23.7
	LDGT (All)	3.137	+66.5	26.70	+31.7	1.739	+31.2
2. Knox Co. Package PUD Vehicles	HDGV	4.751	+105.4	30.61	+52.5	4.204	-9.8
	HDDV	0.872	+45.3	4.756	+45.3	12.575	-3.9
3. NC Service Vehicles (Vans, Pickups, Single Unit Trucks)	LDGT12	1.521	-6.7	16.4	-12.0	1.192	-3.0
	LDGT34	2.441	-7.2	22.87	-8.7	1.59	-1.2
	LDGT (All)	1.76	-6.6	18.08	-10.8	1.295	-2.3
	HDGV	2.182	-5.7	20.69	+3.1	4.67	+0.2
	HDDV	0.617	+2.8	3.18	-2.9	11.634	-11.1
4. NC & Knox Co. Long Haul Trucks	HDDV	0.537	-10.5	2.908	-11.2	12.647	-3.4

Table 49. Vehicle Usage Class Emission Factor Results –Single Non-Default Input Runs

Run	Non-Default Input	Vehicle Class	Composite Emission Factors (grams/mile)					
			VOC	% Change	CO	% Change	NOX	% Change
1	Average Speed Only	LDGT (All)	2.733	+45.1	21.98	+8.4	1.593	+20.2
	Starts per Day Only	LDGT (All)	2.359	+25.2	25.66	+26.6	1.535	+15.8
2	Average Speed Only	HDGV	3.017	+30.4	30.61	+52.5	4.204	-9.8
		HDDV	0.872	+45.3	4.756	+45.3	12.58	-3.9
	Starts Per Day Only	HDGV	4.062	+75.6	23.18	+15.5	4.846	+4.0
		HDDV	0.615	+2.5	3.417	+4.4	13.20	+0.8

APPENDIX B

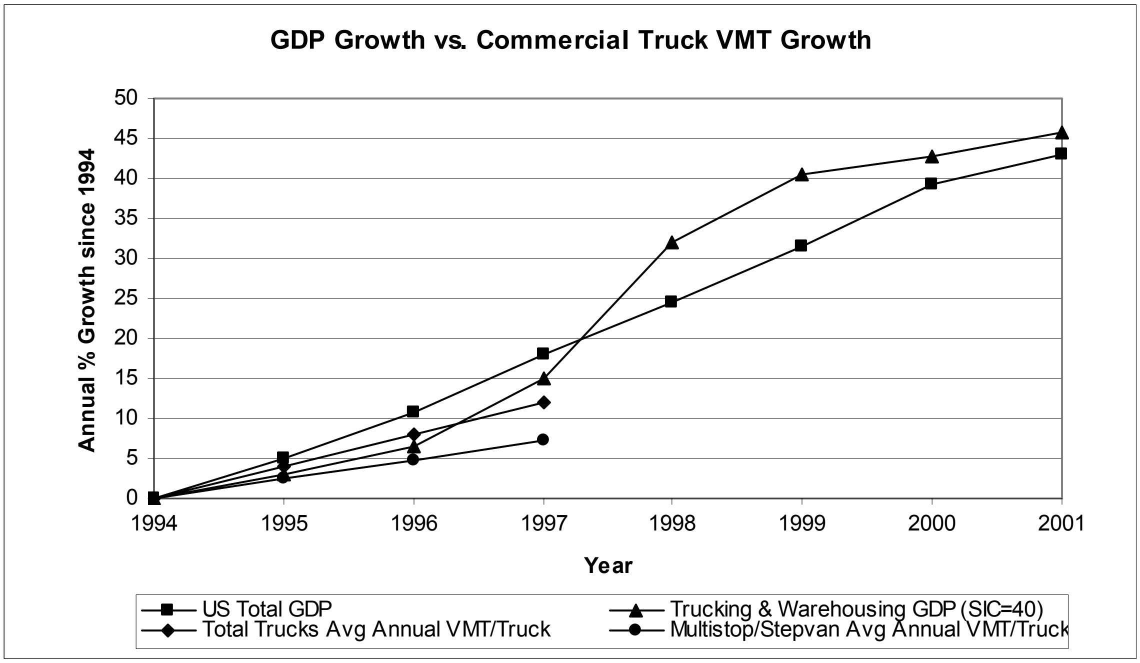

Figure 1. US Gross Domestic Product Growth 1994-2001

Sources: US Department of Commerce, Bureau of Economic Analysis, US Census Bureau websites

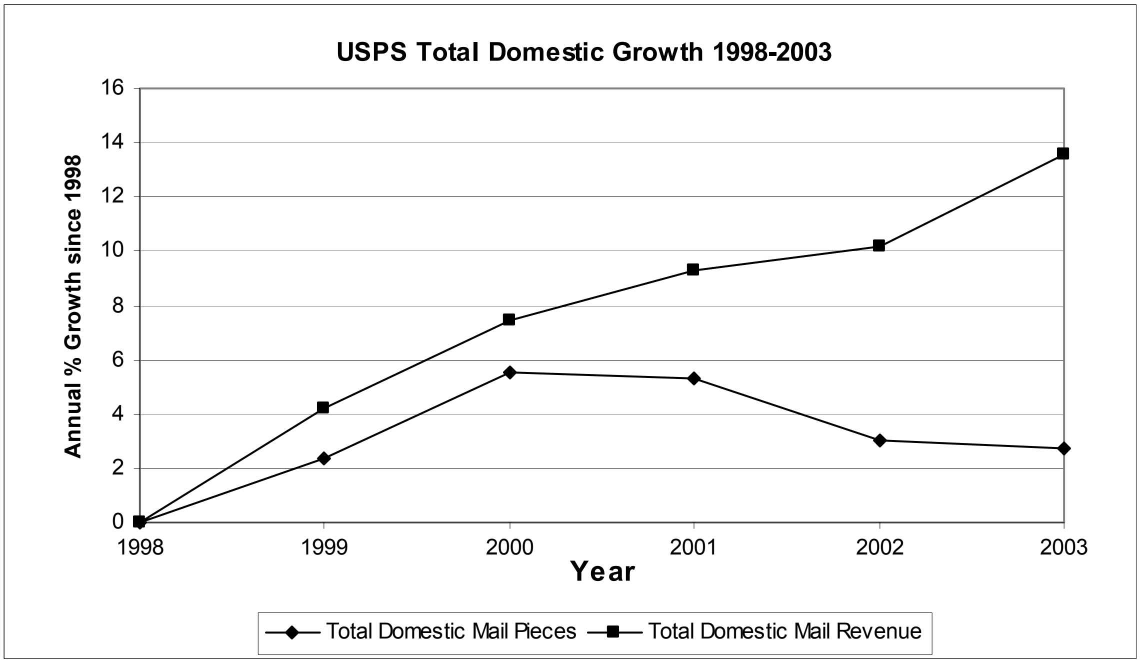

Figure 2. USPS Total Domestic Growth 1998-2003

Source: United States Postal Service website

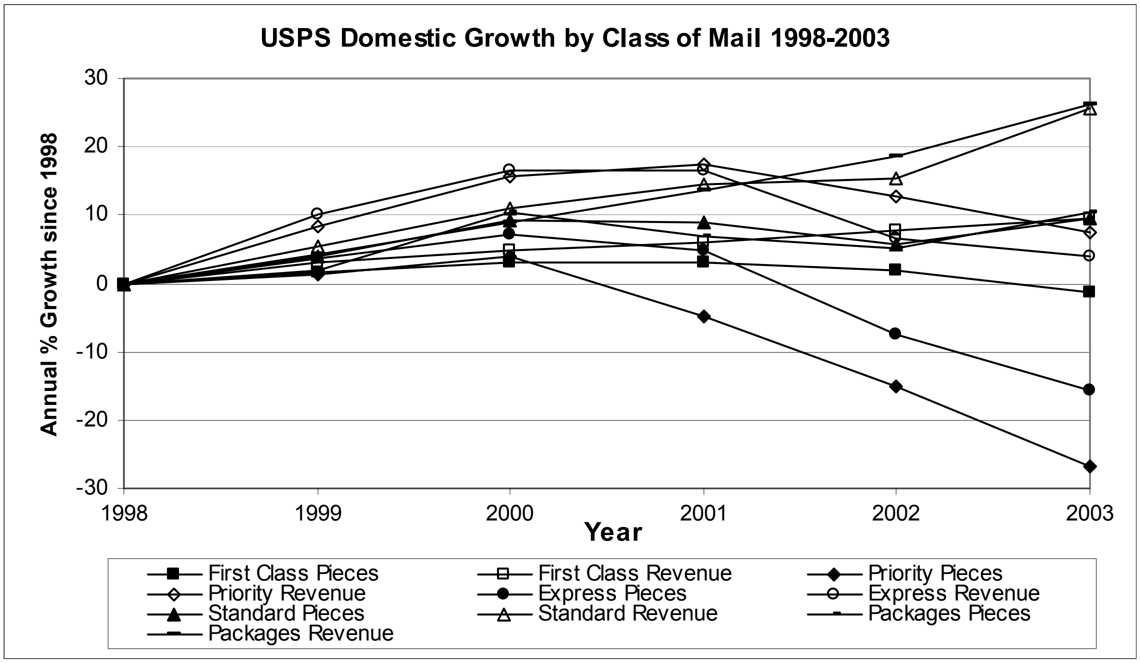

Figure 3. USPS Domestic Growth by Class of Mail 1998-2003

Source: United States Postal Service website

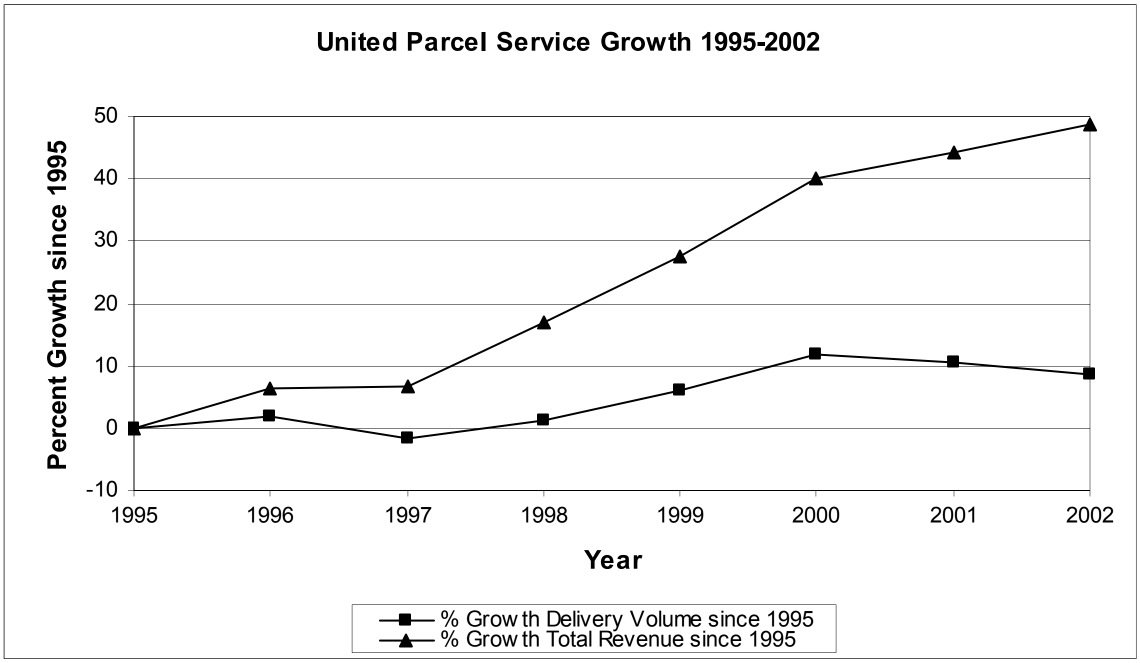

Figure 4. United Parcel Service Growth 1995-2002

Source: United Parcel Service website

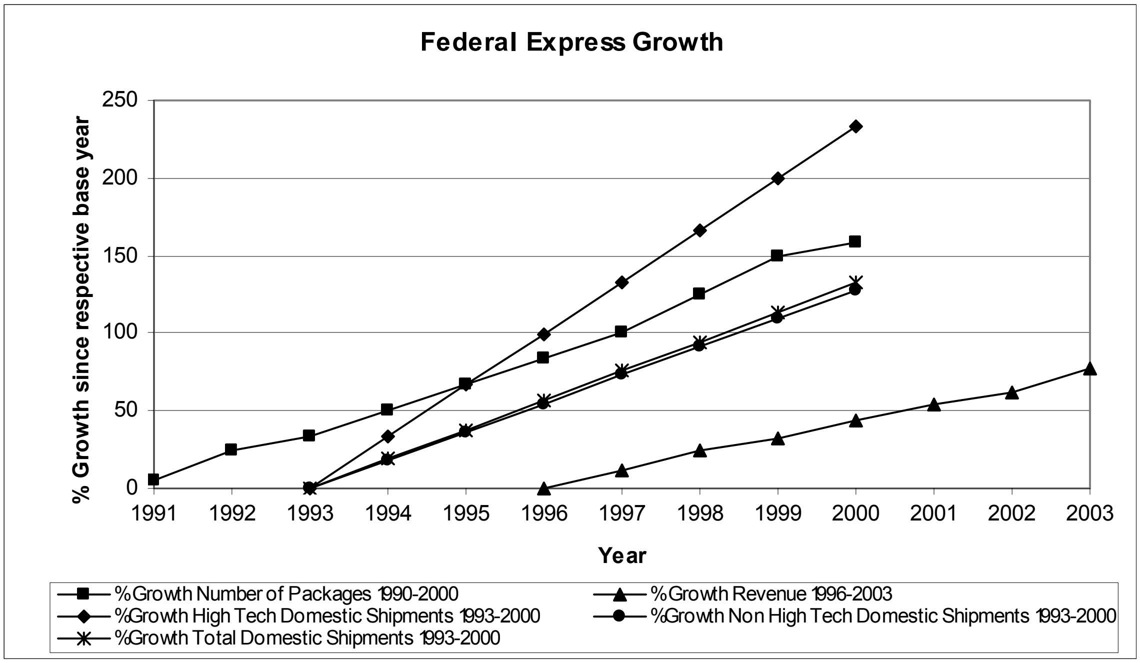

Figure 5. Federal Express Growth

Source: Federal Express website

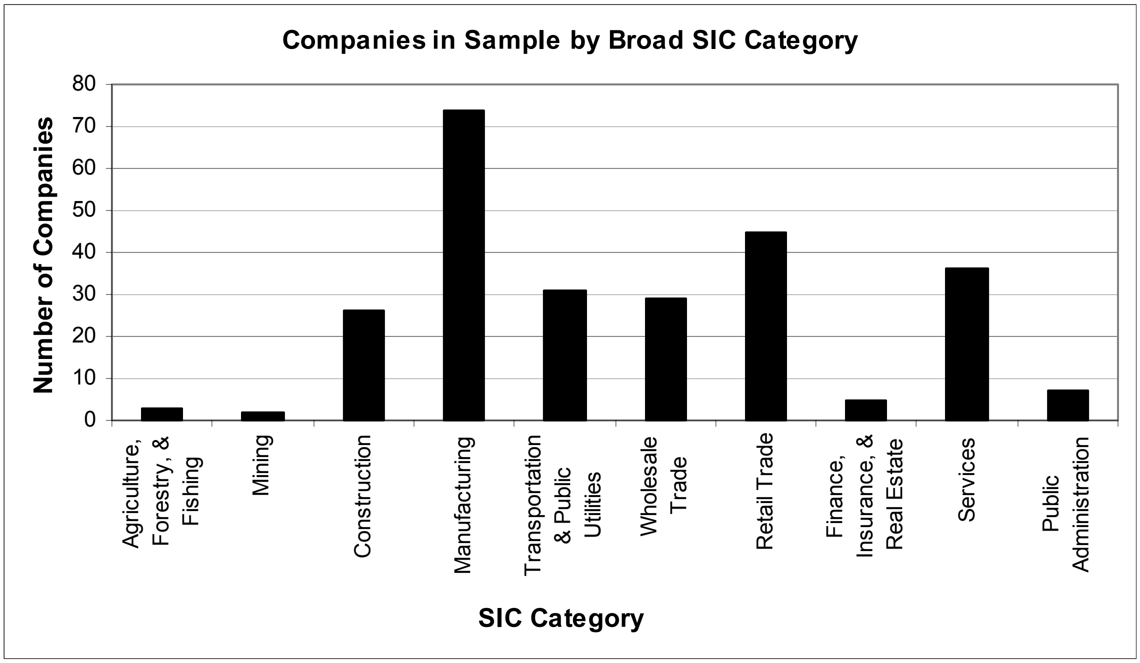

Figure 6. NC Data Companies - SIC Category

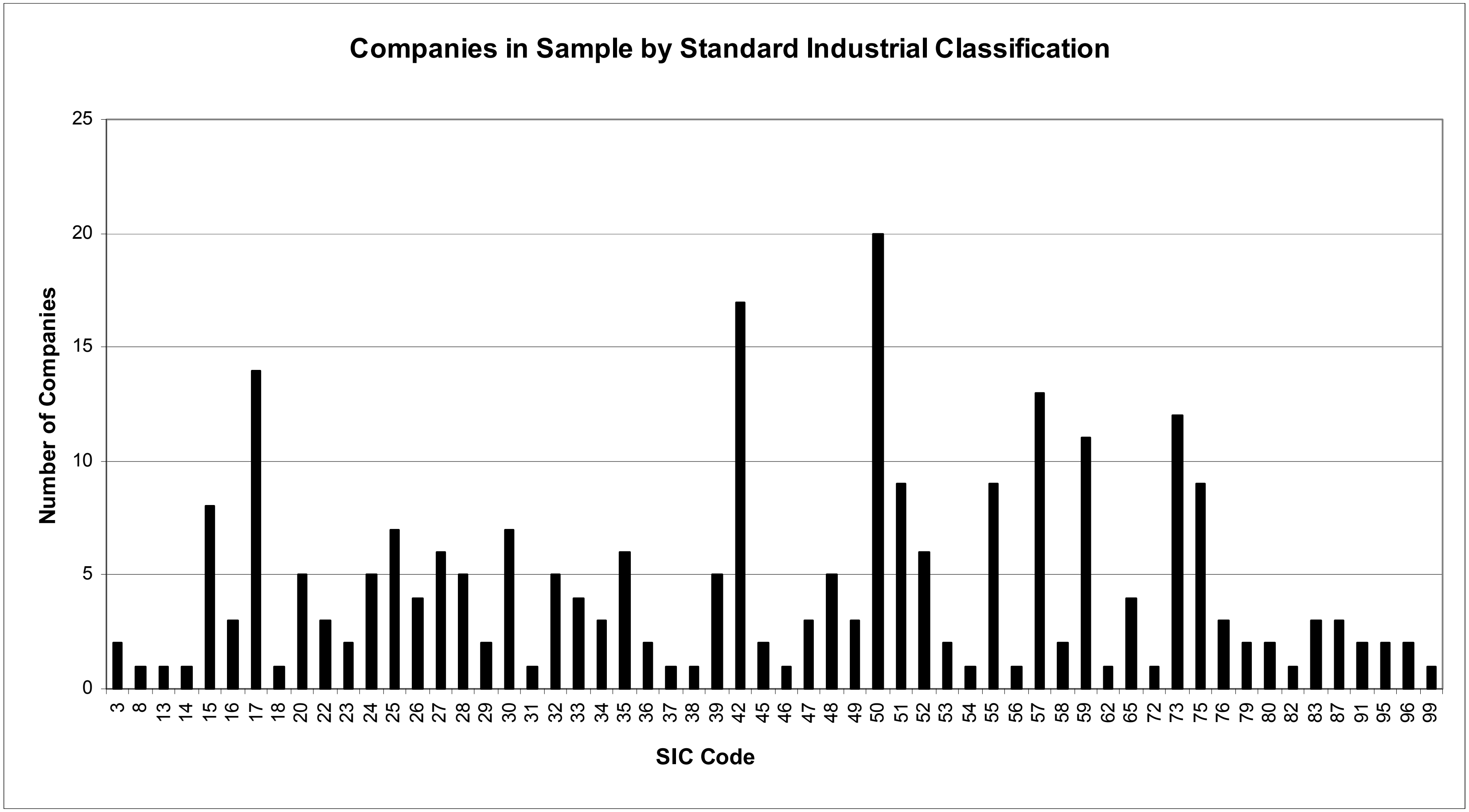

Figure 7. NC Data Companies - SIC Code

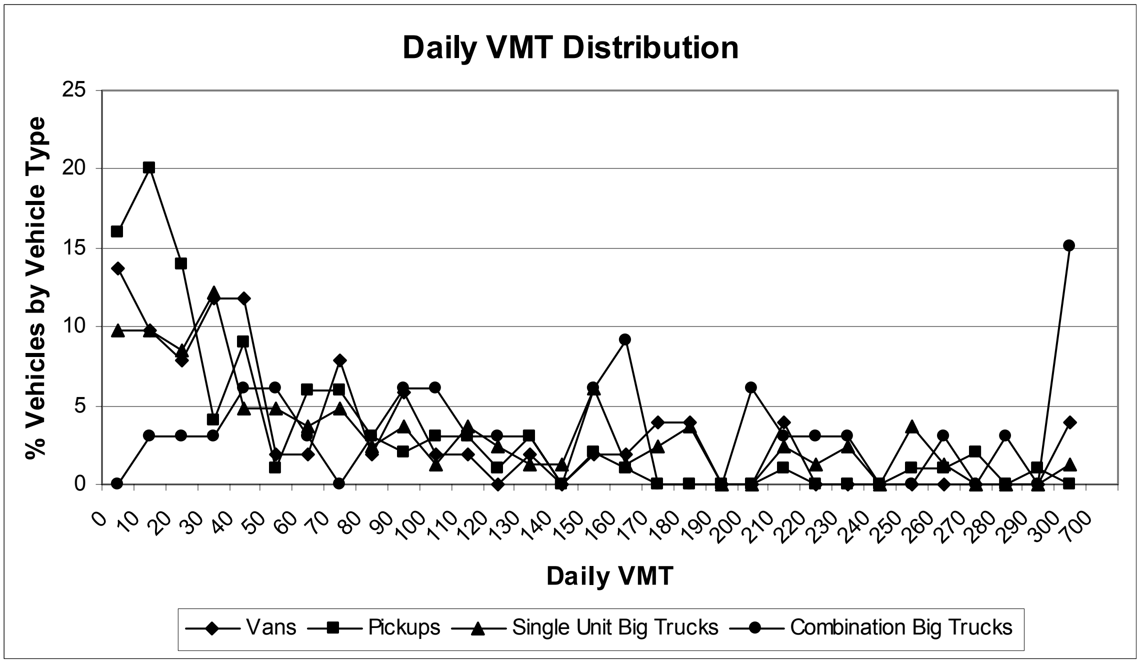

Figure 8. NC Data - Daily VMT Distribution

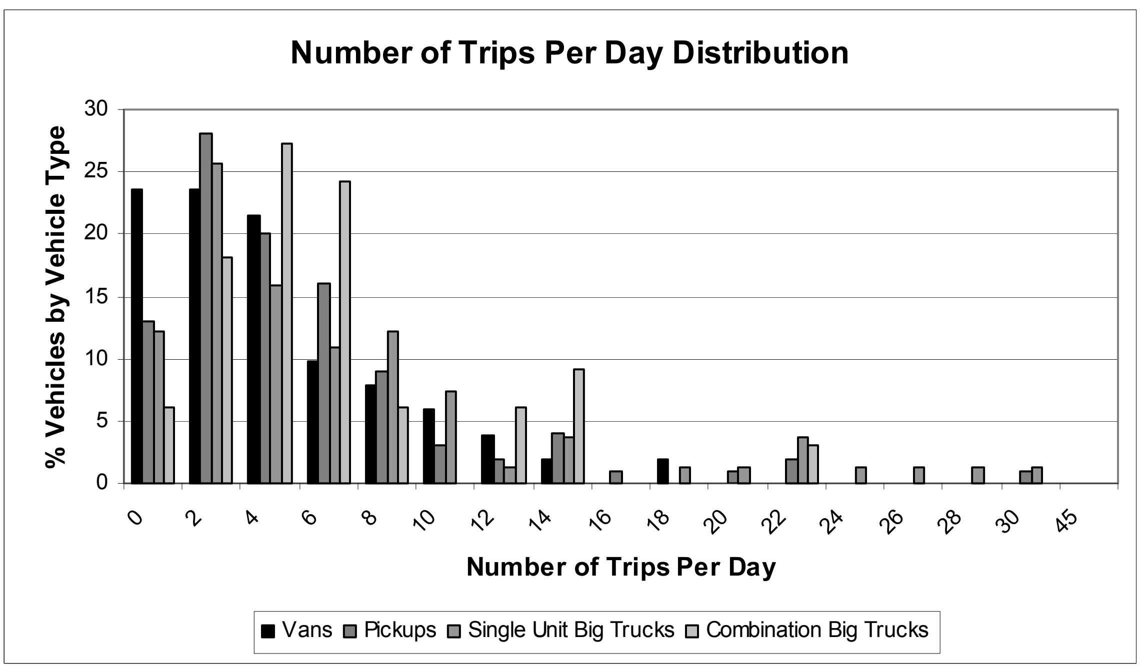

Figure 9. NC Data - Number of Trips Per Day Distribution

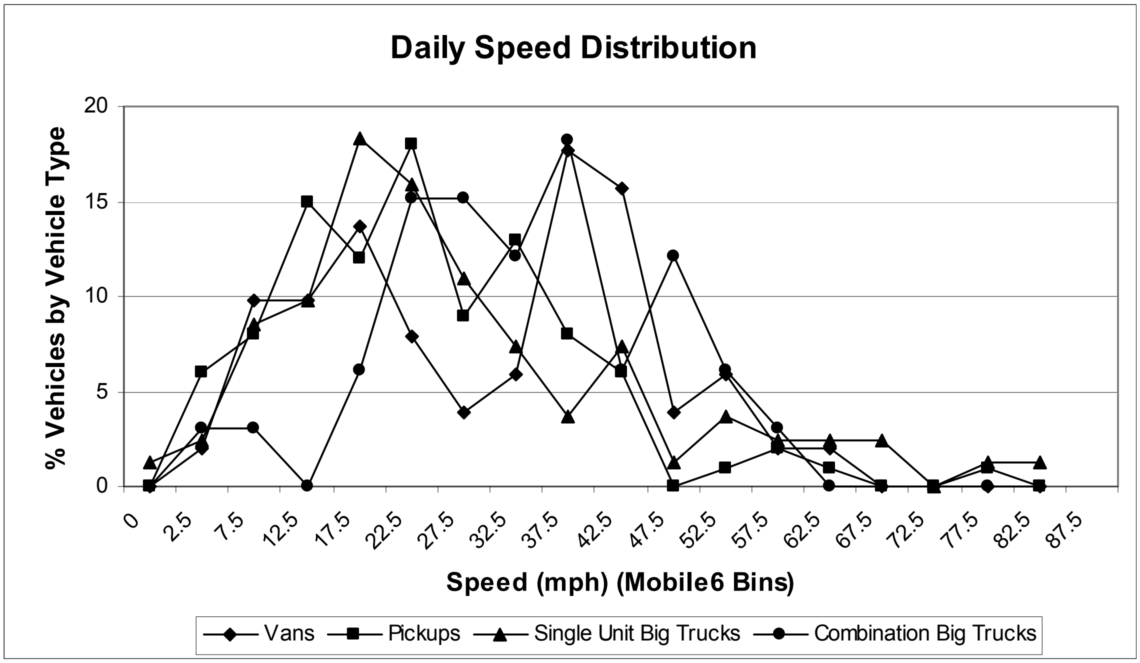

Figure 10. NC Data - Daily Speed Distribution

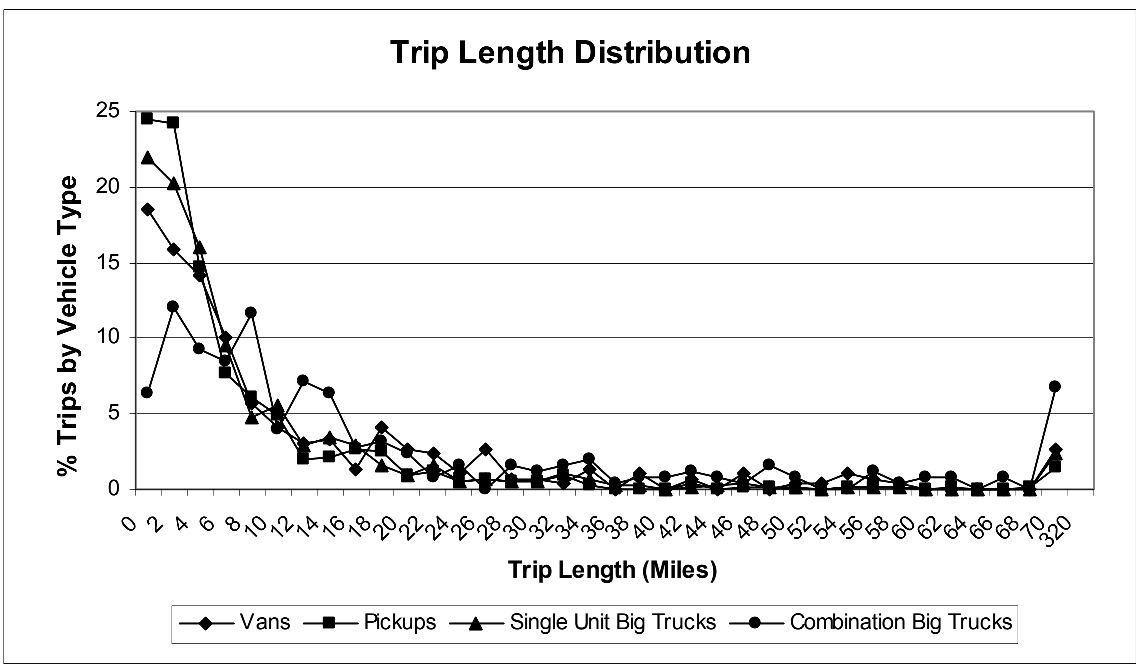

Figure 11. NC Data - Trip Length Distribution

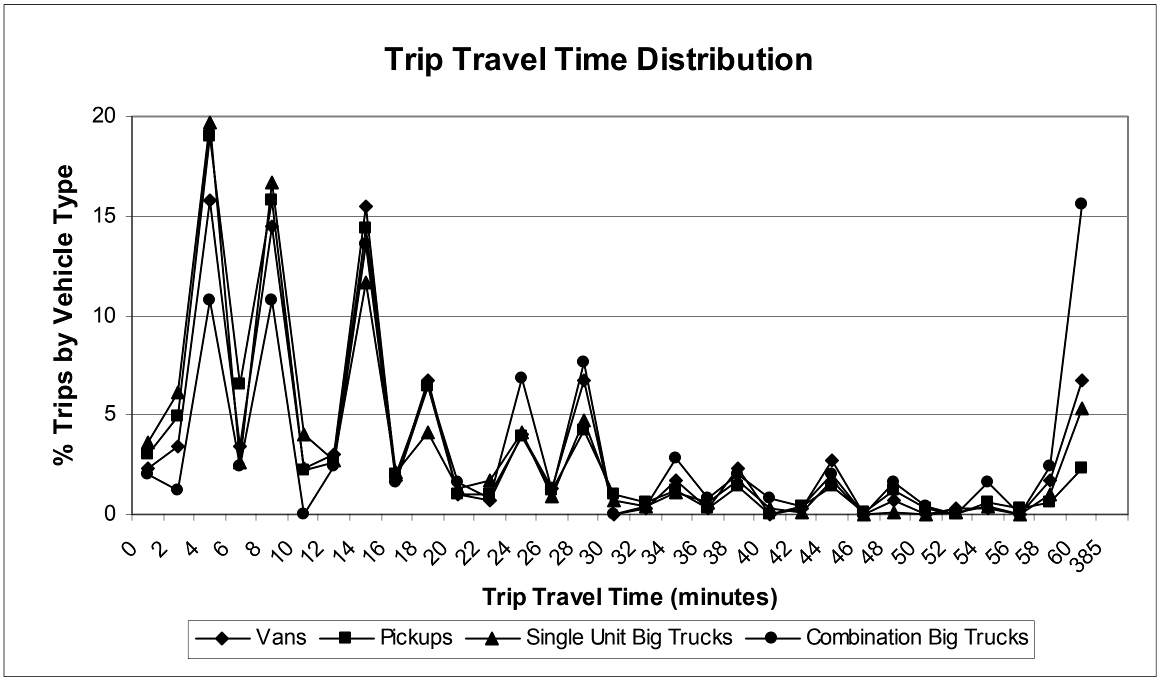

Figure 12. NC Data - Trip Travel Time Distribution

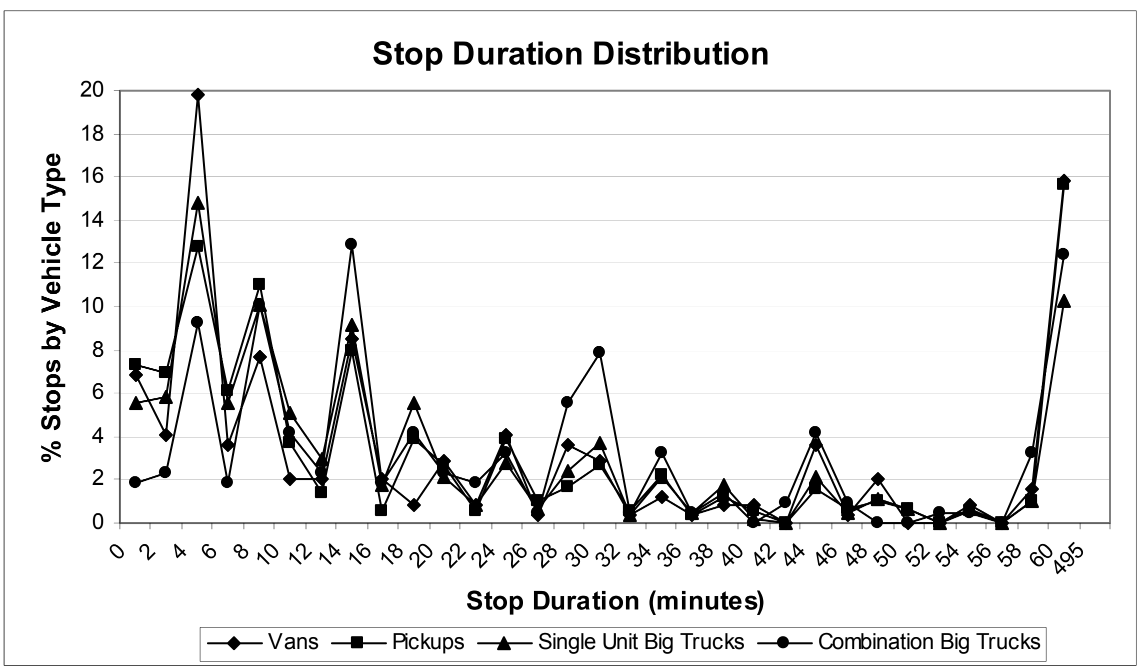

Figure 13. NC Data - Stop Duration Distribution

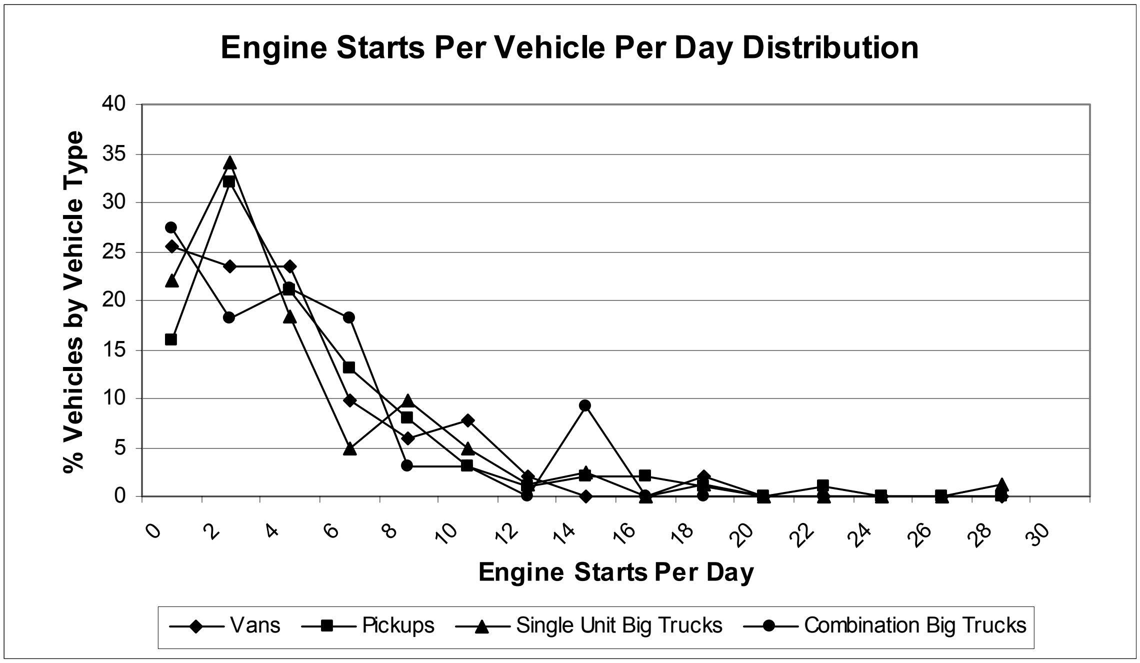

Figure 14. NC Data - Engine Starts Per Vehicle Per Day Distribution

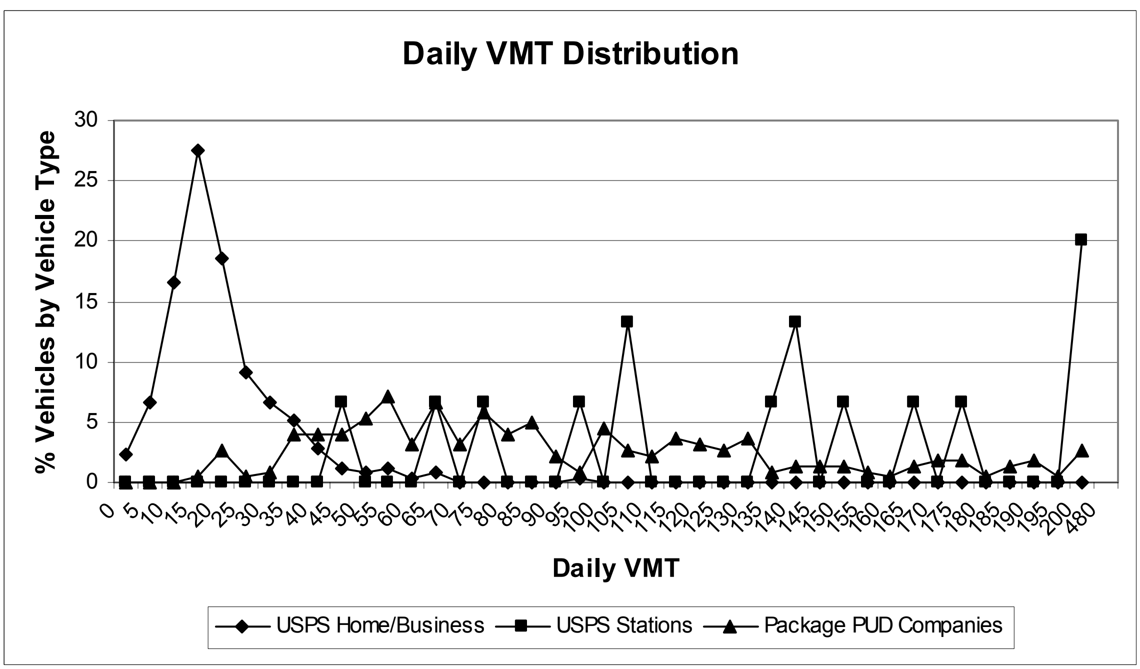

Figure 15. Knox Co. Data – Daily VMT Distribution

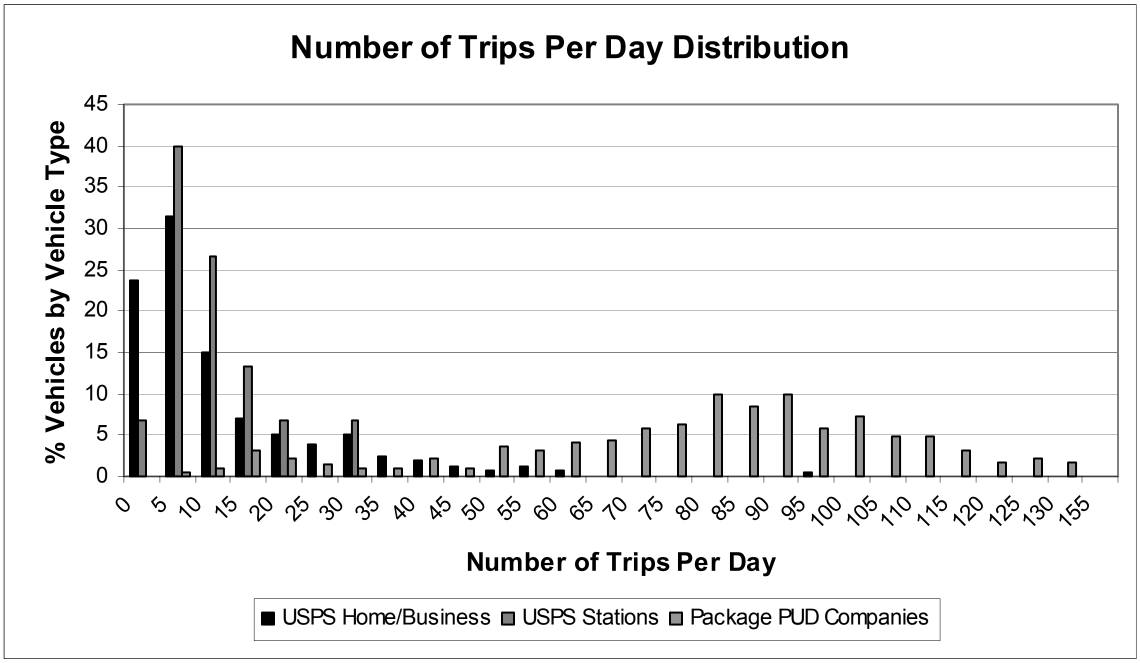

Figure 16. Knox Co. Data - Number of Trips Per Day Distribution

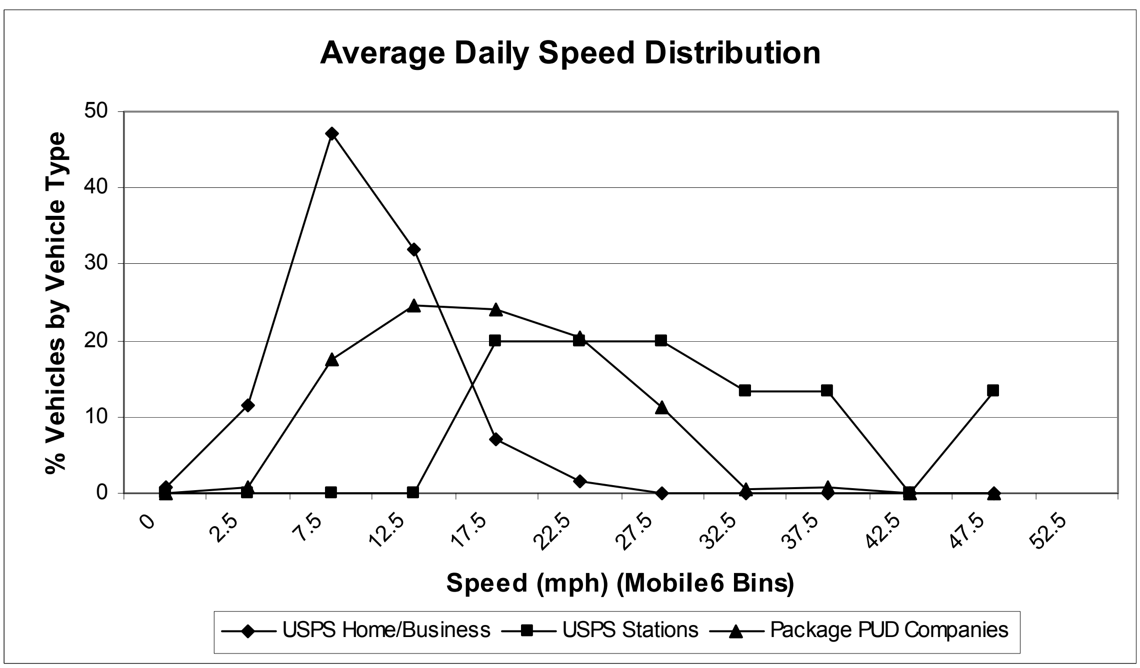

Figure 17. Knox Co. Data – Daily Speed Distribution

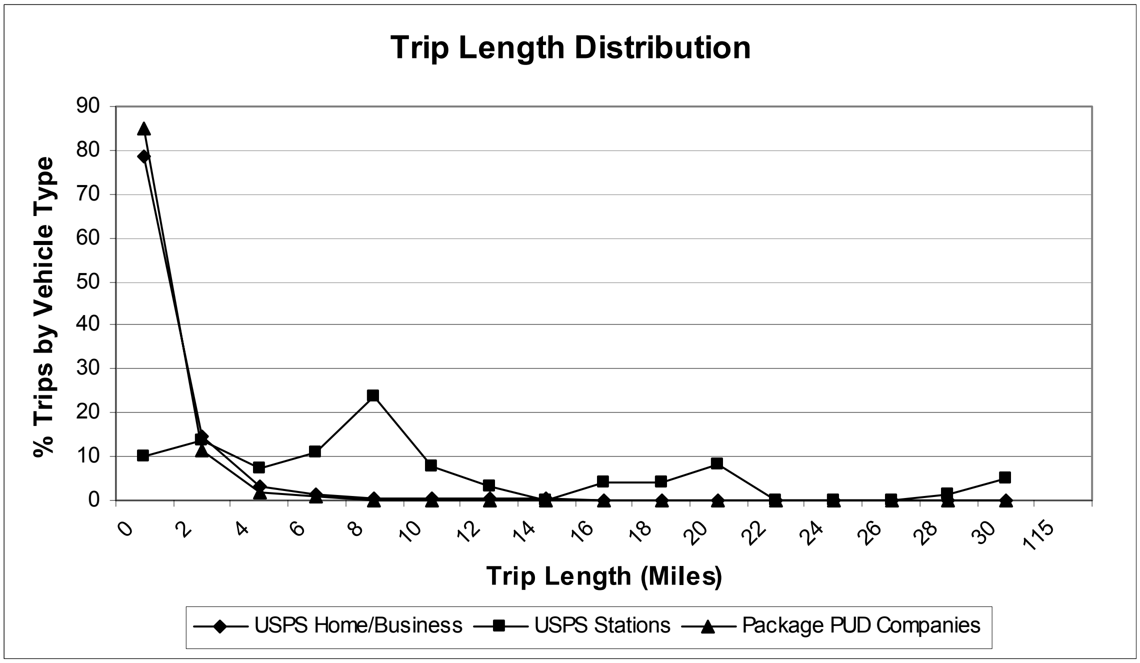

Figure 18. Knox Co. Data – Trip Length Distribution

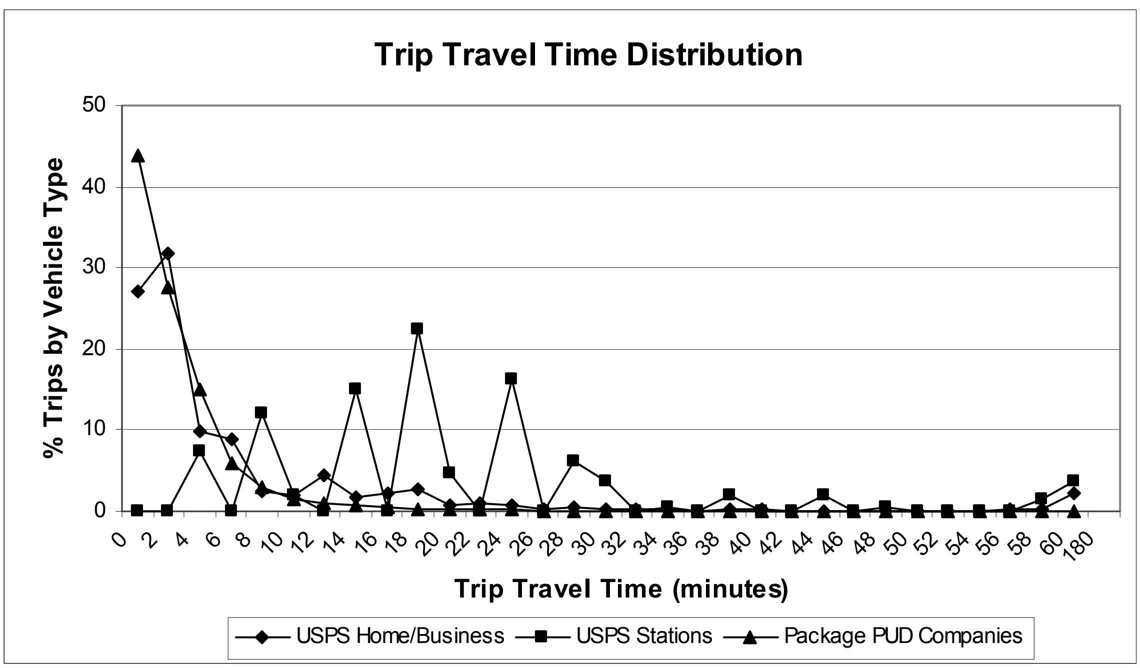

Figure 19. Knox Co. Data – Trip Travel Time Distribution

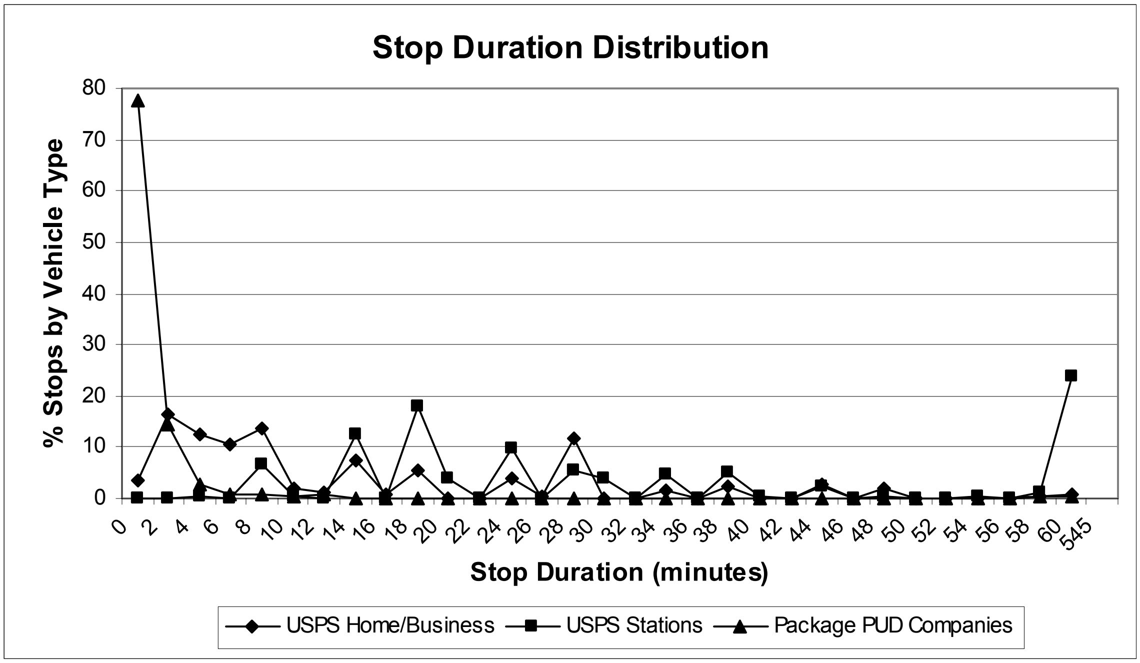

Figure 20. Knox Co. Data – Stop Duration Distribution

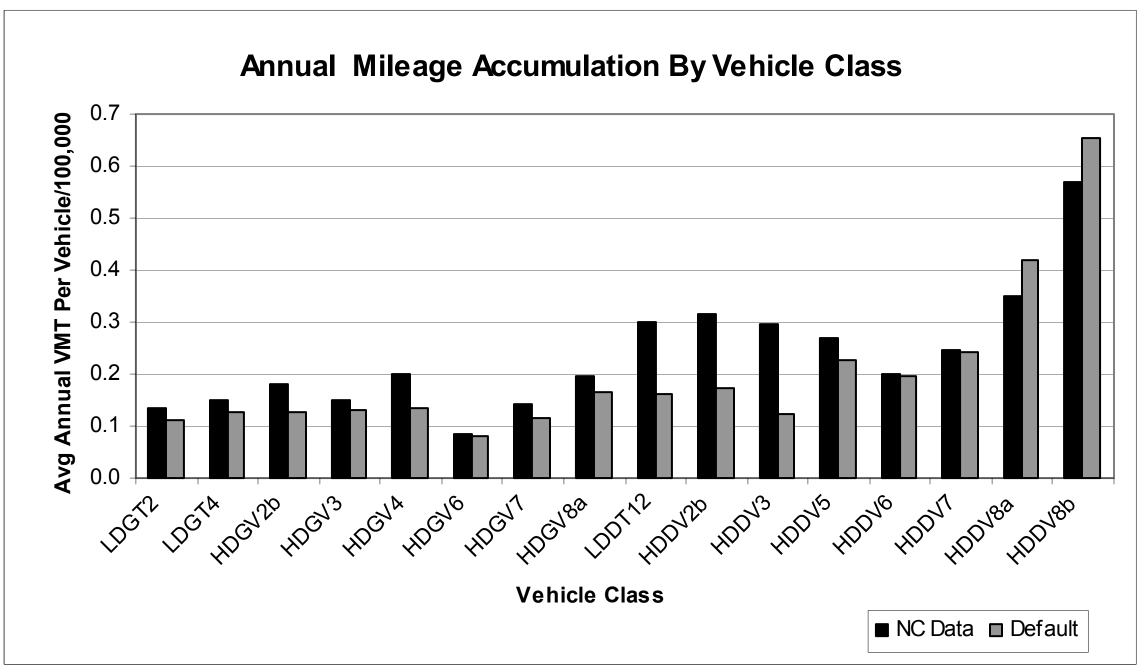

Figure 21. NC Data - Annual Mileage Accumulation

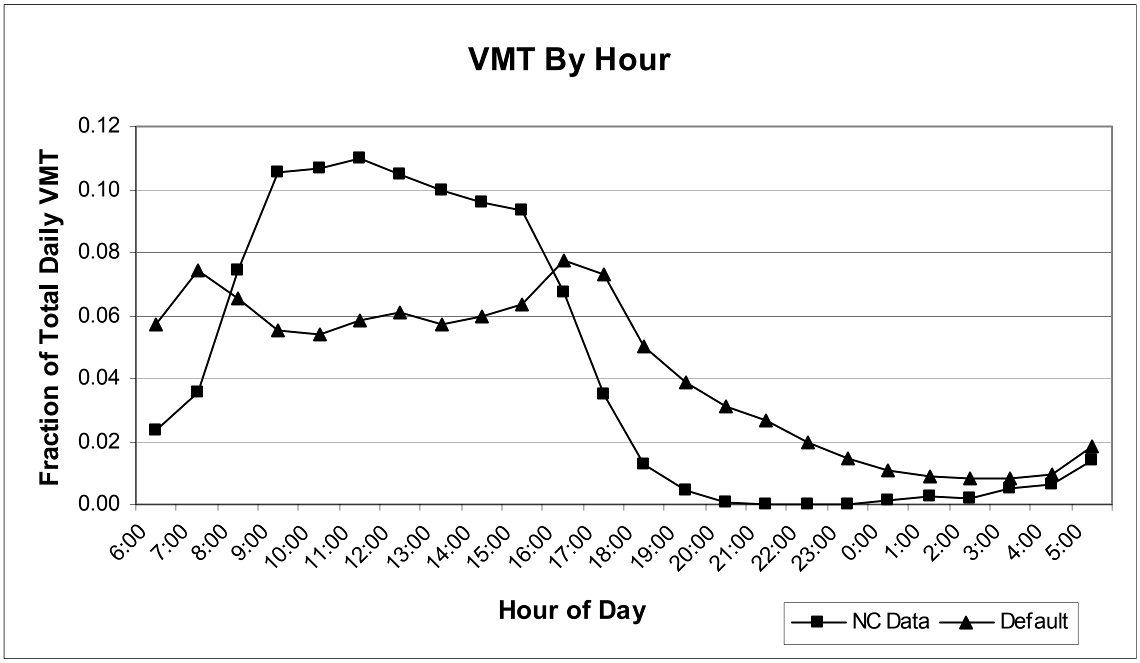

Figure 22. NC Data - VMT By Hour

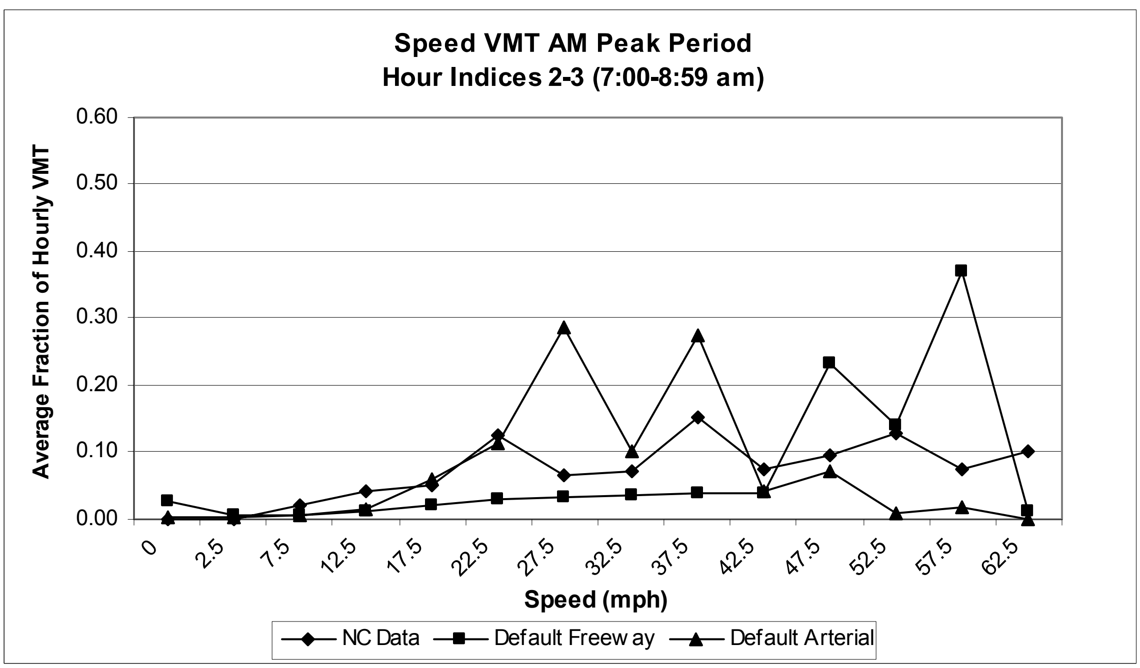

Figure 23. NC Data - Speed VMT AM Peak Period

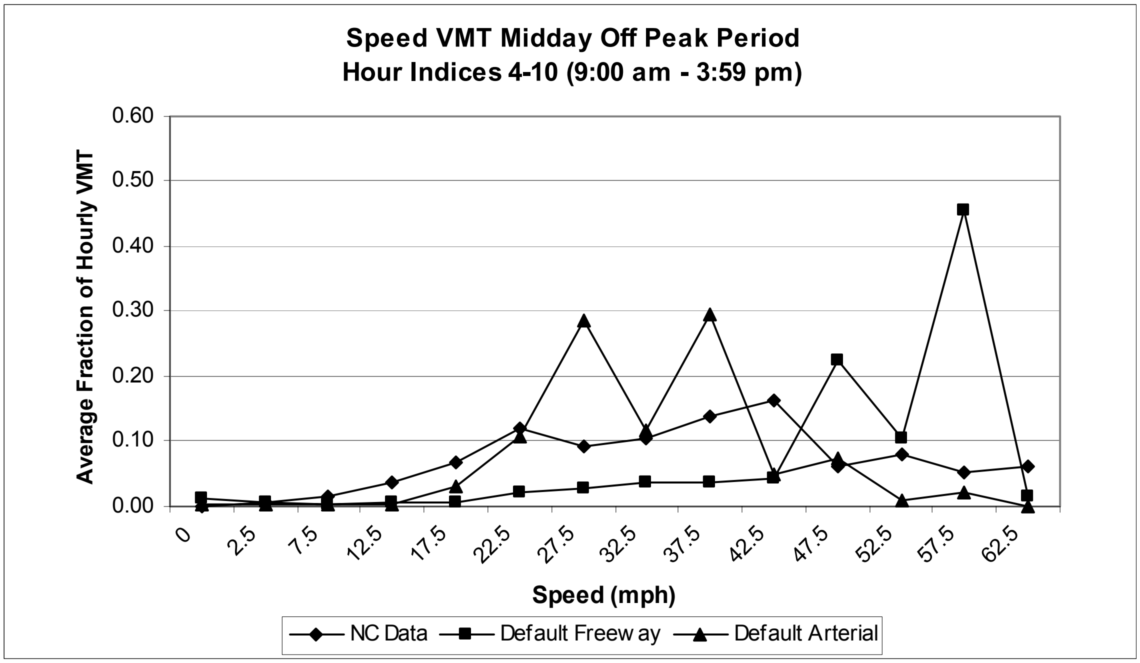

Figure 24. NC Data - Speed VMT Midday Off Peak Period

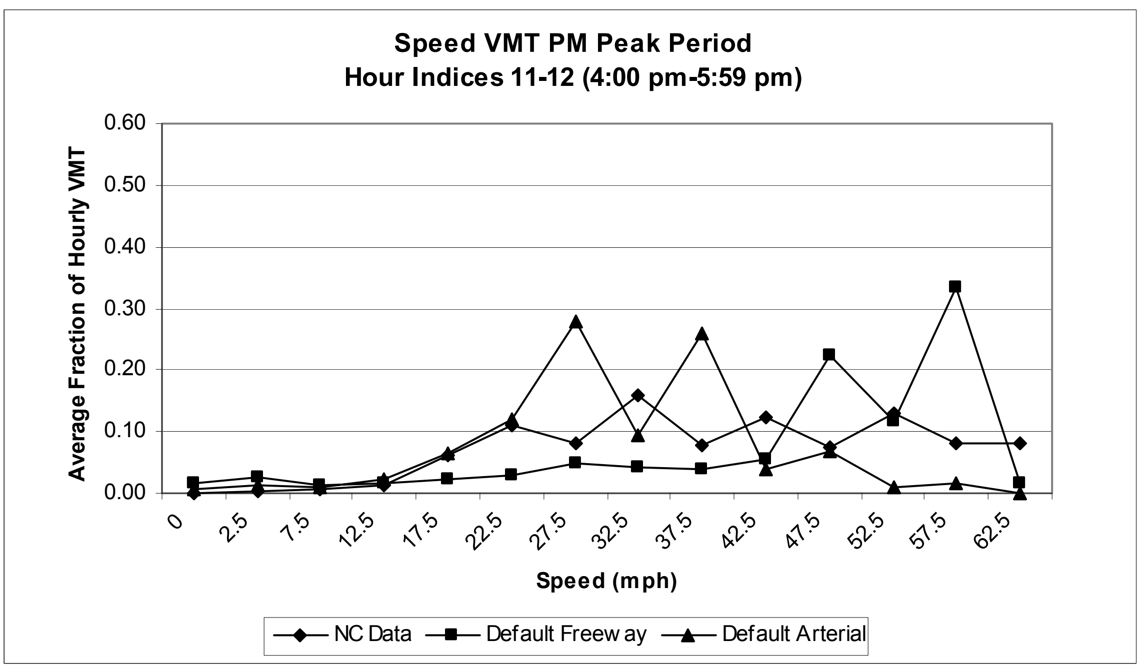

Figure 25. NC Data - Speed VMT PM Peak Period

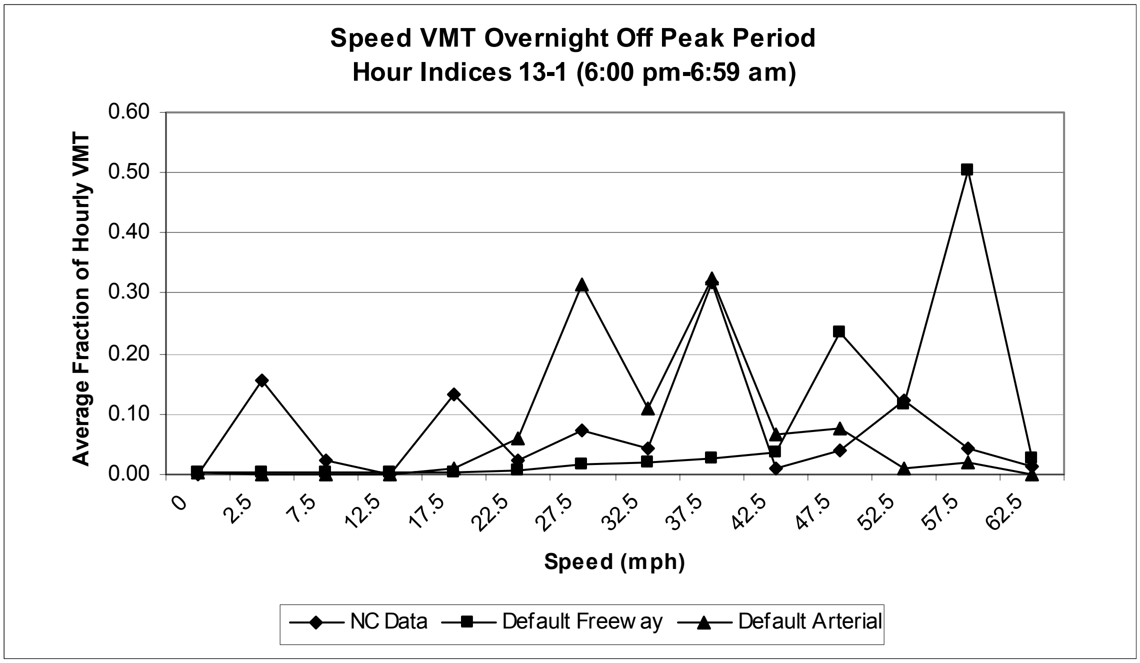

Figure 26. NC Data - Speed VMT Overnight Off Peak Period

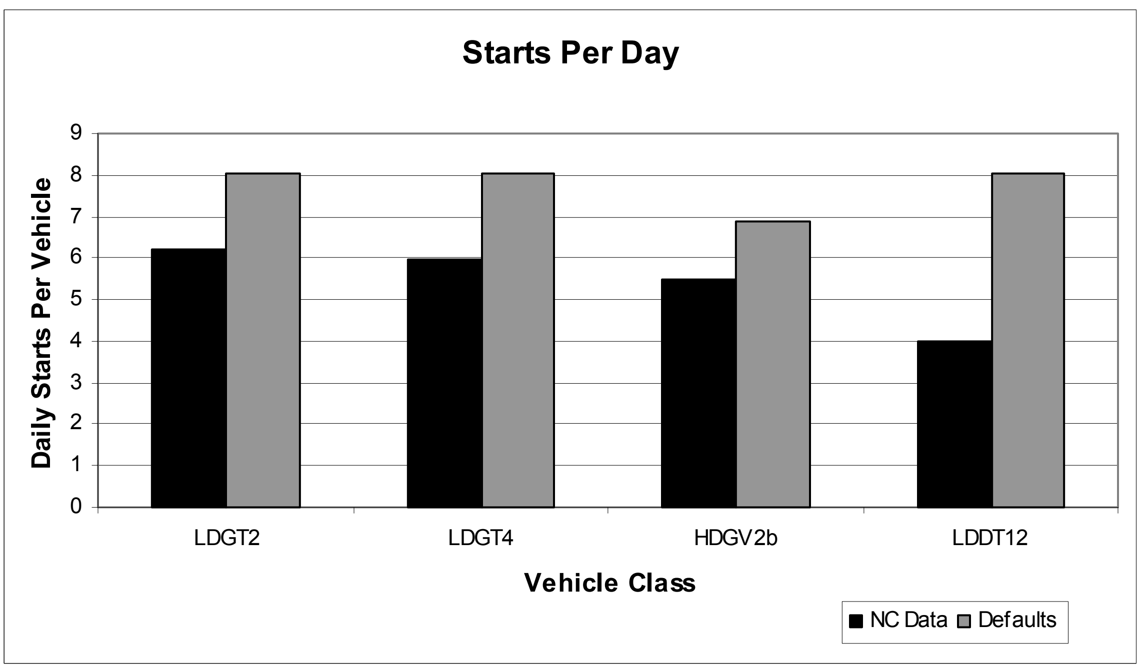

Figure 27. NC Data - Starts Per Day

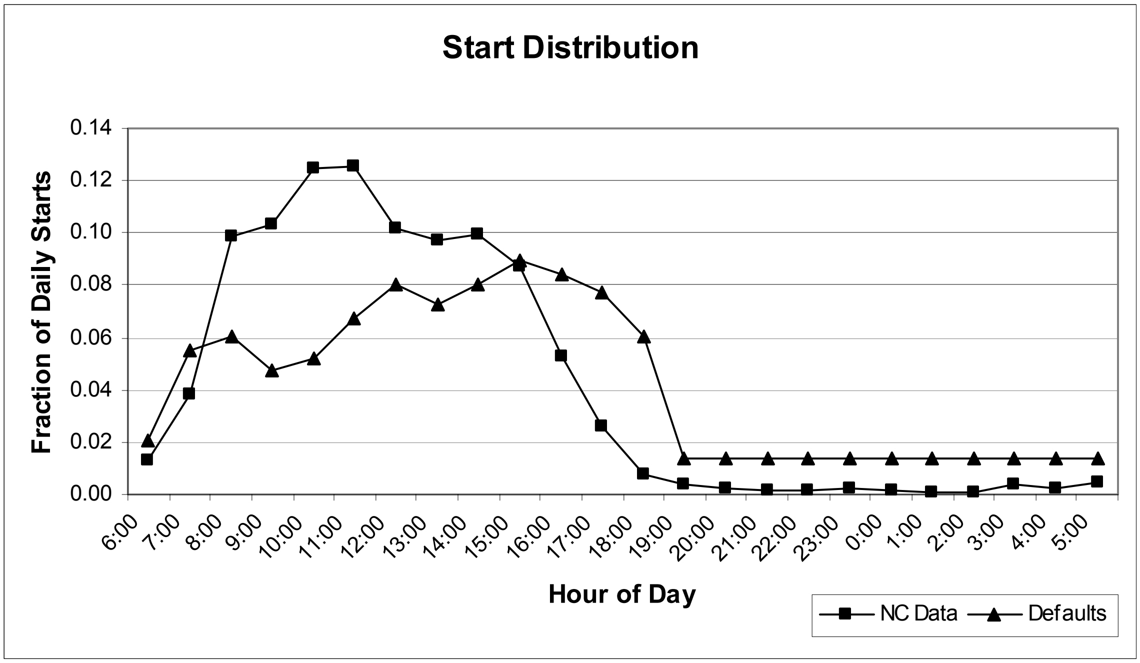

Figure 28. NC Data - Start Distribution

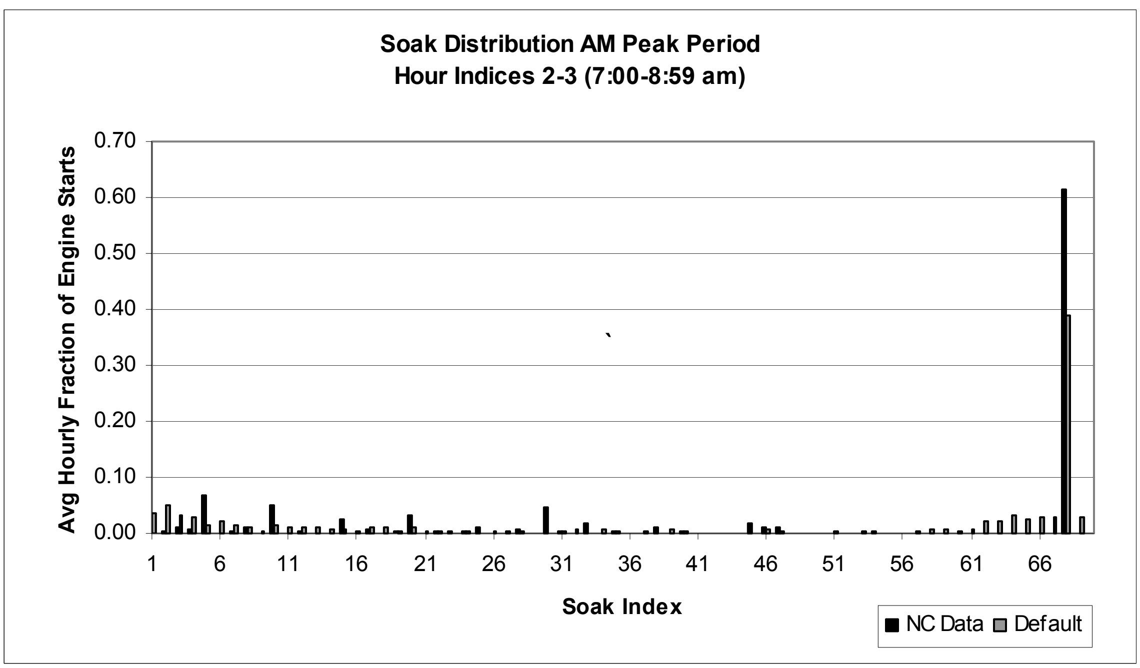

Figure 29. NC Data - Soak Distribution AM Peak Period

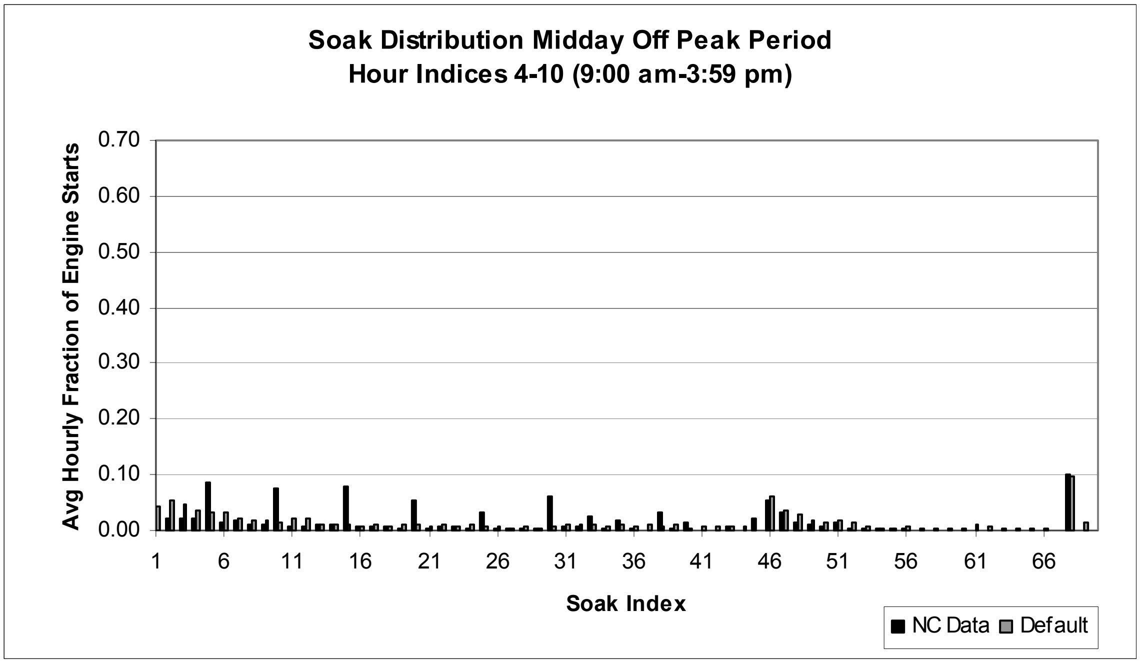

Figure 30. NC Data - Soak Distribution Midday Off Peak Period

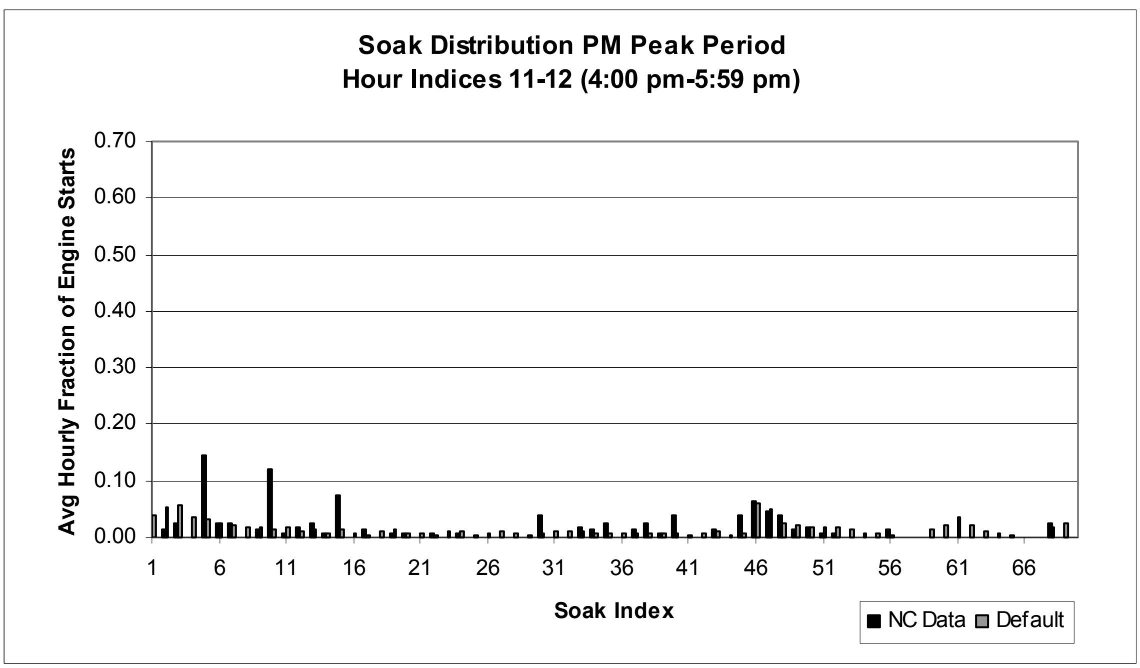

Figure 31. NC Data - Soak Distribution PM Peak Period

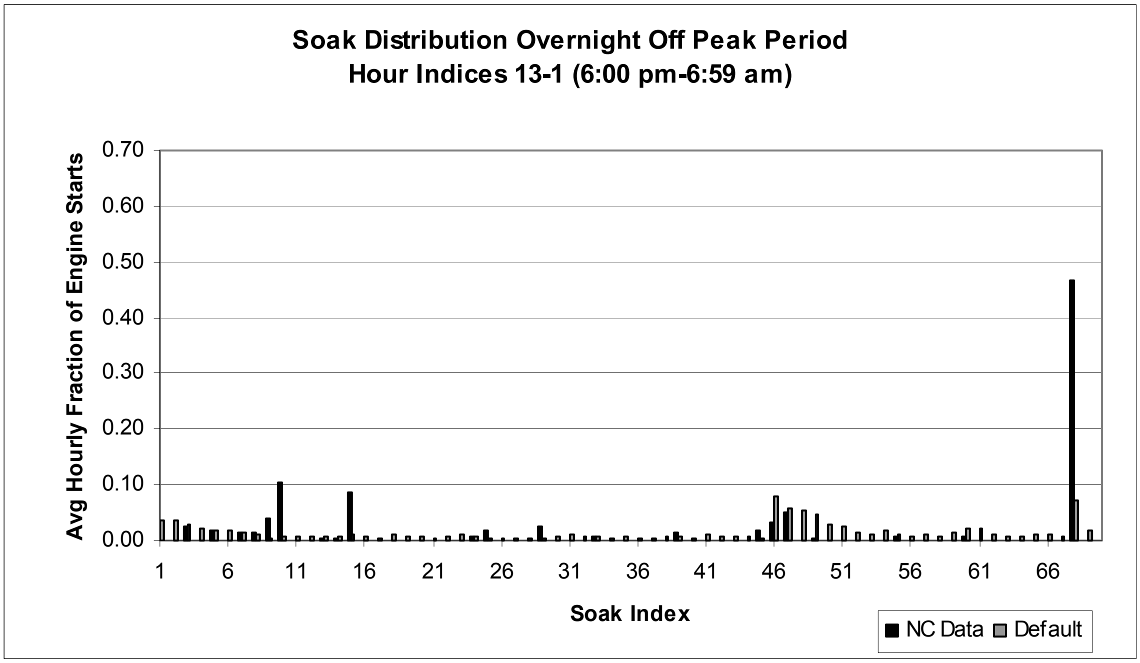

Figure 32. NC Data - Soak Distribution Overnight Off Peak Period

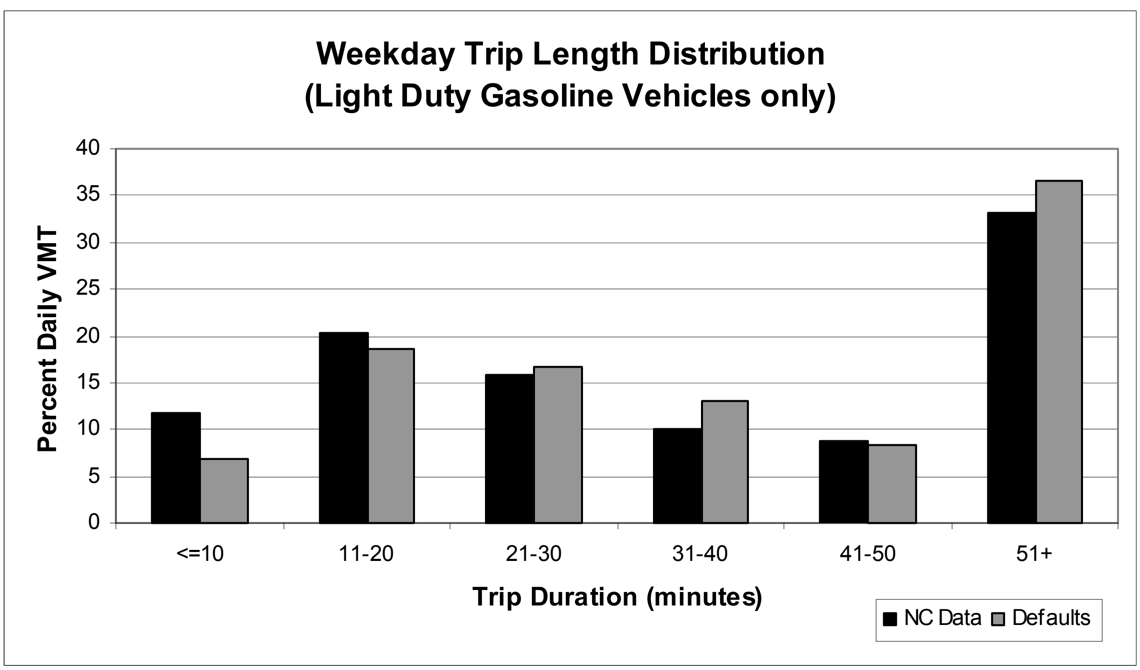

Figure 33. NC Data - Weekday Trip Length Distribution

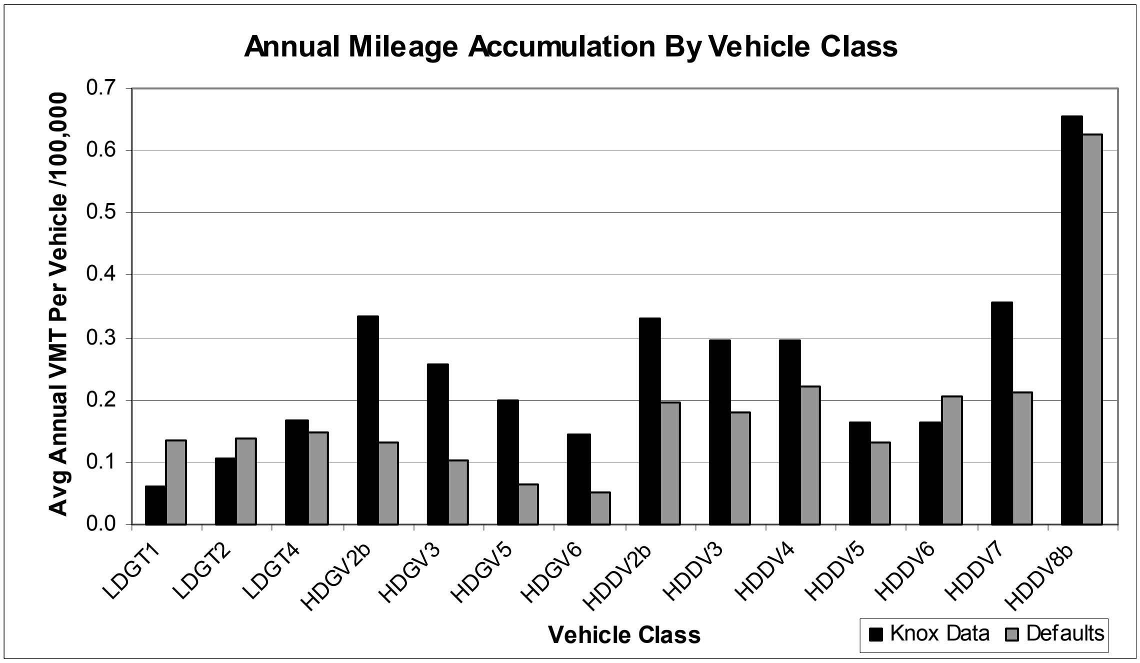

Figure 34. Knox Co. Data – Annual Mileage Accumulation

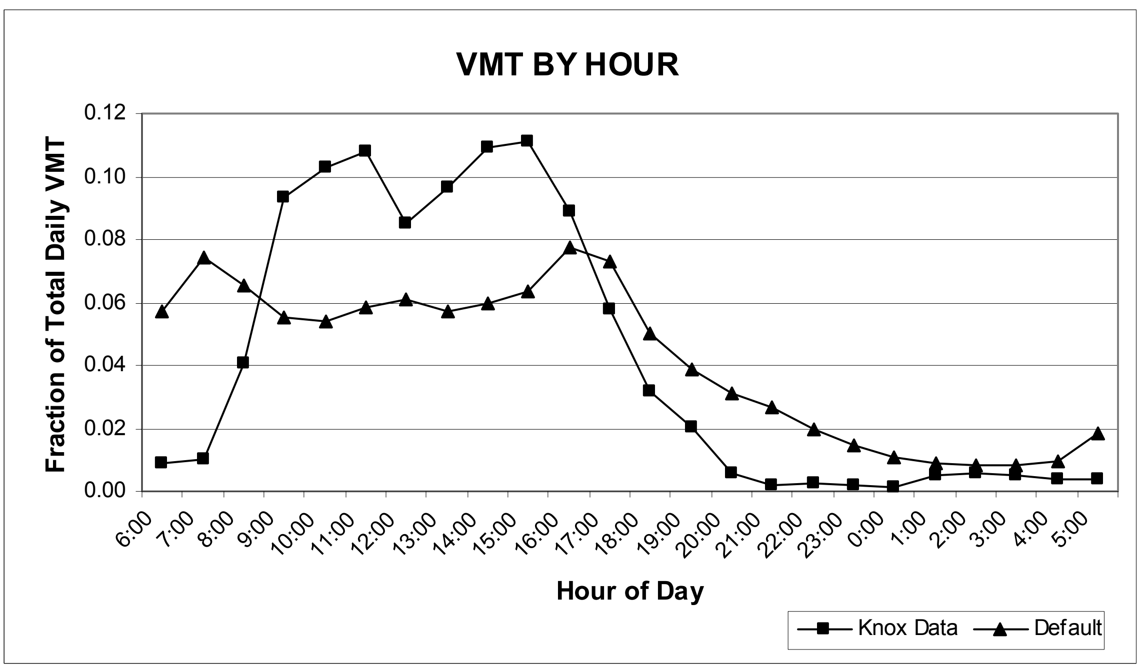

Figure 35. Knox Co. Data – VMT By Hour

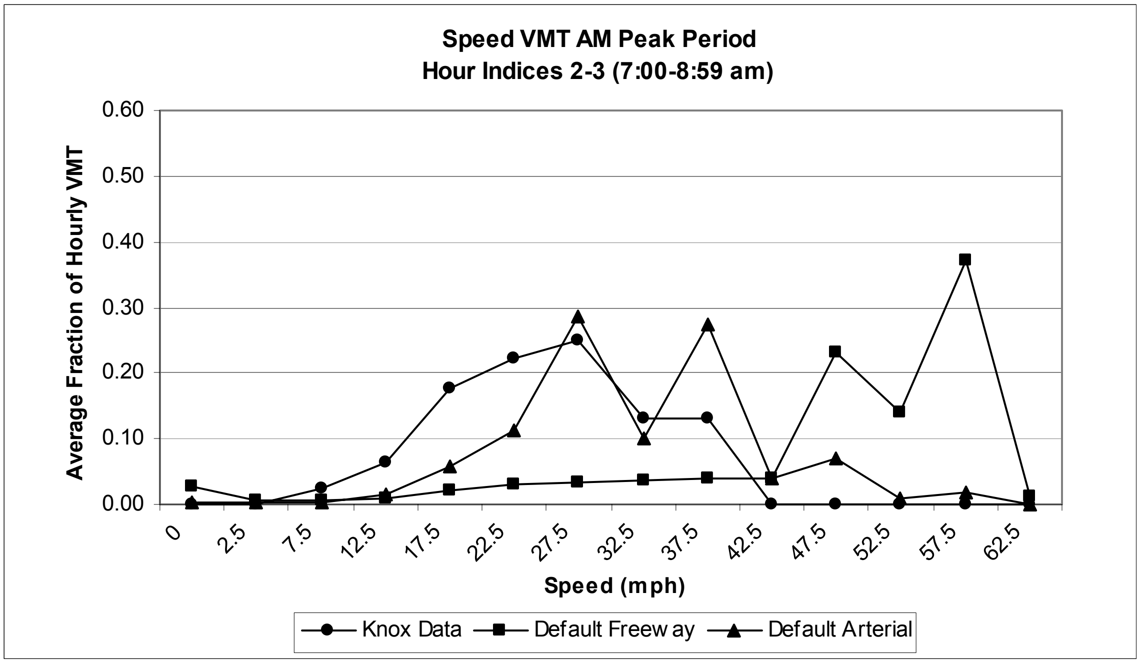

Figure 36. Knox Co. Data – Speed VMT AM Peak Period

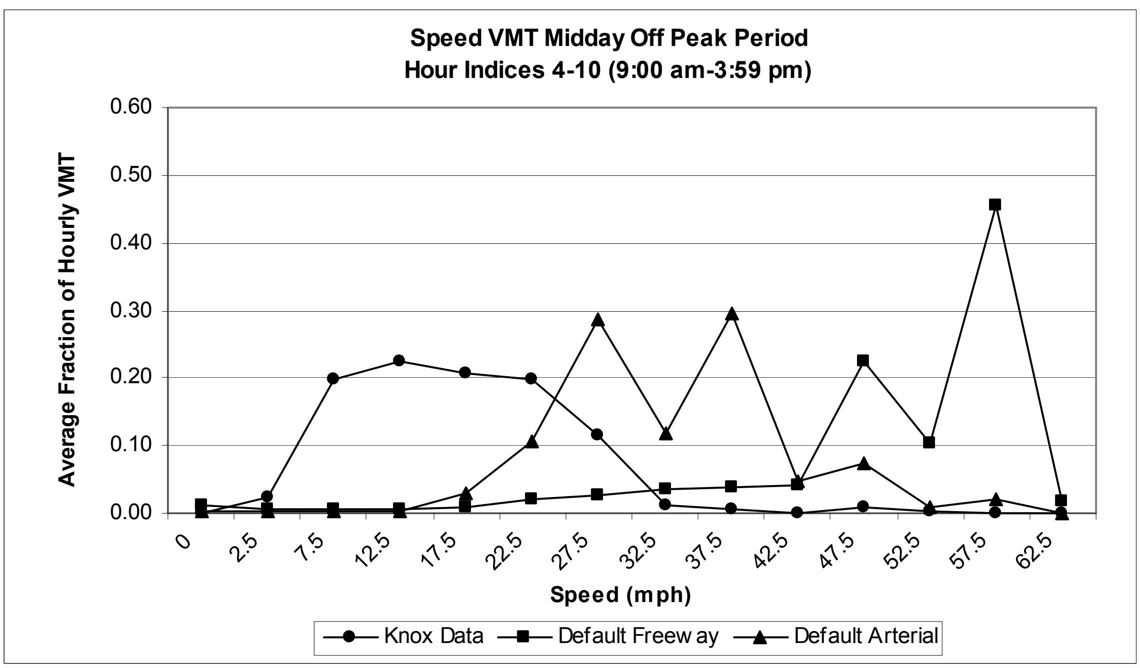

Figure 37. Knox Co. Data – Speed VMT Midday Off Peak Period

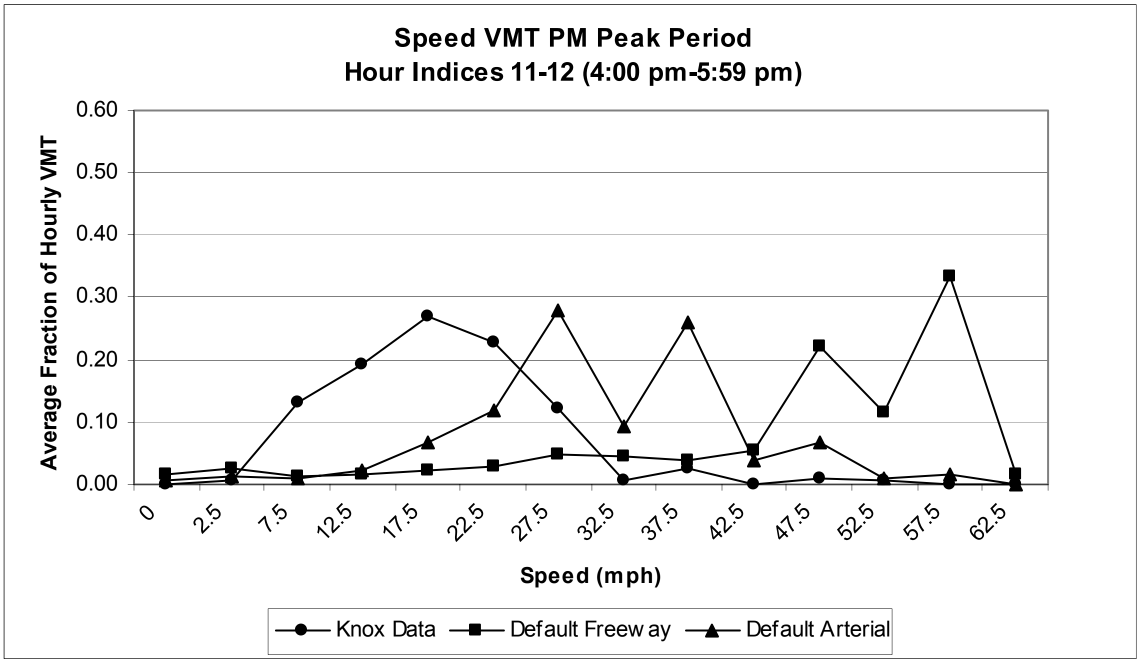

Figure 38. Knox Co. Data – Speed VMT PM Peak Period

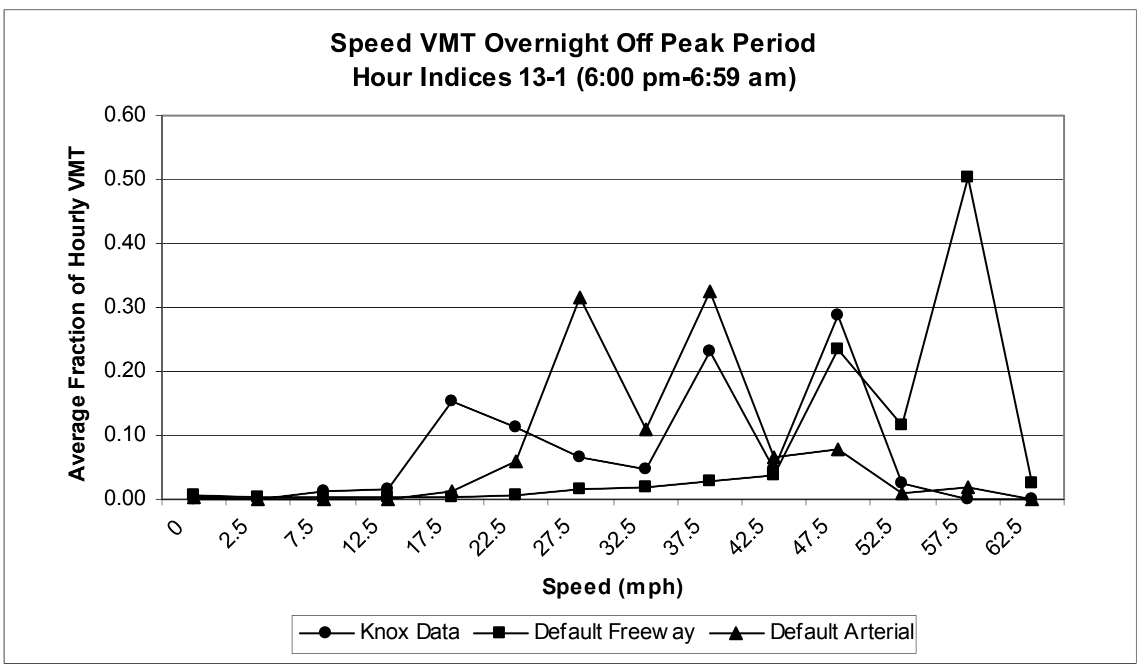

Figure 39. Knox Co. Data – Speed VMT Overnight Off Peak Period

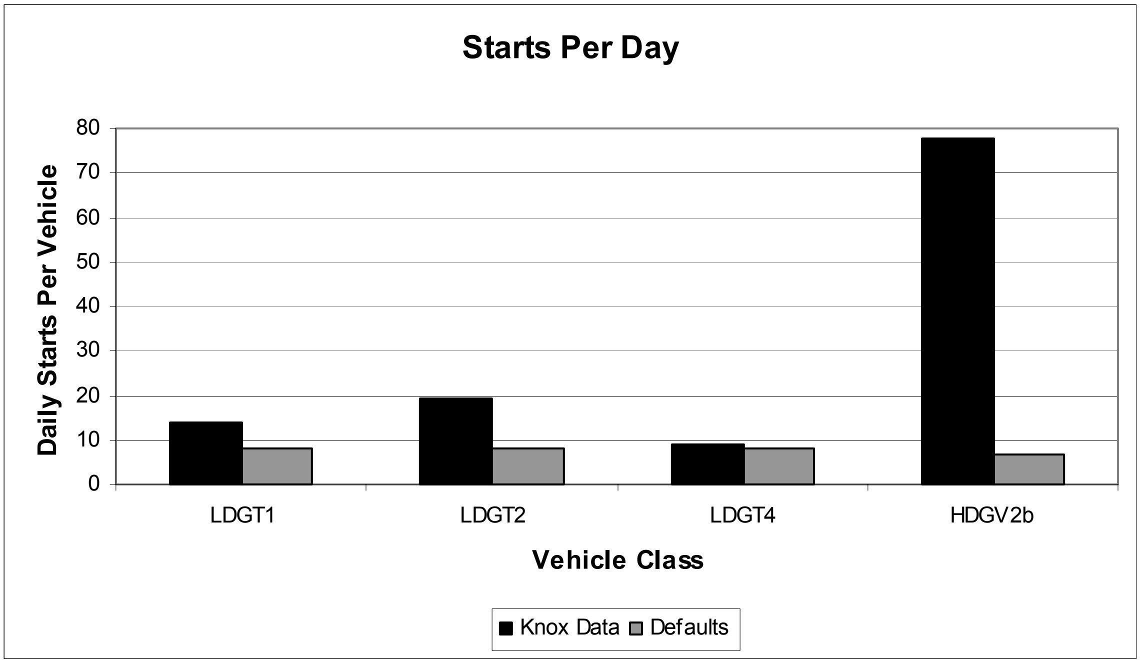

Figure 40. Knox Co. Data – Starts Per Day

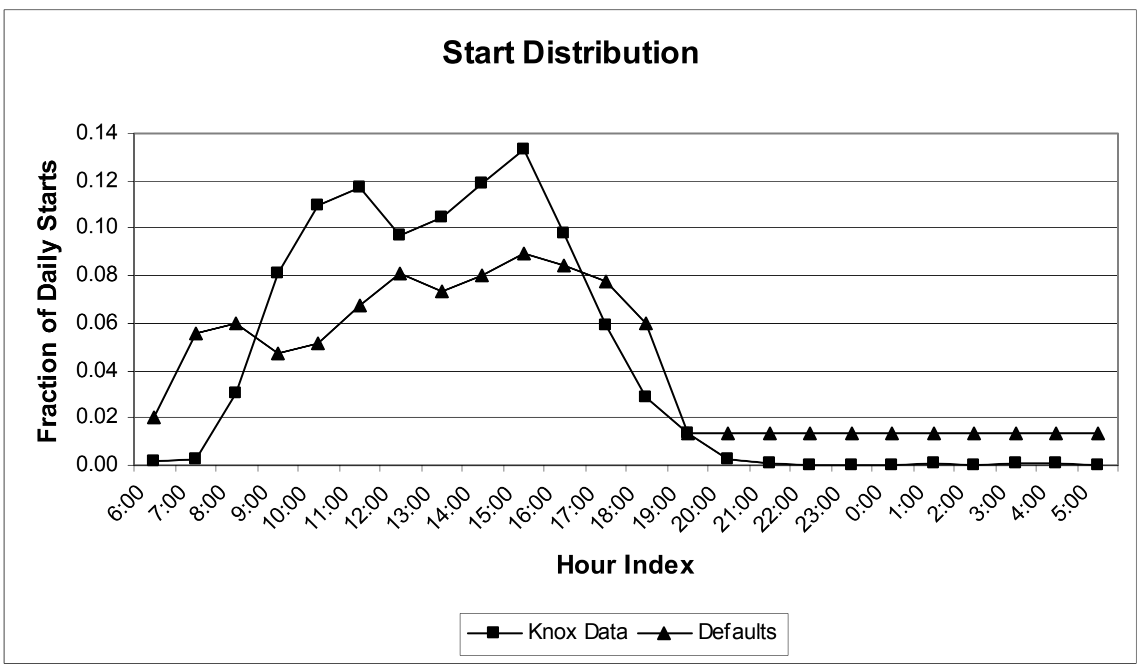

Figure 41. Knox Co. Data – Start Distribution

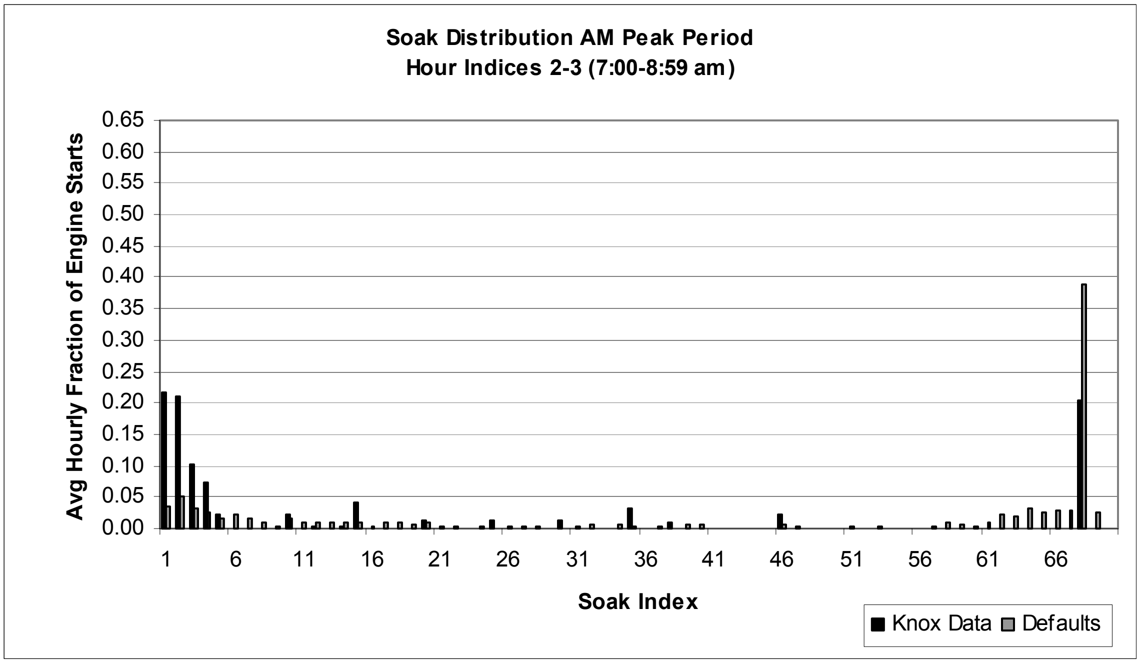

Figure 42. Knox Co. Data – Soak Distribution AM Peak Period

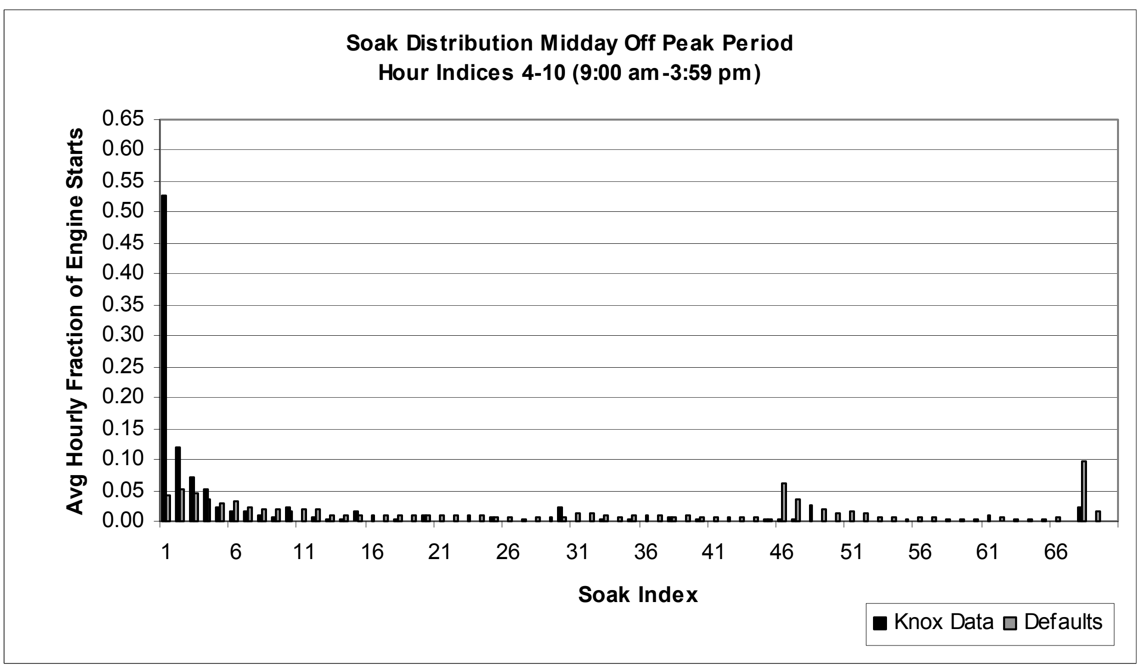

Figure 43. Knox Co. Data – Soak Distribution Midday Off Peak Period

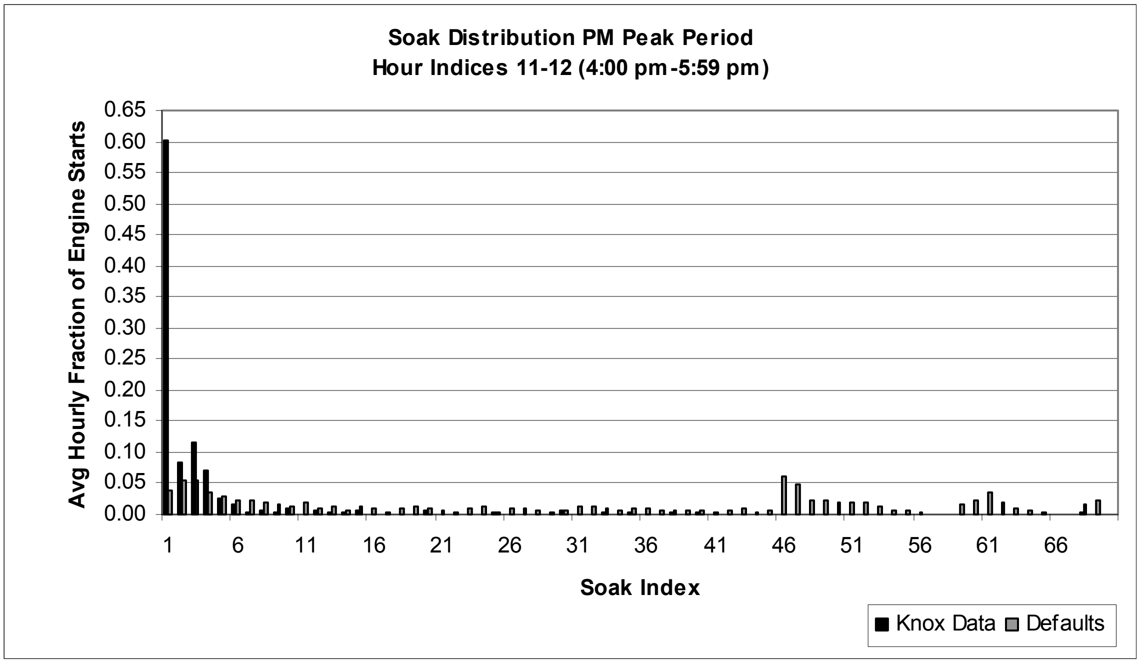

Figure 44. Knox Co. Data – Soak Distribution PM Peak Period

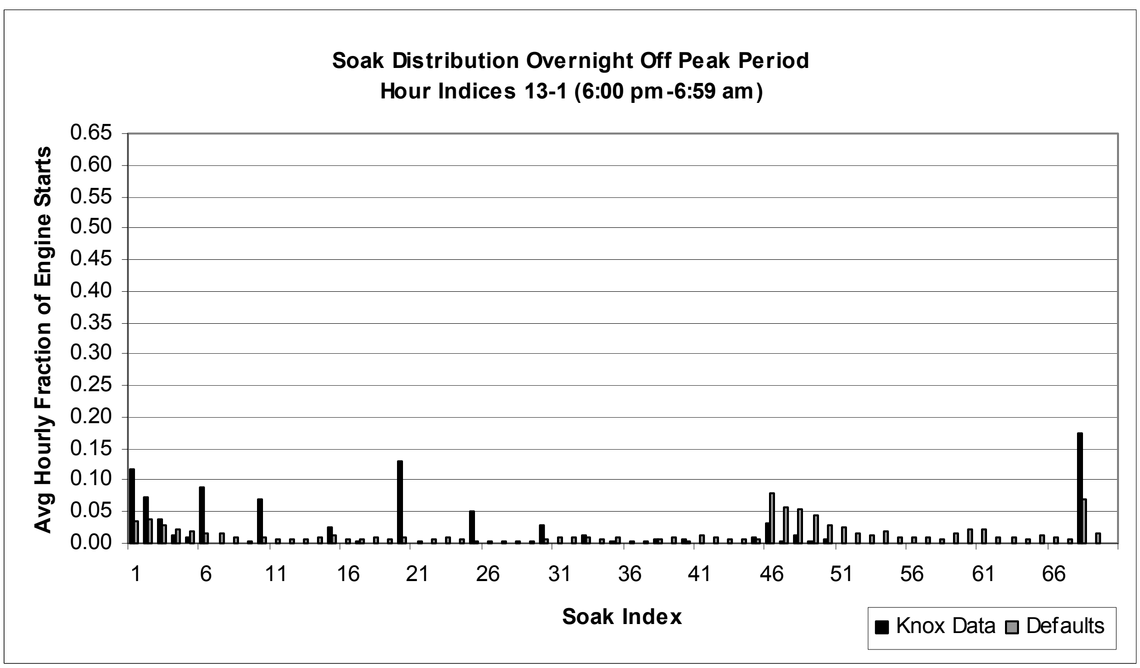

Figure 45. Knox Co. Data – Soak Distribution Overnight Off Peak Period

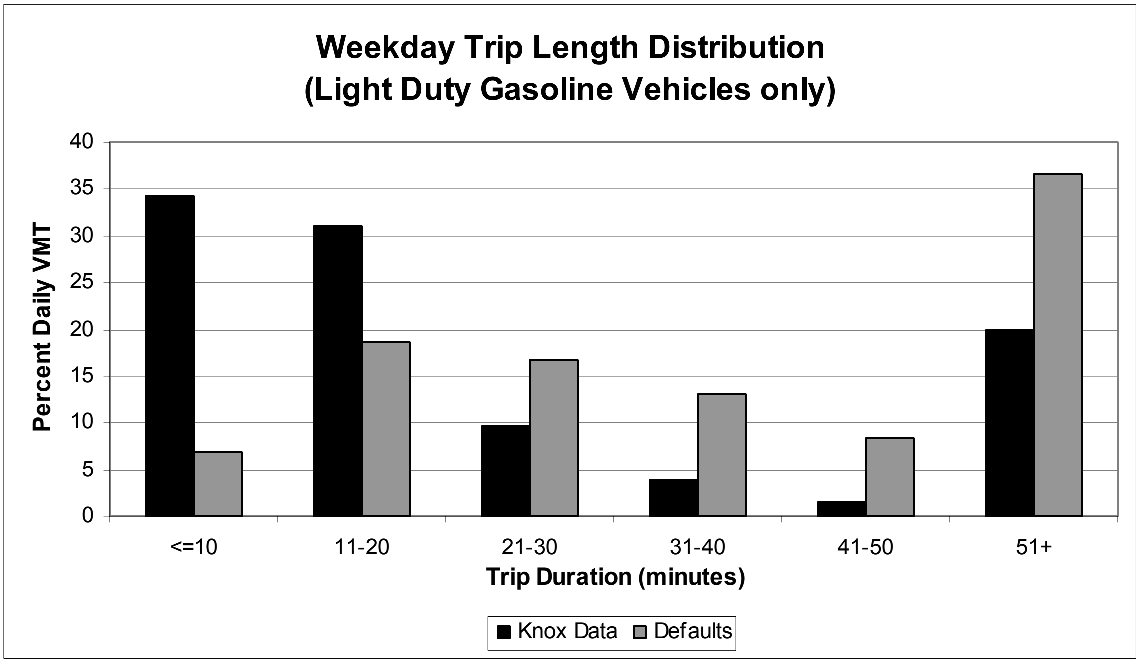

Figure 46. Knox Co. Data – Weekday Trip Length Distribution

VITA

Annie Protopapas was born on November 6, 1974 and raised in Limassol, Cyprus. She graduated from Foley's Grammar School in 1993. From there, she went on to attend the University of Tennessee, Knoxville where she received B.S. and M.S. degrees in Civil Engineering in 1997 and 1998 respectively. In 2000, she returned to the University to pursue a Ph.D. degree in Civil Engineering with a minor in Geography, which she received in 2004.