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Date July 24, 1991

An Analysis of Traffic Parameter Profiles used in a High Resolution Mobile Source Emissions Inventory

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jerry Don Everett

August, 1991

DEDICATION

This thesis is dedicated to the two I love the most Mary Odom and Jesus Christ. Mary has sacrificed much to allow me to spend the time and energy required to complete this project. Her patience and understanding over the past several months have helped me to love her more with each passing day. I owe all that I am and all that I have to Jesus. He provided me the knowledge, perseverance, and strength that I needed to complete this project. I take credit for any mistakes or errors in this document and offer him the glory if any good ever comes from it.

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ABSTRACT

The purpose of this analysis was to determine the impact of traffic parameter profiles on air pollutant emissions in a high resolution mobile source emissions inventory. The relationship between transportation and air pollution was explained in both qualitative and quantitative terms.

The air pollution modeling process was diagramed and explained. The implications for transportation of the Clean Air Act Amendments of 1990 were examined. U.S. EPA guidance concerning the development of traffic parameter profiles for mobile source emissions inventories was provided. Brief explanations of traffic parameter profile development methodologies currently being used were given.

The sensitivity of emission factors developed by MOBILE4 to traffic parameter inputs was analyzed. The emission factors for CO, HC, and NOx were found to vary by 80%, 80%, and 20% as speed was increased from 10 mph to 55 mph. NOx emission factors were found to be very sensitive to the HDDV VMT mix fraction.

A case study of the development and use of traffic parameter profiles for a mobile source emissions inventory for Tennessee was provided. Emissions produced by two inventory development approaches -- UTK and FTP -- were compared on a countywide and 5 km grid by 5 km grid basis for Rutherford county Tennessee. The emissions developed by the UTK

approach were 41% less for CO, 25% less for HC, and 34% higher for NOx on a countywide basis. Grid level emissions of CO for the UTK approach ranged from 12% to 66% less than the FTP approach. The UTK approach produced HC emissions that ranged from 1% to 39% less than the FTP approach when emissions in grids were compared. NOx emissions for the UTK approach ranged from 33% less to 155% more than the FTP approach in individual grids.

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CHAPTER 1

INTRODUCTION

Recent studies have indicated the dangers that air pollution poses for our natural resources, crops, and human health; air quality now is a major national issue. Air pollution may be defined as, "the presence in the outdoor atmosphere of one or more contaminants or combinations thereof in such a way as to be injurious to human, plant, or animal life or property; it interferes with the comfortable enjoyment of life or property or the conduct of business."(1) It results from many of the processes and activities that are essential to the functioning of modern society such as the generation of electricity, the production of steel, and the transporting of people and goods. Air pollution resulting from transportation activities, or mobile sources, will be evaluated in this document.

Transportation covers a wide range of activities such as boating, air travel, train operations, and automobile usage. However, for the purpose of this study only air pollution resulting from highway traffic (non-stationary sources of pollutants, such as autos, trucks, and buses) was studied.

Pollutants

Hydrocarbons (HC), carbon monoxide (CO), photochemical oxidants (O_3), nitrogen oxides (NOx), particulants, and lead are air pollutant species associated with transportation facilities. In the United States the Environmental Protection Agency (EPA) has had some success in its efforts to reduce air pollution. Recently, the removal of lead from gasoline has trimmed the number of mobile source related pollutants causing serious problems down to carbon monoxide and ground-level ozone.

Carbon monoxide is a colorless and odorless gas formed through the incomplete combustion (oxidation) of fossil fuels which contain carbon. While natural and industrial sources contribute to ambient CO concentrations, mobile sources (primarily gasoline-powered internal combustion engines) account for most of the carbon monoxide present in the atmosphere.(2) Excessive exposure to CO in humans can result in impairment of vision and judgement, cardiovascular changes, and, at high concentrations, even death.

Ground level tropospheric ozone, is not emitted directly into the atmosphere. It is formed through complex chemical reactions between emissions of volatile organic compounds (VOCs) such as hydrocarbons, and nitrogen oxides (NOx) in the presence of sunlight. Emitted VOCs and NOx are often labeled precursors because they act as the major building blocks for ozone production. This ozone should, however, not be confused

with stratospheric ozone which shields the planet from damaging ultraviolet rays.(3) Ozone is very reactive chemically and irritates both the respiratory system and the eyes. It can cause wheezing, coughing, and shortness of breath. Thus far, ozone exposure has not been demonstrated to have long-term debilitating consequences in humans.

Nitrogen oxides (NOx) are a family of poisonous, highly reactive gases. These gases form when fuel is burned at high temperatures as in motor vehicles. Nitrogen dioxide is one member of the family that is a suffocating, brownish gas. It is a strong oxidizing agent that reacts with water to form corrosive nitric acid, as well as, playing a major role in the atmospheric reactions that produce ozone.

Hydrocarbons are a family of gases made of different combinations of hydrogen and carbon. Hydrocarbons in and of themselves are considered relatively harmless in ambient concentrations. In fact, the national ambient HC standard is not really a standard at all but a guideline to be used in meeting the ozone standard. Automobile emissions of HC's arise from tailpipe emissions, refueling losses, running losses, and routine untrapped evaporation from the fuel system.(2)

Regulation

It is the duty of the EPA to set National Ambient Air Quality Standards in order to protect the public health and

welfare from know effects of the major air pollutants. These standards have been set and revised several times since air quality became a national issue.

Local and state agencies, in turn, are responsible for utilizing the tools the EPA provides (e.g., technical assistance, research, and funding) in order to develop regulatory strategies for controlling air pollution. Agencies must prepare plans, adopt and enforce regulations, issue permits, inspect facilities, and monitor the ambient air to ensure that steady progress is being made towards meeting the standards. If any of the National Ambient Air Quality Standards are not meet for an air quality control region (based on monitoring data) it is classified as a non-attainment area.

The problem facing Americans today is that in many cases these minimum standards are not being met. After almost two decades of effort, 68 areas of the country still failed to meet the ozone related ambient air quality standard by the December 31, 1987 deadline.(4) Similar non-attainment statistics were reported for the carbon monoxide standard. As expected the non-attainment areas include large cities such as Los Angeles, Houston, New York, Chicago, and San Diego. Smaller cities such as Memphis, Nashville, and Birmingham also have been found to be nonattainment areas. The fact that in 1987 about one third of the nation's population resided in areas which do not comply with the ozone standard provides an insight as to the magnitude of the problem.(4)

Unfortunately the problem seems to be worsening. Violations of the ozone standard in 1988 increased the number of areas that did not meet the standard to almost 100 and the number of citizens exposed to unhealthy air to more than 130 million. (5)

Transportation's Role In The Problem

For understanding how mobile sources affect air quality, one must examine the following subject areas:

1) The type of pollutants emitted;
2) The amount of pollution emitted by all different types of vehicles;
3) The number and mix of vehicles on highways;
4) The amount of travel by all different vehicle types;
5) How traffic characteristics affect air pollution emissions from vehicles.

Each of these areas is of interest because it affects the location and magnitude of air pollution resulting from mobile source emissions. Thus quantification of each provides information necessary to understand transportation's role in the air pollution problem. In 1977, transportation sources accounted for approximately 85% of carbon monoxide (CO) emissions, 46% of hydrocarbon (HC) emissions, and 43% of oxides of Nitrogen (NOx) emissions nationwide. In 1988, highway mobile sources

accounted for 75% of CO, 54% of HC, and 51% of NOx in the eight counties in central Tennessee.(6) Obviously, these amounts are not only significant but sometimes are the dominant emission source.

Progress has been made in controlling ozone and carbon monoxide under the Clean Air Act. According to an EPA report, "Progress in the Prevention and Control of Air Pollution", between 1979 and 1984 the estimated number of excediences of the ozone standard decreased by 36 percent despite an estimated national growth of almost 200 billion vehicles miles of travel (VMT) between 1980 and 1984. Carbon monoxide emissions from mobile sources decreased 14 percent between 1975 and 1984. The fact that the national fleet is nearly twice as big as it was two decades ago makes these reductions even more impressive. However, we can expect the trend of increasing VMT to continue into the next century. Zoe Schneider of the U.S. Public Interest Research Group in Washington D.C. says, "Vehicle miles traveled are expected to double between 1985 and 2010."(7) Unfortunately many of the gains made through reducing pollutant emissions per VMT have been lost because of the increased VMT.

Cleaner vehicles operating under tighter standards represent only one part of the comprehensive mobile source control strategies needed to achieve improved air quality. Other factors, such as altered driving habits and improved transportation systems, are also vital to such a strategy.(8) A

comprehensive plan for improving air quality should include not only strategies of forcing large industrial operations to install more efficient and expensive control equipment, but also strategies for altering the use of the private automobile, although such strategies would be unpopular. As the role of mobile source emissions in the overall air quality situation is better understood the interest in transportation related solutions will increase.

Clean Air Act Amendments of 1990

The most dramatic example of the increased interest in air quality is found in the Clean Air Act Amendments of 1990 (CAAA's). The long awaited amendments to the Clean Air act were signed into law by President Bush in November, 1990. These amendments have the potential to radically alter the administration of the federal-aid highway program in states with carbon monoxide and/or ozone nonattainment areas. The portions of the amendments expected to have the greatest impact on transportation include vehicle-miles of travel (VMT) forecasting; the transportation and air quality planning processes; the provision for highway funding related sanctions; and the conformity of transportation plans, programs, and projects.(9)

Section 181 of the act divides the ozone nonattainment areas into five classes/categories: marginal, moderate, serious,

severe, and extreme.(10) The classifications are made according to an area's design value. The design value is a measure of the highest daily maximum 1-hour average ozone concentration in an area and is the fourth highest of all of the daily peak 1-hour average ozone concentrations observed within the area over the most recent three year period.(11) Based on 1990 data 39 areas in the U.S. would be classified as marginal, 32 moderate, 16 serious, 8 severe, and 1 extreme.

Section 186 of the act provides for two categories of carbon monoxide nonattainment moderate and serious. The design value for carbon monoxide is the highest daily maximum 8-hour average CO concentration in an area and is the fourth highest of all the daily 8-hour average concentrations observed within an area over the most recent three year period. Each year the list of nonattainment areas is updated and made available in Subpart C of Part 91 of Title 40 of the Code of Federal Regulations.

General Provisions

Much of the responsibility for improving air quality in nonattainment areas has been shifted to transportation professionals by these amendments, so much so that it may be an appropriate time to redefine transportation engineering. The new definition of transportation engineering could be to provide an environmentally compatible transportation system that provides for the safe and efficient movement of people and

goods.

The primary method for shifting the responsibility is in the conformity requirements for transportation plans, programs, and projects. In the past the U.S. Department of Transportation (DOT) and local Metropolitan Planning Organizations (MPO's) made the conformity determinations based on conformity to the State Implementation Plan (SIP). Under the new amended Clean Air Act the emphasis is now on conformity to the "purpose" of the SIP, eliminating and reducing the severity and number of violations of the national air quality standards. Though the DOT and MPO's still make the conformity determinations they now must be based on strict criteria and procedures determined by the EPA.(9)

The number of sanction types available to the EPA to encourage the development of timely and well constructed SIPs under the amended Clean Air Act has been reduced. Highway funding restrictions could become the primary sanction.(12) These sanctions may be applied for four reasons which are: 1) failure to submit a SIP or a portion thereof; 2) EPA disapproval of a SIP; 3) failure to make "any" submission required by the Act, including VMT and congestion level data; and 4) failure to implement "any" SIP requirement.(13) The highway sanction can be imposed regardless of the relevance transportation measures play in attaining the standards for that area.

Nonattainment Classification Provisions

The severity of control provided for in many of the provisions in the amendments are based on the classifications as described previously. Therefore, nonattainment areas are not forced to implement the same type or stringencies of control measures as those in a higher classification.

State Implementation Plan revisions that demonstrate emission reductions of at least 15% in the first 6 years for volatile organic compounds (VOC) must be submitted within 3 years of enactment of the CAAAs of 1990, by States with moderate ozone nonattainment areas.(13) States with serious, severe, and extreme areas must submit SIP revisions within 4 years of enactment that demonstrate VOC reductions that average 3% per year each consecutive 3-year period after the initial 6-year period. This is in addition to the 15% reduction requirement.

States with areas classified as serious or higher for ozone nonattainment will be required to provide data demonstrating whether aggregate vehicle mileage, aggregate vehicle emissions, and congestion levels are consistent with those projected in the SIP. The first submittal date will be 6 years after enactment of the amendments and every 3 years thereafter.(9)

Transportation Control Measures (TCMs) must be a part of the plans of states with areas classified as severe in ozone nonattainment. These states must submit SIP revisions that

identify and adopt TCMs within 2 years of enactment. The TCMs are required to offset any growth in emissions from VMT growth or growth in vehicle trips. Employers of 100 or more will need to reduce work-related trips and VMT of their employees in accordance with guidance issued by EPA.(12)

The only area that has been classified as extreme in ozone nonattainment is Los Angeles. It may be required to reduce the number of heavy-duty vehicles operating during peak periods in addition to following the requirements for other areas.

There are also some transportation provisions related to CO nonattainment areas. The areas that have a CO design value of 12.7 ppm or more must update the SIPs to include VMT forecast for each year until attainment. The amendments also require that a contingency plan be implemented if the forecasts are too low or attainment is not reached on time. Areas classified as serious for CO nonattainment must also include provisions to identify and adopt TCMs to offset emissions growth resulting from increases in VMT or vehicle trips. Provisions are also included concerning areas that fail to meet their respective emissions reductions by December 31, 1995.

Conclusion

Transportation engineering will be affected by the Clean Air Act Amendments of 1990. One area that may see considerable change is data collection. During the coming years,

transportation planners will be called upon to provide inputs to air quality models. This thesis examines the mobile source air pollution modeling process and the availability of transportation data that are needed for these models. It also presents data on transportation inputs that were developed for an actual study in Tennessee. Finally, it demonstrates the difference in mobile source pollutant emissions due to using different inventory development approaches for Rutherford County, Tennessee.

CHAPTER 2

BACKGROUND

Chapter 1 provided an understanding of the air pollution problem and a description of the evolving role of transportation professionals in solving the problem. This chapter will provide a description of the solution process. States with ozone non-attainment areas are required by the EPA to develop SIPs. The three key elements of these plans are emissions inventories, simulation of the photochemical reactions of emissions and their transport, and the development of air quality management strategies.

The emissions inventories must be developed before the simulation effort can begin, but some preliminary strategies can be formed once the emissions inventories are completed. The details of those strategies are, however, dependent upon the simulation results. Both the inventory and the simulation stages can be performed in different ways. The complexity of the process is such that both are now highly dependent on computer modeling. The inventory development and simulation stages could be viewed as a unit entitled the "Air Pollution Modeling Process". Figure 1* shows this process from the initial input step to the final output of pollutant concentrations.

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*All figures and tables are in Appendices 1 and 2.

The development of air quality management strategies involves utilizing the information gathered in the other two sections of the SIP to formulate policies, plans, and programs that will bring the design values for the area below the national standard. These strategies are most successful when they are developed in a manner that addresses the particular air quality problems the non-attainment area is facing. The issues involved in this phase of the SIP are beyond the scope of this thesis.

Dispersion Modeling

As shown in Figure 1 the phase which actually produces the pollutant concentrations is called dispersion modeling. Due to the complexity of both the formation and transport of ozone the use of geographic grid based dispersion models is increasingly being accepted as the standard when ozone modeling is to be part of the SIP. The computer model which the EPA seems to prefer is the Urban Airshed Model (UAM). This is a very complex model which:

> ... numerically simulates the effects of the emission and transport of ozone precursors and ozone, advection, diffusion, chemistry, and surface removal processes on pollutant concentrations in a three-dimensional grid covering an urban area.(14)

The entire area to be modeled is divided into two to five kilometer grids. The UAM model is able to predict pollutant concentrations which are both spatially and temporally resolved.

To perform the predictions accurately the model requires an enormous amount of input data. As shown in Figure 1 these data can be grouped into four broad categories: meteorological, boundary conditions, terrain, and pollutant emissions. The types of meteorological data which must be provided include wind speed, wind direction, mixing heights of pollutants, temperatures, and others. Various boundary conditions must be specified including the concentration of each species of pollutant along each boundary and the height of each column of cells at the beginning and end of each hour of simulation. Information concerning the surface roughness and a deposition factor must be included to describe the terrain. Most of this information must be provided on a grid by grid basis. Values must also be provided for each hour of the simulation if the data varies with time. Finally the ground level emissions of ozone precursors must be included for each grid cell for each hour of the simulation.

Emission Inventories

Emissions can be categorized according to their source. Three groups are usually considered: point sources, area sources, and mobile sources. Developing emission inventories of air pollutants involves gathering the best available information concerning the quantities of each species of pollutant that is emitted by each of the three categories of sources. The degree of

spatial and temporal resolution required varies according to the purpose of the inventory.

Point sources include large industrial, manufacturing, and commercial facilities. If a single source emits 10 or more tons of pollutants per year it would be placed in this group. Area sources typically include all stationary sources with less than 10 tons/year and all non-highway mobile sources. Examples of area sources would be dry cleaners, gasoline stations, and farm equipment. The third category of emission inventories is highway mobile source emissions (those resulting from highway traffic).

Mobile Source Emission Inventories

A variety of methods have been used in the past to develop emission inventories for highway emissions. One technique is to use county wide gasoline sales to yield the gross estimate of emissions for each respective county. This type of inventory would be appropriate in instances when only rough and aggregate vehicle emission estimates are required. This methodology does not provide an inventory that is spatially or temporally resolved to the degree necessary for photochemical dispersion modeling.(15) Thus alternative methods must be considered when the inventory is part of a dispersion modeling exercise.

The alternative methods include the "hybrid" and the "link-based" approaches. For the hybrid approach separate estimates of travel, trip end, and vehicle related emissions are derived and assigned to the grids they occur in. The sum of the three components would constitute the highway emission inventory. In theory this approach can provide very accurate results; however, it is too data intensive to be practical for most analyses.(15) Currently, the most commonly used used approach is the linked-based approach. This method requires two categories of information to calculate highway mobile source emissions -- emission factors and the VMT for each link, i.e. road segment. In this approach the emission factor is an aggregate of the three components of the hybrid approach. It is multiplied by the vehicle miles of travel to obtain total highway emissions. The relationship between these categories and the inventory of emissions from mobile sources is shown in Figure 1.

Vehicle Miles Traveled

Vehicle miles traveled is the traffic volume of vehicles traversing a link in a given time multiplied by the length of the link measured in miles. The EPA recommends two methods for deriving VMT estimates used in urban mobile source emission inventories. The first is the use of an Urban Transportation Planning System (UTPS) computer model. Several variations of

this type of model now exist. The models are can estimate both the VMT and speeds on the links included in the network.

The UTPS modeling process is fairly complex and involves a series of models/steps. The network of highways must be coded for computerized analysis. Each link on the network must also be described by its capacity, volume, free flow speed, etc. The entire area must be subdivided into zones and each zone must be described by its housing and employment characteristics. Unfortunately, there are some serious drawbacks to using these models to estimate grid VMTs or link speeds.

1) Networks used in these models usually include only the higher classes of facilities, i.e. arterials and major collectors. This could result in a significant under estimation of VMT on local roads. In a recent study emissions on locals and collectors were estimated to account for as much as 56% of the mobile source emissions in a county due to the slow speeds typical of these facilities.(16)

2) The UTPS models are usually utilized in urban areas with a population of 50,000 or more. Since the inclusion of Standard Metropolitan Statistical Areas(SMSAs) is now a requirement for SIP development, networks would have to be expanded to include the additional areas.

3) The speeds developed by the models may not be useful. The speed values produced by the models represent the result of the most successful allocation of travel, not a prediction of the speed resulting from a level of service on the links. (17)

4) The networks developed for UTPS do not recognize the grids established for dispersion models. Thus a separate effort is needed to group the model generated VMTs by grid.

A different approach which is equally acceptable to the EPA would be to develop a grided inventory. This method would divide the entire area (including the SMSAs) into two to five kilometer square grids. All classes of facilities would be included in the grid cells. Rather than using a UTPS model to estimate VMT, traffic counts are used to derive daily VMT for each link within a grid. This method overcomes the drawbacks of the UTPS based approach, but it is much more data intensive.

Emission Factors

An essential piece of information needed to develop the mobile source inventory is the composite emissions factor. An emissions factor is the amount of a pollutant emitted per unit distance traveled by a vehicle. A composite emissions factor is one that is weighted to reflect the differences in emissions according to vehicle types as well as the proportion of total VMT attributable to each type of vehicle. Separate composite emission factors are calculated for HC, NOx, and CO.

Emissions factors can be developed by hand calculations or by computer model. Usually computer models are used in preparing emission factors. The EPA developed its first mobile

source emissions model in the mid-nineteen seventies. The latest version, MOBILE4, was released in 1989.

> Mobile 4 is a computer program that calculates emission factors for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) from gasoline fueled and diesel highway motor vehicles. The program uses the calculation procedures and emission factors presented in Compilation of Air Pollutant Emission Factors: Highway Mobile Sources AP-42 Fourth Edition, September 1989.(18)

Though the model has been updated with each release the basic structure has remained the same. It is an integrated set of FORTRAN routines which derive emission factors from adjustments to a baseline emission factor. Since all vehicles are required to comply with Federal emissions standards the baseline factor reflects the conditions of the Federal Test Procedure(6).

The set methods used to test the different classifications of vehicles is called the Federal Test Procedure(FTP). The Federal government has categorized vehicles into eight different classes: light duty gasoline vehicles(LDGV), light duty gasoline trucks1(LDGT1), light duty gasoline trucks2(LDGT2), heavy duty gasoline vehicles(HDGV), light duty diesel vehicles(LDDV), light duty diesel trucks(LDDT), heavy duty diesel vehicles(HDDV), and motorcycles(MC). But there are only three different test procedure categories -- light duty vehicles, heavy duty vehicles, and motorcycles.

The test procedures and conditions for the light duty vehicles and motorcycles are basically the same. A full description of procedures can be found in the Code of Federal Regulations (40 CFR Part 86, Subpart B, July 1987)(C). The test conditions have been summarized in "An Investigation of Vehicle Operating Mode Profiles for Use in Preparing a High Resolution Emission Inventory" by Cynthia McIlvaine.(6) McIlvaine states the following concerning the test conditions for light duty vehicles :

1. The ambient temperature range is 68 to 86 degrees F.
2. Absolute humidity is adjusted to 75 grains of water per pound of dry air.
3. The average speed is 19.6 mph with 18% idle operation.
4. The average percent of the VMT in cold-start mode is 20.6 %.
5. The average percent of the VMT in the hot-start mode is 27.3 %.
6. The average percent of the VMT in the stabilized mode is 52.1 %
7. The average trip length is 7.5 miles.
8. The car contains a driver and one passenger only. The air conditioning is not in use. The car has no additional luggage and is not towing a trailer.

These test procedures and conditions were developed based on an average trip in Los Angeles, California.

The test procedures for heavy duty vehicles are somewhat different. A discussion of the conversion between results obtained for heavy duty vehicle tests to light duty vehicle tests

can be found in "Heavy duty Vehicle Emission Conversion Factors, 1962-1997"(19)

MOBILE4 uses the FTP conditions as the default conditions for emission factor calculation. The model makes adjustments to the emission factors based on any differences between assumed and actual modeling conditions. These adjustments are initiated by the MOBILE4 user through the use of correction factor options.

As shown in Figure 1 the required inputs for Mobile 4 can be divided into 5 groups: climate factors, yearly factors, vehicle factors, fuel volatility, and traffic characteristics. Specific information is required for the following input parameters:

1. average travel speed,
2. VMT for vehicle types,
3. trailer towing,
4. extra loading,
5. registration and mileage accumulation-accrual distributions for each vehicle type,
6. percent of VMT accumulated in the cold-start mode by non-catalyst equipped vehicles,
7. percent of VMT accumulated in the hot-start mode by catalyst equipped vehicles,
8. percent of VMT accumulated in the cold-start mode by catalyst equipped vehicles,
9. calendar year,
10. region (low altitude or high altitude),

11. ambient temperature,
12. Reid Vapor Pressure of the fuel,
13. use of air conditioning,
14. use of stage II vapor recovery systems,
15. stringency of inspection/maintenance program, and
16. implementation of an anti-tampering program.

Traffic Characteristics

There are several important MOBILE4 inputs that are linked directly to highway traffic: average vehicle speeds, VMT mix, operating mode mix, trailer towing fraction, and extra load fraction. Some have the potential of significantly affecting the value of composite emission factors which the model develops. The magnitude of the impact which each of these traffic parameters has on composite emission factors varies. Some have very little effect while others can cause a several fold difference in and of themselves. The magnitude of the effect of some traffic parameters is partially dependent on other MOBILE4 inputs such as temperature.

CHAPTER 3

SENSITIVITY ANALYSIS

The input parameters required for MOBILE4 do not all have the same impact on the emission factors the model develops. A good understanding of the relative importance that each parameter has on the magnitude of the emission factors is valuable to those using the model. The model offers two options for many of the required inputs -- 1) the use of default national average values or 2) locally developed values. Most MOBILE4 users will have limited resources available for developing local databases for all model inputs. Therefore, it must be decided which parameters deserve the limited resources and which may be handled with default values. Several factors should be considered when making these decisions:

1) What local information is readily available,
2) What is the magnitude of resources available for data collection.
3) Which parameters have the greatest impact on the emission factors.

Vehicle speed, operating mode mix, VMT mix, percent towing trailers, and percent with extra load are the MOBILE4 input parameters which are categorized as traffic characteristics. This chapter addresses the relative importance of these parameters on the emission factors calculated by MOBILE4.

Temperature is also known to have a significant effect on emissions, therefore the analysis was performed using two different ambient temperatures to identify any interaction between temperature and traffic characteristics.

Parameters Analyzed

Speed

MOBILE4 requires that an average speed be input for each type of vehicle. The user has the option of choosing a single speed for all eight vehicle classes or varying the speed by class of vehicles. The type of speed data needed for MOBILE4 is referred to as average travel speed. Average travel speed is the length of a highway segment divided by the average travel times of vehicles traversing the segment. The travel times used for measuring this type of speed should include stopped delay(20). MOBILE4 allows for speed variations from 2.5 to 55 mph in increments of 0.1 mph. Though rural interstates now have 65 mph speed limits, the EPA does not have enough data at speeds above 55 mph to update the model for these higher speeds. Previous studies have shown that HC and CO emissions are generally higher than FTP levels at speeds below 19.6 mph, and generally lower than FTP levels at speeds above 19.6 mph. NOx emissions are generally higher than FTP rates at speeds under

19.6 mph and slightly lower than FTP rates at speeds greater than 19.6 mph. (18)

Operating Mode Fractions

The portion of the VMT accumulated in the different operating modes is generally considered an important determinant of vehicle emissions. MOBILE4 considers 6 different vehicle type/operating mode conditions based on the 3 modes and the 2 vehicle types, catalyst and non-catalyst. However, only three inputs are required non-catalyst cold-start(PCCN), catalyst hot-start(PCHC), and catalyst cold-start(PCCC). The other values are calculated by the model based on these inputs. The values used for this parameter in the FTP are 20.6%, 27.3%, and 20.6% for PCCN, PCHC, and PCCC respectively.

The percent of the VMT traveled in each operating mode contributes significantly to the quantity of emissions produced. The three operating modes are defined based on the length of time the engine has been in operation and the amount of time since it was previously operated. Emissions are usually the lowest if the vehicle has been in operation long enough to have reached stable operating temperatures. When the vehicle is not "warmed up" but has not been out of operation long enough to completely cool down the emissions are usually higher than when it is stabilized. The emissions are generally the highest

when the vehicle is in its first few minutes of operation from a cold start.

A study was recently performed which focused on vehicle operating mode fractions. A portion of that work dealt with the sensitivity of MOBILE4 emission factors to the vehicle operating mode mix. To avoid performing duplicative work, MOBILE4's sensitivity to operating mode fractions was not evaluated in this study. Therefore, the FTP operating mode fractions were used in all portions of this analysis. Should further information on vehicle operating mode fractions be desired refer to reference(6).

VMT Mix Fractions

The vehicle miles traveled mix in MOBILE4 specifies the fraction of total VMT that is accumulated by each vehicle classification. This information is used only in determining the composite emission factors. It is not part of the determination of vehicle class specific emission factors.(18)

MOBILE4 develops an emission factor for each of the eight following categories of vehicles: light duty gasoline vehicles (LDGV), light duty gasoline trucks1 (LDGT1), light duty gasoline trucks2 (LDGT2), heavy duty gasoline vehicles (HDGV), light duty diesel vehicles (LDDV), light duty diesel trucks (LDDT), heavy duty diesel vehicles (HDDV), and motorcycles (MC). These individual emission factors are then multiplied by the percent of the total vehicle miles traveled for the particular vehicle type.

The results are then summed to obtain the composite emission factor. This same procedure is used for each pollutant type.

The default VMT Mix is based on the calendar year for which the model is run. For purposes of this analysis the 1988 calendar year was selected. The default VMT Mix for 1988 is 70.8%, 12.8%, 8.6%, 1.5%, 1.3%, 0.4%, 3.6%, and 1.0% for light duty gasoline vehicles, light duty gasoline trucks1, light duty gasoline trucks2, heavy duty gasoline vehicles, light duty diesel vehicles, light duty diesel trucks, heavy duty diesel vehicles, and motorcycles respectively.(18)

The eight vehicle classes can be grouped into gasoline and diesel categories. Gasoline vehicles usually have higher CO emissions than diesel vehicles. However, diesel vehicles usually have much higher NOx emissions. The difference is substantial for HC emissions. At low speeds gasoline engines produce slightly higher HC than diesel vehicles and at high speeds the reverse is true.

Light duty gasoline vehicles contribute over 70% of the total annual VMT for the U.S. Thus the composite emission factors are heavily dependent on the emissions of this class of vehicles. The emission characteristics and VMT accumulated must both be considered to determine the effect of other vehicle classes on the composite emission factors. The emissions of the two light duty gasoline truck classes are very comparable to other light duty gasoline vehicles. The two light duty gasoline truck classes combined consistently contribute over 20% of the

annual VMT in the U.S. The emissions of motorcycles are usually somewhat different than other gasoline vehicles. For example exhaust emissions of HC are usually higher and exhaust emissions for CO and NOx are usually lower than for other gasoline vehicles. However, only about 1% of the annual VMT is contributed by motorcycles.

The difference in emission characteristics between light duty gasoline vehicles and heavy duty gasoline vehicles can be substantial. Heavy duty gasoline vehicles can easily produce twice as much exhaust HC and three or more times the amount of exhaust CO and NOx emitted by light duty gasoline vehicles. However, heavy duty gasoline VMT is usually very low. The emissions for light duty diesel vehicles are also typically different from LDGVs. But, their annual VMT is usually less than 2% of the annual total.

The only class of vehicles other than LDGVs that has the potential to significantly alter the character of the composite emission factors is HDDV. Heavy duty diesel vehicles have substantially different emission characteristics from LDGVs and their annual average VMT varies between 3 and 4 percent when all classes of highways are considered. However, on some roadways during certain hours of the day the percent of VMT for HDDV can be 50% or more. This vehicle class was, therefore, deemed worthy of more detailed analysis.

Additional Correction Factors

MOBILE4 offers three additional correction factors for light duty gasoline fueled vehicles: air conditioner (AC), extra load, and trailer towing fractions. The user has the option of adjusting the default value of 0% usage for any of these factors. The input value for each factor must be between 0 and 100 percent. The model adjusts the exhaust emission factors based on these corrections for each of the three classes of light duty gasoline vehicles -- LDGV, LDGT1, and LDGT2.

Emission corrections due to carrying an additional 500 lb. load are accounted for by using the extra load factor. The trailer factor is used to model the impact of vehicles towing trailers. The air conditioner factor simply adjusts the emissions to account for the differences due to the utilization a vehicle's air conditioner. Due to the complexity of using the AC factor only the effects of using the extra load and towing factors were considered in this study.

Procedure

The analysis was performed using the Release 1 of EPA's latest mobile source emissions model, MOBILE4. The results of this analysis were to be compared to previous work performed for a case study in Tennessee. Therefore, similar settings for

MOBILE4's input parameters were used. Exhaust emission factors were developed for three pollutants -- HC, CO, and NOx.

In developing the emission factors the default values for the registration and mileage accrual rates and for tampering rates were used. No inspection and maintenance program or anti-tampering program were considered. The Reid vapor pressure was set at 11.5 pounds per square inch (psi). A low altitude region with an American Society for Testing and Materials (ASTM) volatility class C rating was considered. The MOBILE4 runs were made for the 1988 calendar year. The FTP operating mode fractions with 20.6% of the VMT assumed to be in cold-start mode, 27.3% in hot-start mode, and 52.1% in stabilized mode were used. To model this situation with MOBILE4 the operating mode mix is set at 20.6 for PCCN, 27.3 for PCHC, and 20.6 for PCCC. The minimum temperature was set at 69.0 degrees, the maximum at 93.0 degrees, and runs were made using both 69.0 and 93.0 as the ambient temperature for a "worst case" summer day. Finally, the speed was varied from 10 to 55 mph in 1 mph increments.

Findings

One portion of the analysis focused on the relationship between the magnitude of the composite emission factors for each pollutant type and average travel speed. The findings on this subject are presented in this section. Figures 2 and 3 show

composite emission factors for three pollutant types for 1988 with the default VMT mix at ambient temperatures of 69 and 93 degrees respectively. It is obvious that CO emissions are much greater than either of the other two pollutants regardless of the temperature. At both 69 and 93 degrees CO emissions decrease at a decreasing rate as speed is increased from 10 to 55 mph. This is further evidenced by considering that increasing speed in 5 mph increments provides a decrease in emissions of 32%, 23%, 20%, and 17% between 10-15, 15-20, 20-25, and 25-30 mph respectively for an ambient temperature of 69 degrees. The total decrease in emissions as speed increased from 10 to 55 mph is 48.5 grams/mile or 80%. Similar results occurred when the ambient temperature was 93 degrees.

The effect of temperature on CO emissions can be seen in Figure 4. At 10 mph the rate of CO emissions increases from 61 to 82 grams/mile and at 55 mph from 12 to 17 grams/mile when the ambient temperature is increased from 69 to 93 degrees. The effect of the temperature increase is a 34% rise in CO emissions at both 10 and 55 mph.

Figures 5 and 6 provide a better presentation of the variation in the magnitude of HC and NOx emissions. HC emissions are higher than NOx emissions at low speeds and lower at high speeds for both ambient temperatures. The speed at which the curves cross is 19 and 24 mph for temperatures of 69 and 93 degrees F respectively.

Figure 7 shows that hydrocarbon emissions decrease at a decreasing rate as the speed increases from 10 to 55 mph for both ambient temperatures. The rate of decrease in HC emissions is almost exactly the same as for CO emissions between 10 and 30 mph. Increasing speed by 5 mph steps between those speeds provides decreases in HC emissions of 32%, 23%, 19%, and 17% in those increments at 69 degrees. A total decrease of 80% or 3.84 grams/mile occurred between 10 and 55 mph for HC emissions at 69 degrees. The emissions at 93 degrees decreased at approximately the same rate. The change due to variation in the ambient temperature is a almost uniform 11% increase with temperature or an absolute increase of .55 and .11 grams/mile at 10 and 55 mph respectively.

As was the case with HC and CO emissions, temperature variation only changes the values of the NOx emissions factors not the shape of the curve as seen in Figure 8. For both ambient temperatures NOx emissions decrease by 16% between 10 and 30 mph, remain constant between 30 and 35 mph, then increase by 20% between 35 and 55 mph. An increase in ambient temperature from 69 to 93 degrees for NOx emissions brings a slight decrease in emissions. The emission factors decrease .29 grams/mile at 10 mph and .37 grams/mile at 55 mph to provide 10% and 12% changes respectively.

HDDV Emissions

Several observations about HDDV emissions can be made from considering Figures 9 and 10. The first is that HDDV emissions do not change with a change in ambient temperature between 69 and 93 degrees. This indicates that none of the differences due to temperature shown previously were attributable to HDDVs. NOx emissions are higher than CO emissions, and CO emissions are higher than HC emissions at every speed from 10 to 55 mph.

The shape of the curves for the individual pollutants are very similar to the composite emission factor curves viewed previously. Both CO and HC emissions decrease at a decreasing rate as speed is increased. CO emissions decrease by 10.6 grams/mile from 10 to 20 mph and 4.4 grams/mile from 20 to 30 mph for 46% and 35% decreases respectively. Between 10 and 55 mph the total decrease in CO emissions is 73% or 16.91 grams/mile.

HC emissions decrease at a lower rate at low speeds than CO emissions. Between 10 and 20 mph HC emissions go down by 1.33 grams/mile or 32%. The decrease between 20 and 30 mph though only .83 grams/mile is still a 30% decrease in HC emissions. The overall reduction in HC emissions as the speed is increased form 10 to 55 mph is 2.92 grams/mile or about 70%.

NOx emissions decrease by 8.3 grams/mile from 10 to 30 mph, remain stable from 30 to 35 mph, and increase by 6.4

grams/mile from 35 to 55 mph. The change in HDDV NOx emissions between 10 and 30 mph is 32%. As speed is increased from 35 to 55 mph the change in emissions amounts to 37%.

LDGV

Emissions for LDGV at both ambient temperatures are shown in Figures 11, 12, and 13 compared to HDDV emissions. As seen in Figure 11, emissions for LDGV of CO at both temperatures decrease at a decreasing rate as speed increases. Interestingly, LDGV emissions decreased 66% from 10 to 30 mph and 43% between 30 and 55 mph for both temperatures. The absolute changes were decreases of 37.7 and 51.7 grams/mile from 10 to 30 mph for 69 and 93 degrees respectively. Between 30 and 55 mph emissions decreased by 8.6 grams/mile at 69 degrees and 11.6 grams/mile at 93 degrees. As an example of the strong relationship between LDGV and the composite emission factors consider that LDGV CO emissions dropped 80% as speed was increased from 10 to 55 mph. This is exactly the same percent reduction that occurred in the composite CO emission rate for that same interval. The 80% reduction amounted to 46.3 grams/mile at 69 degrees and 63.3 gram/mile at 93 degrees.

HC emissions for LDGV have basically the same shape of curve between 10 and 55 mph as CO emissions as displayed in Figure 12. The decrease in emissions at both temperatures is

65% from 10 to 30 mph and 42% from 30 to 55 mph. These decreases are 2.88 and 0.66 grams/mile at 69 degrees and 3.24 and 0.72 grams/mile at 93 degrees. The decrease in HC emissions from the minimum speed to the maximum speed was 80% at both ambient temperatures. The absolute differences were 3.54 and 3.99 grams/mile for 69 and 93 degrees respectively.

Figure 13 shows graphically that the NOx emissions for LDGV vary only slightly throughout the range of speeds. They decrease about 8% from 10 to 30 mph, remain the same between 30 and 35 mph, and increase about 14% from 35 to 55 mph. The 8% decreases translates into changes of 0.15 and 0.17 grams/mile for 69 and 93 degrees respectively. An increase of 0.28 grams/mile for 69 degrees and 0.21 grams/mile at 93 degrees accounts for the 14% changes.

LDGV -vs- HDDV Emissions

Figures 14, 15, and 16 demonstrate the differences in emissions between LDGV and HDDV. Figure 14 shows that LDGV CO emissions are from 2.0 to 2.5 times higher than HDDV CO emissions at all speeds between 10 and 55 mph at 69 degrees and from 3.0 to 3.3 times higher at 93 degrees. Figure 15 indicates that at higher speeds HC emissions are greater for HDDV. HC emissions for LDGV become higher than for HDDV at a speed between 12 and 17 mph depending on the ambient

temperature. Since the HC emissions for LDGV increase at higher temperatures the transition takes place at 16 mph for the 93 degree curve. Speeds must decrease to almost 12 mph before LDGV HC emissions are higher than HDDV HC emissions on the 69 degree curve. HDDV NOx emissions dwarf LDGV NOx emissions at each point in the range of speeds as seen in Figure 16. Perhaps the most significant finding concerning the relationship between NOx emissions for LDGV and emissions for HDDV is that emissions for LDGV are only about 1/10 of the emissions for HDDV.

Another way to compare LDGV and HDDV emissions is to look at the percent difference between the two as a function of speed and temperature. Figures 17, 18, and 19 provide a visual representation of these differences for CO, HC, and NOx respectively. The comparisons were made by subtracting the emissions factors for HDDV at each speed from the emissions factors for LDGV and then calculating the percent difference between the two.

The differences in CO emissions are at their highest -- 60% and 71% -- at 10 mph for 69 and 93 degrees respectively as shown in Figure 17. The least amount of difference recorded was 44% at 69 degrees and 59% at 93 degrees both at 55 mph. Both curves dip slightly at 15 mph then rise again until about 30 mph. From 30 mph the percent difference decreases steadily all the way to 55 mph.

At 10 mph LDGV emissions of HC are higher than HDDV emissions by 6% at 69 degrees and 16% at 93 degrees as seen in

Figure 18. Emissions per mile are equal at 11.5 mph and 15.5 mph for 69 and 93 degrees respectively. From those points on, the amount that HDDV emissions of HC are higher than LDGV emissions steadily increases. The maximum differences of 40% at 69 degrees and 25% at 93 degrees occur at 55 mph.

Figure 19 illustrates the huge differences in NOx emissions between these two classes of vehicles. The largest percentages of difference 1150% and 1375% for 69 and 93 degrees respectively occur at 10 mph. The percent difference decreases as speed is increased from 10 to 35 mph. Between 35 and 55 mph the percent difference increases steadily.

VMT Mix

The differences in emission characteristics between LDGV and HDDV were described in the previous three sections. This section will show how those differences affect composite emission factors for each type of pollutant. This is accomplished by varying the percent of the HDDV in the VMT mix. So that a range of data could be considered, four different VMT mixes were used -- 0%, 3.6%, 10% and 50% HDDV. The percent of the VMT traveled by LDGV was reduced the same amount that the HDDV VMT percentage was increased in each case. The VMT mix with 0% HDDV would be very similar to one found on local streets. The default VMT mix for 1988 includes 3.6% HDDV; therefore it was included in the analysis. During most hours of the day the percent of VMT accumulated by

HDDV on urban interstates and other principal arterials will range between 3.6% and 10%. For this reason a 10% HDDV VMT mix was included. The final mix of 50% HDDV was used because for some hours of the day the portion of VMT traveled by HDDV on rural interstates is approximately 50%.

The effect of changing the percent VMT traveled by HDDVs on composite CO emission factors can be seen in Figures 20 and 21. At both 69 and 93 degrees the 0%, 3.6%, and 10% curves are almost overlaping throughout the speed range. However, a VMT mix of 50% provides a significant difference in the composite emission factors. The 50% HDDV mix would provide approximately 30% less CO emissions at 10 mph and about 20% less at 55 mph for both ambient temperatures.

Figures 22 and 23 show that changing the VMT mix has a less noticeable effect on HC composite emission factors. As with the CO factors the 0%, 3.6%, and 10% curves are almost identical at both ambient temperatures. The 50% HDDV mix changes the emission factor by only 15% at the point of greatest difference, 69 degrees, and only 10% at 93 degrees. The 15% and 10% differences amount to 0.2 and 0.1 grams/mile respectively for HC.

The most dramatic differences due to changing the HDDV VMT mix occur in the NOx composite emission factors. Figures 24 and 25 show that the emission factors developed with a 3.6% HDDV mix are approximately 1.5 times those with 0% HDDVs. Increasing the percent HDDV VMT mix to 10% provides emission factors twice those with 0% HDDV. The NOx composite emission factors for a HDDV VMT

mix of 50% are a minimum of 5 and a maximum of 7 times higher than a mix of 0% HDDVs for both temperatures.

Extra Load and Trailer Corrections

MOBILE4 assumes that all light duty gasoline vehicles carry no additional load, and are not pulling a trailer. The model user does, however, have the option of altering these assumptions. In the U.S. vehicle occupancy rates are usually around 1.1 and few vehicles regularly tow trailers except on seasonal recreation roads. Therefore, a value of 10% was assumed as an upper limit for both correction factors. The effects of 10% of LDGVs, LDGT1s, and LDGT2s carrying and extra load on composite emission factors was analyzed for each of the three pollutant types. The analysis was repeated using 10% pulling trailers.

The effect of these corrections on CO composite emission factors is shown in Figures 26 and 27. The CO factors at 69 degrees are unaffected by either correction factor as seen in Figure 26. When the ambient temperature is increased to 93 degrees the composite emission factors are increased only slightly by the extra load correction. However, at 93 degrees the emission factors for those towing trailers are about 23% higher than those with no corrections at all speeds.

The curves in Figures 28 and 29 show the effects of vehicles with an extra load or pulling trailers on HC composite emission factors. Figure 28 shows that the HC emission factors at 69 degrees

are the same with the 10% corrections as they are without them at each speed from 10 to 55 mph. At all speeds, the composite emission factors in Figure 29 for vehicles that are pulling trailers are approximately 5% higher than those which are not when the ambient temperature is 93 degrees. The HC emission factors remain unaffected by the extra load correction even at the higher ambient temperature.

The composite emission factor comparisons for NOx are shown in Figures 30 and 31. At every speed value in Figure 30 the curves for no corrections, vehicles with an extra load, and vehicles pulling a trailer overlap. This indicates that there is almost no difference in the composite emission factors for either of the corrections at 69 degrees. Figure 31 shows that once again the extra load correction factor has no effect on emissions even at the higher ambient temperature. The vehicles towing trailers increased the composite emission factors by about 2% when the ambient temperature is 93 degrees.

Summary

Several important conclusions concerning the sensitivity of the emission factors developed by MOBILE4 to different input parameters can be drawn from this analysis. First it should be noted that the minimum, maximum, and ambient temperatures were representative of summer not winter conditions. It is assumed that the emission factors the model would develop for

temperatures between 69 and 93 degrees would be between those developed at 69 and 93 degrees. Temperature does have a significant effect on emissions of all three pollutants in the areas analyzed except for HDDVs.

Speed had a very strong effect on all three types of pollutant emissions. CO and HC emissions generally decrease at a decreasing rate as speed is increased. NOx emissions tend to be at their highest at the extremes of the speed range and are lowest between 30 and 35 mph. The pollutants' basic relationships to speed was the same regardless of vehicle type.

Due to the differences in emission characteristics between LDGV and HDDV the VMT mix is an important factor in the development of the composite emission factors. Only small differences in emission factors occurred between the three mixes with few HDDVs for CO and HC emissions. Significant differences in NOx emissions were reported even for small changes in the VMT mix. When the VMT mix contained 50% HDDV relatively large differences were measured for the composite emission factors of all three pollutant types.

Neither the trailer towing nor extra load correction factors were found to have a significant effect on any of the pollutants' emission factors when the ambient temperature was 69 degrees. However, the trailer towing factor did have a small impact on CO and NOx emissions at the higher ambient temperature of 93 degrees.

CHAPTER 4

A CASE STUDY

Project Overview

As part of Tennessee's State Implementation Plan revisions researchers at the University of Tennessee, Knoxville recently prepared a high resolution emissions inventory for ozone nonattainment areas Nashville and Memphis. The research team is currently preparing a similar inventory for Knoxville.

The UTK researchers were responsible for preparing the inventories for the Tennessee counties surrounding Nashville and Memphis. The responsibility for the inventory development in the two counties where Nashville and Memphis are located, Davidson and Shelby counties respectively, rested with their respective air quality control offices. However, the Knoxville study, including Knox and the surrounding counties, will be performed by UTK researchers.

The purpose of this chapter is to describe the methodology used in preparing the mobile source emission portion of these comprehensive inventories. The traffic data required for this project and the process undertaken to develop the traffic data profiles are described in the following sections.

Procedure

Maps of each analysis area were overlayed with a 5 km by 5 km grid. Each grid was given a geographic designation of either -- urban core, urban fringe, or rural. The roads within these categories were assigned one of five functional classifications -- Interstate, Principal Arterial, Minor Arterial, Collector, or Local. The underlying assumption to the approach used was that profiles of traffic inputs could be developed for each of these 15 geographic/highway classifications for each hour of the day. This was necessary to provide the high degree of spatial and temporal resolution desired for the emission inventories. Figure 32 shows an example of the matrices developed for the various traffic inputs. Profiles at this level of detail were developed only for the most important traffic parameters -- average travel speed, VMT mix fractions, and VMT distribution.

The urban core area was defined as a five kilometer square grid centered in the three major cities' central business districts. An area would be designated urban fringe if it were outside the urban core yet still within the city limits of the major cities -- Memphis, Nashville, or Knoxville -- or anywhere in the city limits of the smaller cities. The portion of the study area lying outside the urban fringe area but within the boundaries of the study area was classified as rural. The classification of roads was

performed by comparing the known characteristics of a facility to those generally associated with each functional class by the transportation community. The road was then categorized according to the functional classification it most nearly matched.

The traffic data developed was used for two purposes. The first was to produce VMT profiles for each road segment in the study areas by hour of the day. The second use of the traffic data was as inputs to the EPA's mobile source emissions model, MOBILE4. This model was used to develop emissions factors for each of the previously described road designations for various ambient temperatures for a "worst case" July day in Tennessee.

Mobile Source Emission Inventory

The project team sought to make the best possible utilization of resources and was therefore compelled to allocate resources in a manner commensurate with the importance of the information. Several assumptions were made concerning the various categories of data required to prepare the mobile source emission inventory. Among those assumptions were:

1) spatially resolved VMT information was critical,
2) temporally resolved VMT information was slightly less important,
3) speed and VMT mix fractions were the most important traffic parameters in developing emission factors,

4) operating mode fractions were important, but too complex to allow for detailed profile development for this project, and

5) extra load and towing correction factors would not affect emission factors enough to warrant their usage.

The traffic characteristic profiles used in the production of this inventory were developed based on these initial assumptions.

EPA Guidance

The Environmental Protection Agency has the authority to decide what data collection methods and modeling techniques are appropriate for the development of mobile source inventories. The EPA is also responsible for issuing guidance as to where and how to obtain the information required to follow its recommended methods and techniques. Therefore, the first step in developing the input parameter profiles was to ascertain the EPA recommendations and requirements related to this subject. The traffic parameters needed for MOBILE4 addressed in detail were operating mode fractions, VMT mix fractions, and speed. EPA guidance as to the development of the VMT profiles was also considered.

Vehicle Miles Traveled

There is a one to one correspondence between VMT and vehicle emissions calculated using a given emissions factor. For

example, if the emission factor is 30 grams per mile and there was 500 miles of VMT then 15,000 grams of pollutant would be produced. If the VMT were doubled to 1000 miles, the quantity of pollutant produced would also double to 30,000 grams. There is no "Default VMT" value which can be applied to a city or county. Estimates of local VMT are required for mobile source emission inventories. A variety of techniques are available for making these estimates. They vary in methodology, accuracy, and in the level of resolution they are capable of producing. The following are some of the categories of methods currently being used by states developing mobile source emission inventories:

1) Network
2) Hybrid Network
3) HPMS
4) Manual
5) Fuel Apportion(21)

Versions of UTPS models have been used to model most highway networks for areas in the U.S. with a population of 50,000 or more. The network VMT method is based on link volumes developed by these models. VMT is determined by multiplying the link volumes by the length of the link then summing the results. Many areas classified as nonattainment contain areas that lie outside the boundaries typically coded in the UTPS models. The network hybrid approaches are those that combine one technique for estimating rural VMT with the network method for the urban area.

The U.S. Federal Highway Administration has developed and maintains a national traffic database. This Highway Performance Monitoring System (HPMS) includes sample roadway travel data for a variety of facility types. Some states have chosen to utilize the information collected for the HPMS in developing their estimates of VMT.

At least one city, Chicago, has chosen to use the manual method of developing VMT estimates. Chicago uses VMT for 11 facility types ranging from highway to local roads by county. VMT is not assigned to individual facilities within a county.(21) Obviously, this is a very coarse method and can only provide aggregate VMT estimates at the county level.

Tampa, Florida is using a variation of the fuel apportionment method. Total VMT estimates are developed by multiplying daily average fuel consumption by an average miles per gallon. The VMT calculated from its network model is then subtracted from the total VMT to get the non-network portion of the VMT.(21)

Operating Mode Fractions

Due to the nature of the parameter accurate profiles of the percent of VMT traveled in each operating mode are very difficult to develop. There are no convenient ways of gathering the data necessary to estimate the portion of the VMT traveled by vehicles operating in each mode.

The values used for this parameter in the FTP are 20.6%, 27.3%, and 20.6% for non-catalyst cold-start (PCCN), catalyst hot-start (PCHC), and catalyst cold-start (PCCC).respectively. The EPA will generally accept the use of these values in the development of SIP related emission inventories.(18) However, recently it was shown that in some cases other fractions may be more appropriate when high resolution inventories are being developed. That research showed that the total emissions for an entire day throughout the urban area vary only slightly with changes in the operating mode fractions. However, considerable differences occurred for some grid cells at various times of the day. Thus some temporal and spatial variations may not be accounted for if the FTP mix is used uniformly through out the study area.(6)

VMT Mix Fractions

MOBILE4 provides the option of using a default VMT mix or a mix based on locally available information. The default VMT mix is based on national averages and is considered appropriate in cases where emission factors are being developed for comparison purposes only. But the U.S. EPA

> ...generally requires states to develop and use their own specific estimates of VMT by vehicle type for inventory construction purposes.(18)

A variety of methods could be utilized to develop the VMT mix fractions needed for emission factor development. Trip

based, network model based, and ADT based methods are each currently being used. Model and ADT based methods disagregate the total VMT traveled by all vehicle type on each facility by its functional class. The distribution is performed by estimating the percent of the total VMT traveled by each vehicle class on the different functional classes of roads. The data used to distribute VMT by vehicle class is usually obtained from state departments of transportation, state and local motor vehicle agencies, the Nationwide Personal Transportation Study (NTPS), or the Motor Vehicle manufactures Association (MVMA) Facts and Figures.(22)

The trip based approach also utilizes these four resources but in a different manner. This technique estimates the number of daily trips and trip lengths for each vehicle classification based on the travel characteristics of the different vehicle types as summarized in these sources. The number of daily trips is multiplied by the average trip length for each vehicle class. The total VMT is obtained by summing the results of those class specific calculations. The percent of travel by a particular class is determined by dividing the VMT for that class by the total VMT estimated for all roadway classifications.

Average Travel Speed

Another traffic characteristic that has a considerable effect on MOBILE4's calculation of emission factors is speed. The speed used in the FTP of 19.6 mph is assumed to be the average speed for a typical urban commute. Since MOBILE4 is based on the

FTP, the emission factors are adjusted by the model for speed values other than 19.6 mph. Thus for some situations, such as composite modeling of an entire urban area, the EPA recommends using 19.6 mph as the average speed. However, for cases where high resolution analyses are being performed, 19.6 mph may not be appropriate. A single speed value should not be used for all functional classes of roads in these types of studies. Localized speed data is deemed the most suitable information for these types of modeling exercises. Unless the local data suggests otherwise it is usually assumed that the speed does not vary by vehicle class.

The EPA recommends that two factors be considered when selecting speeds to be used in air quality modeling -- the time period of the analysis and the geographic location of the road.(22) The time period for which the analysis is performed could range from a specific hour to an annual average. The degree of resolution desired for the study should dictate the type of speed data acquired. For example the average speed chosen for modeling an early morning hour such as 5:00 a.m. could be very different from one used to model an afternoon peak hour. So if the analysis is being performed on an hourly basis then the speed profile developed should be on an hourly basis.

The possibility of variation in speed due to a road's location within a study area should also be considered. Most study areas in ozone nonattainment encompass both urban and rural areas. The speeds used in urban areas may vary significantly by hour

of the day. For instance the speeds during morning and afternoon rush hours for some cities are much lower than in other times of the day. On the other hand, rural speeds are generally constant through out the day.(22)

The use of local speed data is preferable to state or national averages for the development of mobile source emission factors. The EPA suggests Metropolitan Planning Organizations (MPOs), Local Councils of Government (COG), and city traffic departments as possible sources of local speed data.(22) If local data is not available the following sources are suggested:

1) State Highway Departments,
2) Traffic Engineering offices in other cities,
3) Characteristics of Urban Transportation Systems: A handbook for Transportation Planning (CUTS).

State Highway departments can often provide information for developing vehicle speed profiles which is not available locally. Traffic engineering offices of cities in other states having characteristics similar to the air quality study area are another possible source. An additional source would be Characteristics of Urban Transportation Systems: A handbook for Transportation Planning.

> The "CUTS" manual reports roadway capacity and average speed per lane for all vehicle types by location of facility. Using knowledge of local conditions, a MOBILE4 user can select the most appropriate average vehicle speeds for local

volume-to-capacity conditions. The CUTS manual is revised annually to reflect changes in traffic speed trends.(22)

Several methodologies of estimating speeds currently being practiced are discussed in "The Preparation of Highway Vehicle Emission Inventories" which was prepared for the EPA.(21) The following five methods are discussed in that document:

1) Network: Volume to Capacity
2) Distance Matrix
3) Capacity Restraint
4) Speed Runs
5) MOBILE4 Defaults

The network: volume to capacity method establishes a volume to capacity (v/c) ratio based on volumes generated by transportation network models. These link level v/c ratios are then used to estimate speeds external from the model based on information from the "Highway Capacity Manual". A second method described as the distance matrix has been utilized by Portland, Oregon. Portland air quality modelers develop speed profiles based on the time it takes for a vehicle to travel between traffic zone centroids rather than using output from the traffic assignment process.

The capacity restraint method, an offshoot of the urban transportation modeling process, is a third method utilized by some cities. Capacity restraint is one of the traffic assignment algorithm options available in most UTPS models. This algorithm attempts to assign traffic based on the v/c ratios on the network

links. Speeds are developed internally by the model based on the traffic conditions on the links as represented by the v/c ratios. These speeds are then used as inputs into the emission factor model.

Two additional methods are being used in some parts of the country. Utilizing MOBILE4's default speed of 19.6 mph for all classes of facilities is a method used by cities such as Chicago, Illinois. The method used in Boston to estimate speed data involves collecting actual speed data by making several speed runs for each facility type. If the analysis being performed requires a high level of resolution the speed runs are made during different hours of the day to account for temporal variations.

Vehicle Miles Traveled Approach

The VMT estimates needed for the study had to meet several requirements: represent an average weekday in July, be estimated for each 5 km by 5 km grid, and be classified according to commonly used highway functional classification scheme.

The source of ADT values was "Traffic Flow Maps of Tennessee Roads and Streets 1988 Average Daily Traffic".(23) ADT values were not available for all road segments. The missing values were estimated by examining those on adjacent segments. ADT values had to be adjusted to represent an

average weekday in July. The adjustment factors were based on the "Monthly Variation Factors, by Day of the Week," which is published annually by TDOT(24). These factors recognize variations in traffic volume by the day of the week and the month of the year. Separate factors were available for rural interstate highways, other rural roads, urban roads, and recreational roads.

This inventory involved developing VMT estimates for several hundred grids and many thousand road segments. To accelerate this tedious process various computer programs were utilized. AUTOCADD was used to measure the lengths of various road segments. A computer program "ADT-EDIT" was developed in house for recording the ADT for each road segment, and subsequently to perform the calculations needed for developing VMT estimates.

Estimation of VMT for Rural Grids

Large size (scale: 1 inch = 1 mile) highway maps were obtained from TDOT for each county, and grids were drawn on the maps. These maps showed all roads on the state highway system and also county roads. For grids in rural areas, a straight forward procedure was used. First the roads in each grid were color coded according to the five classes of roads used in this study -- Interstate, Principal Arterial, Minor Arterial, Collector, and Local.

The second step was to identify individual road segments. Intersections with major roads and the grid boundaries usually served as the the limits of these segments. Once the segments were identified the length of each was measured. The fourth step was to estimate the ADT on each segment. Since both the ADT and length were now known the VMT for each segment was calculated by multiplying ADT by length. The VMT for each grid was then summed for each of the five road classifications.

Estimation of VMT for Small Urban Area Grids

The procedure for estimating VMT on all arterial roads in these grids was similar to that used for rural grids. The AUTOCADD system used for rural roads was utilized for tracing arterial roads and measuring the length of each segment. ADT values were recorded for each segment using the special program developed for this purpose, and the VMT was calculated by multiplying each segment's ADT by its length.

The maps used for estimating the VMT did not show all collector or local roads in small urban areas. Therefore, VMT on collector and local roads in grids located in small urban areas was estimated in a manner different than the one used in rural areas. If collectors and locals were not shown in a grid the estimates were made indirectly by assuming a proportion, or ratio, with respect to the VMT on arterial roads in the grid. The following distribution of VMT according to functional classification was assumed for small urban areas:

Functional Class	Percent of Total VMT
Arterial (all types)	70%
Collector	16%
Local	14%

Based on the above proportions the VMT on collector and local roads respectively was estimated as follows:

VMT on Collector Road = (VMT on Arterial/70%) x 16%

VMT on Local Road = (VMT on Arterial/70%) x 14%

The total VMT for grids in small urban areas was obtained by first adding the VMT traveled on segments of the same functional class then summing these roadway class totals.

Development of Emission Factors

The first version of MOBILE4 was the emission factor model used in the analysis. Default values and settings are available for many variables in MOBILE4. Others require local information to be used. In developing the emission factors for this project the default values for registration and mileage accrual rates and for tampering rates were used. No inspection and maintenance programs or anti-tampering programs were modeled. The 1988 calendar year using MOBILE4 default operating mode fractions of 20.6, 27.3, and 20.6 was modeled. Each portion of the state of Tennessee that was part of this modeling exercise had an elevation below 5500 feet Mean Sea Level thus the value for low altitude areas was used for the region variable.

The ASTM volatility class "C" was deemed appropriate to model a July day in Tennessee. The suggested limit for the RVP corresponding to ASTM class "C" areas is 11.5 psi(25). This value was assumed to be the in use RVP for the base year 1988. No attempt was made to model an RVP control program in this inventory. Thus the RVP was not changed and the start year was set at 20 representing the year 2020 as recommend in the model's user's manual.(18)

Minimum and maximum daily temperatures of 69 and 93 degrees F respectively were used to represent the summer conditions in the Nashville area. Slightly higher temperatures were used for the area around Memphis. The ambient temperature varies considerably throughout the day thus a different scenario for all 24 average hourly temperatures was run in MOBILE4. These hourly values, ranging from 69 to 93 degrees F, were based on temperatures collected for the "ten highest ozone days" in middle Tennessee. Once again slightly different temperatures were used in other sections of the state.

Traffic Parameter Profile Development

In a previous section, the need for daily VMT for estimating vehicle emissions was discussed, and procedures for the estimation of VMT were examined. The development of the emission factors used in combination with VMT to construct the mobile source emission inventory also requires detailed information about travel, which includes the following:

1. Distribution of traffic by hour of day (on different classes of roads);
2. Vehicle-mix, i.e., portion of trucks of different types in the traffic;
3. Travel speed for different types of vehicles (on different classes of roads).

The data for the above listed items were not readily available. A variety of sources were explored, and information about each item was developed. The findings of this effort are reported in the following sections.

VMT Distribution by Hour of Day

In order to calculate emissions on a hourly basis throughout the day, the proportion of daily ADT occurring in each hour was needed. There are several possible sources of variation in the hourly distribution, and these include:

1. Type/class of roadway
2. Size of urban area.

Hourly distribution data was not readily available for the study area. Therefore, a literature search was performed for other sources. The most useful document resulting from the search was the Quick Response Urban Travel Estimation Techniques and Transferable Parameters User's Guide. (Commonly referred to as "The 187 Manual"). A variety of information necessary for transportation planning is presented in this guide including national average hourly distributions of total

travel. These hourly distributions are categorized by the population of urbanized areas and type of roadway. Additionally, distributions are provided for three subareas within an urban area -- Central Business District (CBD), Central City, and Suburb. The Central City and Suburb distributions are designated by orientation as either radial or cross-town.

This was the best information available and was therefore utilized in the study. The values shown in Tables 1, 2, and 3 for Interstates; major and minor arterials; and collectors and locals respectively provide the hourly distributions used for this study. The data for rural Interstates was obtained from the Tennessee Department of Transportation. The remaining values in these tables were extracted from "The 187 Manual"(26). The suburban cross-town values were used for locations designated Urban Fringe or Rural because it was believed that they most appropriately described the region's travel activity. The CBD values will be used for the urban core of Knoxville. Figures 33, 34, and 35 are graphs of the values found in Tables 1, 2, and 3 respectively.

VMT Mix Fractions

As previously explained MOBILE4 develops an emission factor for eight categories of vehicles. Ideally, information should be developed for these eight classes of vehicles for each of the 15 geographic/highway classifications. However, usually detailed vehicle classification data are available only for the higher classes

of roads, i.e., interstate highways, and other principal arterials. Another source of variation in the proportion of different types of vehicles is the hour of the day. On major roads with substantial truck traffic, the proportion of large trucks varies significantly according to the time of day. The location of a road -- urban or rural -- is also a source of variation in the proportion of heavy trucks.

Because of the lack of sufficient data on detailed vehicle classification, it was decided that only two classes of vehicles would be recognized for this study -- large trucks (GVW> 8500 lbs.), and other vehicles. The information needed was "percent trucks" for each hour of the day, Ti, which is the proportion of large trucks with respect to all vehicles during a specific hour i. Data on Ti was not available, and it had to be derived using three different pieces of information as discussed in the following paragraphs.

Data on percent trucks on a daily basis, T, was available from Tennessee DOT for different road classes, and these data are presented in Table 4 and shown graphed in Figure 36.(27) Another type of information that was available for trucks is "hourly distribution of trucks", which was the number of trucks in a given hour expressed as a percent of the daily number of trucks. The hourly distribution of trucks for interstate highways was obtained from TDOT, and those for other arterials and collectors were obtained from the Transportation and Traffic Engineering Handbook(28). The compiled data are presented in Table 5. The third type of information used was the hourly distribution of total

traffic (all vehicles), which was presented earlier in Figures 33, 34, and 35. The formula for combining these data to derive percent trucks by hour (Ti) was developed in the following manner:

$$\text{Percent Trucks for Hour i } (T_i) = \frac{\text{Trucks in Hour i}}{\text{Total Traffic in Hour i}}$$

$$= \frac{\text{(Daily Trucks) (Hourly Dist. of Trucks)}}{\text{(ADT) (Hourly Dist. of Total Traffic)}}$$

$$= \frac{\text{(ADT X T) (Hourly Dist. of Trucks)i}}{\text{(ADT) X (Hourly Dist. of Total Traffic)i}}$$

$$\text{Thus, Ti} = \frac{\text{(T) (Hourly Dist of Trucks)i}}{\text{(Hourly Dist. of Total Traffic)i}}$$

Average Travel Speed

Based on the best available data it was determined that the average operating speeds in the study areas, considering all roadway types and geographic locations, ranged from 10 to 60 mph. However, 55 mph is the maximum allowed in MOBILE4. Therefore MOBILE4 was used to develop emission factors at 10, 20, 25, 35, 45, and 55 mph for each ambient temperature. The emission factors of these discrete speed values were then used as the basis for interpolating the actual emission factors for a given speed in that range at the various ambient temperatures.

Vehicle speed is one of the most important input parameters to MOBILE4. This is a complex parameter because

speed can be measured in different ways, and also there are several sources of variations of speed. The type of speed needed for MOBILE4 is referred to as "average travel speed". The travel time used for measuring an average travel speed includes stopped delay times. A search for data on "average travel speed" revealed that there is not much data available on this parameter. Highway and traffic engineering agencies at state and local levels do have abundant data on "spot speed", which does not reflect stopped delays. Spot speeds basically are running speeds at specific locations. Therefore, the commonly available 'spot speed' data were not applicable for MOBILE4.

The sources of variation in average speed include: type or class of roadway, location of roadway, and time of day. Figure 32 demonstrates how a three dimensional matrix could be developed based on these sources of variation with each dimension stratified into its own categories. An "average travel speed" could to be determined for each combination of these categories. It is obvious that a major study would be needed to develop a complete speed profile as described with original data. Such a major effort was not within the scope of this study. Therefore, a combination of primary and secondary data was used, and the cross-classification scheme was simplified.

Rather than separate profiles being used for urban fringe and rural areas a single set of values was developed. This profile does provide speeds by both road type and hour of the day. The following were the primary sources used to develop the urban

fringe/rural profile: "Average Daily Operating Speed By Air Quality Analysis Zone and Functional Class" for Nashville-Davidson County 1989(29), Characteristics of Urban Transportation Systems October 1985(30), and Hourly Running Speed Data by functional class for several Tennessee communities furnished by the Tennessee Department of Transportation(31,32).

The urban core speed profile was developed by collecting data in the city of Knoxville. As recommended in the Transportation and Traffic Engineering Handbook the "average speed" driving strategy was utilized. This is a method where the driver of the vehicle travels at a speed that, in his opinion, is representative of the speed of the traffic at every point and time. The required time to traverse each link, including stop delay, and the length of each link was recorded. After the data gathering was completed the total distance and total time traveled were calculated for each of the five road types. From this the "average travel speeds" by functional classification were determined.

This data collection was not performed for each hour of the day. The information was, however, gathered both during peak hours for Knoxville, 7:00 - 9:00 a.m. and 4:00 - 6:00 p.m., as well as for off peak periods. Table 6 provides a summary of the average speeds calculated for the urban core. Also included in this table are the quantity of time and number of miles driven to develop those averages for each functional class during both peak hour and off peak conditions.

The urban core speeds for local streets are the lowest at 10 and 13 mph for peak hour and off peak respectively. The average speed on the interstate was determined to be 55 mph during both off peak and peak hour conditions. As expected the speeds calculated for collectors, minor arterials, and principal arterials other than interstates were in between the two extremes. Interestingly, less than 5 mph separated the average speeds for these three classes of roads. The differences between the speeds determined for peak hour and off peak hours were not significant either, except on local roads. The peak hour speed for local roads is about 23% less than the off peak speed.

The narrow range of speed between collectors, minor arterials, and major arterials as well as the lack of difference between the off peak and peak hour speeds are believed to be due to the volume to capacity ratios and the signal timing on the roads which were driven. The difference in geometrics between these classes of streets might be expected to provide differences in average speed. Though the higher classes of roads had higher design speeds the timing of the traffic signals negated its effect on average travel speed. It would also be reasonable to expect the increased volumes during peak hours to affect average speeds. Apparently the traffic volumes were such that reasonably low v/c ratios occurred on these roads even during peak hours. Thus the signal timing at the intersections rather than lane capacity became the controlling factor in determining

the speeds at which the vehicles traveled over a roadway segment.

Table 7 summarizes the speed profiles for all area types. The urban fringe and rural speeds shown were used in developing the Nashville and Memphis area emission inventories and will be used for the Knoxville inventory. The urban core speeds will be used for the urban core grid in the Knoxville study.

CHAPTER 5

RUTHERFORD COUNTY EMISSIONS

The sensitivity of mobile source emission factors to traffic parameter inputs such as VMT mix fractions, average travel speed, trailer towing, and extra load correction factors was discussed in Chapter 3 of this thesis. The development of the traffic parameter profiles utilized in constructing a high resolution emissions inventory for several ozone nonattainment areas in Tennessee was addressed in Chapter 4.

This chapter describes the differences in the quantity of daily mobile source pollutant emissions calculated for Rutherford county on a grid by grid basis as well as a countywide basis when using two inventory development approaches -- FTP and UTK. The first approach, FTP, is so named because it is based on using the default values in the mobile source emissions model, MOBILE4, which is based on the Federal Test Procedure (FTP). The second approach, UTK, is the one used by University of Tennessee, Knoxville, researchers to develop the Tennessee emissions inventory.

Rutherford county is located near the center of the state and is one of the counties included in the Nashville area inventory. The majority of the 91 grids in the county, 77 grids, were considered to be rural. However the remaining 14 grids, primarily in the Murfreesboro area, were designated urban

fringe for this study. For a typical July weekday in the calendar year considered for this analysis, 1988, there was an estimated 3,850,000 vehicles miles of travel in the county. Fifty-seven percent occurred in the 14 urban fringe grids. The remaining 43% of the vehicle miles traveled were in the rural areas of the county.

Overview of FTP and UTK Approaches

MOBILE4 was used to develop the emission factors for both approaches. The daily VMT values used for each approach were developed on a grid by grid basis as described in the VMT section of Chapter 4. The difference between the two approaches is reflected in the characteristics of the traffic parameters that are used. The FTP approach is to use aggregate or default values for VMT, speed, and VMT mix fractions. No attempt to account for differences in these parameters due to roadway class, roadway location, or time of day is made in this method. The UTK approach varied the traffic parameters according to five classes of roads, two geographic locations, and the hour of the day.

The quantity of VMT for each grid by facility type was the same for each approach. The values for rural and urban fringe areas from Tables 1, 2, and 3 were used to distribute the VMT by hour of the day on Interstates, Principal & Minor Arterials, and Collectors & Locals respectively for the UTK approach. For

illustrative purposes the VMT and VMT mix fraction profiles for the FTP are shown in the figures in this chapter as being distributed by hour of the day and geographic location. This was accomplished by dividing the total daily values by 24 to obtain a uniform hourly value. This had no effect on emissions because in the FTP approach the same emission factors were multiplied by the VMT regardless of the hour of the day, type of road, or its location.

FTP Approach

The MOBILE4 settings used in the FTP method to develop emission factors for Rutherford county varied only slightly from those described for the UTK approach in Chapter 4. No inspection and maintenance programs or anti-tampering programs were considered. The 1988 calendar year using MOBILE4 default operating mode fractions of 20.6%, 27.3%, and 20.6% was modeled. The value for low altitude areas was used for the region variable. The ASTM volatility class "C" with a corresponding RVP limit of 11.5 psi was utilized.

Minimum and maximum daily temperatures of 69 and 93 degrees Fahrenheit respectively and a single ambient temperature of 87.4 degrees Fahrenheit were used. The same average speed, 19.6 mph, was used for all roads in both geographic classes of grids for each hour of the day for the FTP method. The same VMT mix fractions with 3.6% HDDV was used

to determine emission factors throughout the county regardless of facility type or location. Because there was no variation in MOBILE4 inputs only one emission factor was developed for each of the three pollutant types -- HC, CO, and NOx.

UTK Approach

The MOBILE4 settings used in the UTK approach are described in detail in Chapter 4. However, the traffic parameter profiles used are briefly reviewed here. The speeds used in the UTK approach varied from 22 to 55 mph according to the type of facility and time of day. The same speeds were used for both rural and urban fringe areas. The VMT mix fractions were developed by considering two classes of vehicles -- HDDV and others. The portion of the total daily VMT traveled by HDDVs varied for the five classes of roads and their geographic location from 0% on local roads to 29.14% on rural Interstates.

Two hourly distributions of VMT were used for Interstates -- one for urban fringe and the other for rural. No distinction was made in the hourly distribution for principal and minor arterials by location or facility type. The same hourly VMT distribution was used for both collector and local roads located in each of the two geographic locations.

Vehicle Miles Traveled in Rutherford County

Estimates of the quantity of vehicle miles traveled for a typical July weekday in 1988 in Rutherford county were made for each of the five classes of roads -- Interstate, Principal Arterial, Minor Arterial, Collector, and Local -- on a grid by grid basis. The grids were each given either an urban fringe or rural geographic classification. There was a total of 10 geographic/functional classes of roads in the county. Of the 3.85 million VMT per day, approximately 29%, 30%, 7%, 25%, and 9% occurred on Interstates, principal arterials, minor arterials, collectors, and locals respectively. Table 8 shows the portion of the total VMT traveled on each functional class that was traveled in each of the geographic area designations. The portion of the total VMT that was traveled in the two area types is shown in Table 9 distributed by functional class.

Figures 37-41 show the portion of the total VMT occurring in each grid that was traveled on the respective classes of roads. The individual grid numbers are not shown in the figures. However, the figures were developed based on the grids being arranged in ascending order of VMT per grid from left to right across the X-axis of the figures. Thus the grids on the left side of the figures had a relatively small portion of the total daily VMT while those on the right contained larger portions of daily VMT for Rutherford county.

Figure 37 shows that Interstate VMT was typically either a large percentage of the VMT in a grid or a very small percentage. Also apparent in this figure is that the grids which had Interstate segments in them were also the ones that had the largest portions of the countywide VMT. Both of these findings are reasonable if one considers the relatively large amount of ADT generally associated with Interstate highways.

Figures 38 and 39 show VMT traveled on principal and minor arterials respectively. In Figure 38 it can be seen that grids with VMT occurring on principal arterials also tend to be the ones with higher total VMT percentages. Only about 7% of the total VMT occurred on minor arterials. But, as seen in Figure 39 VMT, on minor arterials accounted for twenty percent or more of the total VMT in the 9 grids that had any VMT on minor arterials.

The portion of a grid's vehicle miles of travel that takes place on collectors varied from 0% to 100% as shown in Figure 40. There is a slight tendency for larger portions of VMT to occur on collectors in grids with a smaller portion of the total VMT as seen in the same figure. The percent of VMT traveled in each grid on local roads is shown in Figure 41. The percent of a grid's VMT that occurs on local roads generally decreases as the total amount of vehicle miles traveled increases in a grid. The difference in the relationship between the portion of vehicle miles traveled in a grid on a functional class and the total vehicle miles of travel in a grid are most evident when the figure for

local roads is compared with the figure for the highest functional class -- Interstates.

Comparisons of Two Approaches

The two inventory approaches differ significantly in the way they address three important parameters -- VMT distribution, vehicle speed, and VMT mix fractions. Each of these parameters have a sizable impact on the quantity of emission calculated. Thus the incorporation of different methods of addressing them in an inventory development approach has the potential to cause significant differences in the mobile source pollutant emission quantities. The differences in the strategies for handling these parameters will be addressed in the following sections.

Hourly Distribution

Understanding the differences in the way that total daily vehicle miles traveled was distributed temporally by the two approaches is an important step in understanding the difference in the quantities of pollutant emissions calculated. More than 1500 hundred emission factors for each pollutant type were developed for the UTK approach. These different composite emission factors reflected differences based on the ambient temperature for the hour, the estimated speed on the road, and

the fraction of the hourly VMT on a given facility that was HDDVs. Conversely, a single emission factor for each pollutant type was used in the FTP approach and these same emission factors were used throughout the day. The differences in emissions are due to the differences in these emission factors and the quantity of VMT that is multiplied by each.

The hourly distribution of traffic on Interstates in Rutherford county is shown in Figures 42 and 43. A uniform distribution on rural Interstates would provide higher volumes from 8:00 p.m. to 8:30 a.m. and lower volumes for the remainder of the day than the UTK profile as seen in Figure 42. The UTK profile would provide higher VMTs during the peak hours for urban fringe Interstates, lower during the evening and early morning hours, and approximately the same as the FTP profile for the midday hours as can be seen in Figure 43.

The same distribution of traffic for the UTK approach was used for principal and minor arterials in both geographic areas as seen in Figures 44-47. The actual volumes on these classes of roads did, of course, vary between the four geographic/functional classes. But the relationship between the UTK profiles and the uniform distribution used in the FTP profiles is the same for each. In all four cases the UTK profile is smaller between 10:00 p.m. and 6:30 a.m., higher during the morning peak hours and from 11:00 a.m. to 10:00 p.m., and approximately the same from 9:00 a.m. to 11:00 a.m.

The hourly distribution of traffic used for collectors and locals was identical for geographic/functional class designations. Therefore, though the values of the hourly VMT vary, the same relationship between the profiles of the two approaches exist as shown Figures 48-51. In each case the FTP profile would provide higher VMT estimates from 9:30 p.m. to 6:30 a.m., lower from 6:30 a.m. to 10:00 a.m. and from 10:00 a.m. to 9:30 p.m., and the same as the UTK profile at 10:00 a.m.

Speed

The difference between the average speed profiles used for these two inventory approaches is dramatic. The same average travel speed, 19.6 mph, was used at all times in the FTP approach. The average travel speeds used in the UTK profiles varied by functional class of road and hour of the day. Three periods of the day -- peak hour, midday, and off peak -- were used in the Interstate, principal arterial, and minor arterial profiles. Only two time period designations -- day and evening -- were used for the collector and local classifications. The profiles for all road classifications for both the UTK and FTP approaches by hour of the day are shown in Figure 52. The most noticeable difference is not the lack of temporal variation in the FTP profile, but is that the FTP speed is lower than the speeds used for each functional class in the UTK profile for every hour of

the day. Even the lowest UTK speed -- 22 mph for locals -- is 10% higher the the FTP speed.

The FTP speed was determined by averaging the speeds (weighted to reflect the percent of the trip on each functional class) traveled in a typical urban commute in Los Angles, CA. To provide a more equal basis for comparison, the speed profiles used for Rutherford county could be averaged into a composite trip speed. If the speeds for each functional class are weighted by the portion of the total VMT traveled on that class in Rutherford county an average speed of 34.1 mph is calculated. Thus the "typical commute speed" used in the UTK profile is approximately 74% higher than the one used for the FTP.

VMT Mix Fractions

The MOBILE4 default VMT mix fraction for heavy duty diesel vehicles (HDDV) for the 1988 calendar year was 3.6%. That means that the composite emission factors for all three pollutant types were developed based on the assumption that 3.6% of the total VMT was traveled by HDDV on all roadway classes. Because this assumption was not reasonable for all geographic/functional classes of roads during all hours of the day the profiles in Table 4 and Table 5 were developed for use in the UTK approach. Table 4 shows the portion the the total daily VMT on each class of roads in both area types that is trucks. The distribution of these percentages by hour of the day is shown in

Table 5. The 1988 default value for HDDV, 3.60%, is a composite of the travel of heavy duty diesel vehicles on all types of roads. By multiplying the values in Table 4 by the estimated VMT by functional class and area type a composite value could be developed for Rutherford county. The result of these calculations was a HDDV composite value of 9.20%. Thus the UTK composite would be more then 2.5 times the FTP value.

Figures 51-60 show how the HDDV vehicle miles traveled for each of the 10 geographic/functional classes is distributed throughout the day for the UTK and FTP approaches. The FTP profile was developed by dividing the total daily HDDV VMT for each of the 10 classes of roads by 24 thus providing the uniform distribution shown in each figure.

Values of 7.70% and 29.14% were used as the HDDV portion of the total daily VMT on urban and rural Interstates respectively as seen in Table 4. Some of the greatest differences between the profiles of the two approaches occur on Interstates. The differences are most evident on rural Interstates as seen in Figure 53. At 8:00 p.m. the UTK profile is 9 times that of the the FTP with an absolute difference of 10,000 VMT in that hour. Even during the period of the least difference -- 3:00-5:00 a.m. -- the UTK profile is 5 times higher than the FTP profile. On urban fringe Interstates the differences are less pronounced. Figure 54 shows that at the time of greatest difference -- 8:00 p.m. -- the UTK profile is about 3 times the FTP while there is a

58% differential of about 350 vehicle miles travel during the period of least difference -- 3:00-5:00 a.m.

The same hourly distribution of trucks was used for principal arterials, minor arterials, and collectors in both of the geographic area types for the UTK approach. However, a unique value was used in the UTK approach for the portion of the total daily VMT traveled by heavy duty diesel trucks for each of those 6 road classes. The UTK profiles show almost 0% of the HDDV VMT being traveled between 8:00 p.m. and 6:00 a.m. in both the urban fringe and rural areas for all three functional classes of roads.

The daily HDDV VMT portions used for principal arterials were 5.20% for urban fringe and 6.80% for rural areas. Figures 55 and 56 show the portion of the daily VMT on Rutherford county principal arterials that was traveled by heavy duty diesel trucks distributed by hour of the day for both approaches. In both area types the UTK profile is lower from about 6:30 p.m. to 6:30 a.m. and higher during the remainder of the day.

The values used in the UTK approach for the HDDV portion of the total daily VMT on minor arterials were 3.60% and 5.10% for urban fringe and rural areas respectively. Figure 57 shows that the relationship between the profiles of the two approaches for minor arterial were very similar to those used for principal arterials. Interestingly the urban fringe value used in the UTK approach for minor arterials is exactly the same as for the daily

value in the FTP approach. But as can be seen in Figure 58 the UTK value is distributed throughout the day much differently.

Figures 59 and 60 graphically represent the hourly distribution of HDDV VMT on collector roads in rural and urban fringe areas respectively. Only 1.60% of the total daily VMT on rural collectors is traveled by heavy duty diesel vehicles. Figure 59 shows that this relatively low value means the the UTK approach provides a lower estimate of HDDV VMT for almost all hours of the day for these roads. The only exceptions are from 8:30 a.m. to 12:30 p.m. and at 2:00 p.m. A value of 5.40% was used for HDDV VMT for urban fringe collectors. This value was comparable to the ones used for the arterial roads. This was evidenced by the similarity between the curve in Figure 60 and those in Figures 55-58 for arterials.

The value used in the FTP approach for the portion of the daily VMT traveled by HDDVs on local roads was 3.60% as it was for all other functional classes. However, the UTK approach assumed that the HDDV VMT mix fraction for locals was 0.0% at all times. Figures 61 and 62 show that the difference between the two profiles for any given hour is the value of the FTP profile at that point -- 420 or 92 vehicle miles of travel per hour for urban fringe and rural local roads respectively.

Emissions

The differences between the daily emissions developed by the UTK approach and the FTP approach for Rutherford county are significant for all three pollutant types. Not only do large differences occur on a grid by grid basis, but the countywide totals are also quite different. The mobile source emissions for Rutherford county calculated with the UTK approach were 41% lower for CO, 25% lower for HC, and 34% higher for NOx than those determined using the FTP approach. The absolute differences in the daily countywide emissions were 61,233 kg, 6505 kg, and 3304 kg for CO, HC, and NOx respectively.

As one would expect the quantity of emissions in a grid varied closely with the amount of VMT traveled in that grid. Figures 63, 64, and 65 show the relationship between emissions per day and VMT per grid for CO, HC, and NOx, respectively. It is evident in each figure that the emissions for the FTP approach either increase or remain about the same as the VMT per grid increase from left to right on the X-axis. However, the same is not true in the UTK approach, as seen in the figures in some cases the amount of pollutant per grid decreases as the VMT per grid is increased.

Differences by Geographic Area

The amount of difference between the quantity of emissions calculated by the two approaches is partially dependent on the geographic designation of a grid -- rural or urban fringe. The overall differences in emissions between the UTK and FTP approaches were much greater for the rural grids than in those designated as urban fringe for all three pollutant types. Table 10 shows that there was a 48% difference in CO, a 31% difference in HC, and a 63% difference in NOx emissions between the two approaches for rural areas. While in the urban fringe areas the differences were only 36%, 21%, and 13% for CO, HC, and NOx respectively.

Most of the fluctuation between emission quantities and daily VMT per grid that was so apparent in Figures 63-65 is not seen in Figures 66 -71. These six figures show emissions per day per grid with the grids arranged in ascending order of VMT per grid, but the grids have been categorized by geographic location. Figures 66 and 67 show that as before on the FTP curve for CO their were no grids having higher emissions than those with less VMT. In contrast to what was seen in Figure 63 there is only one data point (grid) on the UTK curves in either figure showing significantly higher CO emissions than grids with less VMT. Figures 68 and 69 provide a very similar picture for HC emissions. Very few grids show higher emissions than those having less VMT when they are segregated by geographic

location. Figures 70 and 71 for NOx emissions show a little more variation in emissions verses VMT per grid than seen for CO or HC, but much less than when when the grids were graphed without regard for their geographic designation.

Percent Difference

An additional way to compare the quantities of pollutant emissions between the two inventory approaches is to consider the percent difference between them. This was done on a grid by grid basis and by geographic designation of the grids for all three pollutant types. The percent difference in emissions of CO, HC, and NOx are shown together in Figure 72. Once again the grids are arranged in ascending order of VMT from left to right across the figure.

Two interesting observations can be made from viewing Figure 72. The first is that the amount of difference for all three pollutants is dependent of the amount of VMT traveled in a grid. The differences in the grids with lower amounts of VMT are relatively similar for CO, HC and NOx. The UTK approach calculated emissions to be from about 5% more to about 50% less than those of the FTP approach. However, the variation in percent difference increases by 3 fold or more in grids with larger amounts of VMT. Secondly, the variation seems to follow a pattern rather than being random. For example if there was a large percent difference between the CO emissions determined

by the two approaches in a grid there were also large percent differences in HC and NOx emissions for that grid.

CO Percent Difference

Figures 73, 74, and 75 represent the percent difference in CO emission between the UTK and FTP approaches for all grids, rural grids, and urban fringe grids respectively. As shown in Figure 73 the UTK approach determined emissions to be from 12% to 66% less than the FTP approach when the geographic designation of the grids was disregarded. As seen in Figure 74 the range is almost the same -- 13% to 66% -- when only the rural grids are considered. However, the range narrows to 12% to 48% for the grids located in the urban fringe as shown in Figure 75

If one views Figure 74 it is obvious that all of the variation in the difference between the quantity of emissions and the VMT per grid is not accounted for by the geographic designation of the grids. The seemingly random variation between the percent difference of emissions and the VMT per grid can best be explained by considering that the amount of vehicle miles traveled by functional class in two grids could vary widely and they could still have approximately the same total VMT. The differences in speed and HDDV profiles used for the five functional classes would have resulted in much different CO emission factors and thus in different quantities of CO emissions

for two grids having the same total VMT with different VMT per functional class mixes.

HC Percent Difference

The percent difference in HC emissions between the UTK and FTP approaches are shown for all grids in Figure 76, for rural grids in Figure 77, and for urban fringe grids in Figure 78. Though CO composite emission factors are usually much higher than HC emission factors when all other things are equal the two pollutants tend be similar in their sensitivity to speed, temperature, and HDDV mix. So it is not surprising that Figures 76, 77, and 78 for HC are similar to Figures 73, 74, and 75 for CO except in the magnitude of the differences.

As seen in Figure 76 profiles used in the UTK approach provided from 1% to a 39% less HC emissions when the grids' locations were not considered. The range of difference for the rural grids, shown in Figure 77, was also from 1% to 39%. The urban fringe grids seen in Figure 78 however, had only 9% to 27% differences. The variation in the percent difference between HC emissions for the different approaches in grids with the same geographic designation and approximately the same VMT is attributable to the variation in the amount of VMT by functional class of road in the grids.

NOx Percent Difference

The percent difference in NOx emissions between the two inventory approaches provides the greatest overall range and the most interesting differences due to the geographic location of grids. Figure 79 shows overall percent differences in NOx emissions. While the differences due to geographic designation are shown in Figures 80 and 81. Once again the range of the percent difference for the rural grids, shown in Figure 80, was the same as the overall range -- -33% to +155%. In other words the UTK emission values were from 33% lower to 155% higher than the FTP values. Figure 79 shows that the UTK approach changes from being lower to being higher as the VMT per grid increases.

The curve for the rural grids shown in Figure 80 closely resembles the curve were the grids were not segregated by geographic designation. However, the urban fringe curve seen in Figure 81 is very different from the ones shown in the previous two figures. The stark contrast is attributable to two factors. First the urban fringe grids had a much smaller range of differences and secondly, in all cases the UTK approach provided higher NOx emissions for urban fringe grids. The UTK approach provided emissions that were from 8% to 25% higher than the FTP approach.

This variation in percent difference by geographic designation of the grids can be traced back to differences between the VMT mix fractions used for urban fringe and rural

areas. The composite HDDV VMT mix fraction used for the FTP approach was 3.60%. Composite HDDV VMT mix fractions for the UTK approach calculated for Rutherford county were 9.20% for all grids, 4.90% for urban fringe grids, and 15.0% for rural grids. The UTK approached had approximately a 36% higher composite HDDV VMT mix for urban fringe grids and 315% higher mix for rural grids. As shown in Figures 24 and 25 composite emission factors for NOx are very sensitive to the HDDV mix fraction. For example increasing the percent of the vehicle miles traveled by HDDVs from 3.60% to 10.0% increases the emission factors by 40% or more at all speeds. Thus the small differences in NOx emissions between the two approaches for urban fringe grids and the much larger differences in rural grids in Rutherford county are reasonable.

The difference in the portion of the vehicle miles of travel by functional class of road between the two geographic areas could also explain part of the variability in the percent of difference in emissions. For example Table 9 shows that 46% of rural VMT is traveled on Interstates which have a high HDDV VMT mix fraction -- 29.14%. In the urban fringe areas only 19% of the travel was on Interstates and they had only a 7.70% HDDV VMT mix fraction. Of the VMT in rural areas only 4% was traveled on local roads. While in the urban fringe areas three times that or 12.0% of the VMT was accumulated on local roads which had no HDDV vehicle miles of travel on them. Finally, if one considers that grids typically had either a very high or a

very low portion of their VMT traveled on Interstates then having a range from a negative percent difference between the UTK and FTP approaches for grids with small amounts of VMT to a very large percent difference in grids with large quantities of VMT makes sense for the rural grids.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Highway mobile source emissions represent a major component of comprehensive emission inventories being developed as a part of State Implementation Plan revisions. In 1988, highway mobile sources accounted for 75% of carbon monoxide, 54% of hydrocarbon, and 51% of the oxides of nitrogen emissions in eight counties inventoried in central Tennessee. Due to the magnitude of air pollution from highway vehicles transportation related information is now an essential part of the air pollution modeling process. The two key components of mobile source emission inventories are VMT profiles and emission factors, each of these require significant transportation data to be produced properly. The research arrived at several interesting findings related to how traffic parameters affect air pollution emissions. These findings include the following:

1) High resolution mobile source emission inventories require temporally and spatially segregated profiles of average travel speed, VMT distribution, and VMT mix fractions. However, these data are usually not readily available in a complete form.

2) Emission factors developed by MOBILE4 are especially sensitive to speed. Composite emission factors for CO decreased 80% when speed was increased from 10 to 55 mph.

The total decrease in the value of the HC emission factors when speed was increased from 10 to 55 mph was approximately 80%. Composite NOx emission factors decreased by 16% when speed was increased from 10 to 30 mph, remained constant between 30 and 35 mph, then increased by 20% between 35 and 55 mph.

3) MOBILE4 composite emission factors vary significantly with changes in the VMT mix fractions. Composite emission factors for CO produced with a 50% HDDV mix were 30% less at 10 mph than those developed with the 1988 default HDDV mix of 3.6%, and it was 20% less at 55 mph. The difference in HC emissions between the 50% HDDV mix and the 3.6% mix ranged from a 10% decrease at low speeds to a 15% increase at high speeds. Increasing the HDDV mix to 10% provided NOx emission factors 1.5 times higher than those produced with a 3.6% HDDV mix. Increasing the HDDV mix to 50% caused a 4 fold increase of NOx emission factors over those developed with a 3.6% mix

4) Comparisons were made between emissions produced by two inventory approaches -- FTP and UTK. In the FTP approach temperature and traffic parameters were held constant throughout the day and the same traffic parameter values were used on all types of roads. In the UTK approach emissions were developed by varying the values of traffic parameters and temperature by hour of the day, and traffic parameter values were further varied according to the functional class of road and geographic area. These comparisons showed that significant variations occurred between the results produced by the two

different approaches. A summary of these differences is provided in Table 10. The countywide emissions calculated with the UTK approach were 41% lower for CO, 25% lower for HC, and 34% higher for NOx than those determined using the FTP approach.

The amount of difference in emissions between the two approaches varied by geographic location. There was a 48% difference in CO, a 31% difference in HC, and 63% difference in NOx emissions between the two approaches for rural areas. In the urban fringe areas the differences were only 36%, 21%, and 13% for CO, HC, and NOx respectively.

The percent difference between emissions calculated by the two approaches varied widely among individual grids. The grid level CO emissions calculated by the UTK approach ranged from 12% to 66% less than those calculated with the FTP approach. However, when only urban fringe grids were considered the range of difference narrowed to 12% to 48%. The UTK approach produced HC emissions that ranged from 1% to 39% less than those produced in the FTP approach for individual grids. The range narrowed to 9% to 27% when only urban fringe grids were considered. The UTK emission values were from 33% lower to 155% higher than the FTP values for NOx emissions for individual grids. When only urban fringe grids were considered the UTK NOx emission values range from 8% to 25% higher than the FTP values.

5) The above stated findings lead to the conclusion that the FTP speed and the default VMT mix fractions of MOBILE4 are not appropriate when modeling rural areas even if the inventory is developed for an entire day as a whole.

Based on the findings of the analysis presented in this thesis, the following suggestions are offered for further research:

1) Further development of the data base of traffic parameters used in air quality modeling is urgently needed. Profiles based on actual data for average travel speed are needed. Also, VMT mix fractions and VMT distributions should be produced by functional class of road, hour of the day, and geographic location.

2) This study examined differences in emission estimates by grids using two different approaches -- FTP and UTK. A similar study should be performed to identify differences in emissions according to functional class of roads and hour of the day.

3) Currently MOBILE4 can not produce emission factors for speeds above 55 mph. The model should be updated to account for the differences in vehicle emissions at speeds from 55 mph to 70 mph which are typical on Interstates.

LIST OF REFERENCES

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(1) Wark, Kenneth and Cecil F. Warner, Air Pollution Its Origin and Control, Harper & Row Publishers, New York, 1981.

(2) Cohn, Louis F. and Gary R. McVoy, Environmental Analysis of Transportation Systems, John Wiley & Sons, New York, 1982.

(3) Russel, Milton, "Ozone Pollution: The Hard Choices", Oak Ridge National Laboratory, Martin Marietta Energy Systems. ORNL/TM-10909, 1988.

(4) Russel, Milton, "Tropospheric Ozone and Vehicular Emissions", Oak Ridge National Laboratory, Martin Marietta Energy Systems. ORNL/TM-10908, 1988.

(5) Beckham, Bradley, William Reilly, and William Becker, "Clean Air Act Amendments and Highway Programs", TR News, May-June 1990.

(6) McIlvaine, Cynthia, "An Investigation of Vehicle Operating Mode Profiles for Use in Preparing a High Resolution Emission Inventory", Thesis, University of Tennessee, 1990.

(7) Prendergast, John, "On the Road to Clean Air", Civil Engineering Magazine, August 1990.

(8) Roth, Phillip M., "Effects of Transportation on Ozone in Cities", TR News, May-June 1990.

(9) Shrouds, James M., "Transportation Provisions of the Clean Air Act Amendments of 1990", (unpublished), December 1990.

(10) "Clean Air Act Amendments of 1990, Conference Report to Accompany S1630", U.S. Government Printing Office, Washington, October 1990.

(11) "Urban Ozone and the Clean Air Act: Problems and Proposals for Change", Oceans and Environment Program Office of

Technology Assessment, United States Congress, Washington D.C., April 1988.

(12) Hawthorn, Gary, "Transportation Provisions in the Clean Air Act Amendments of 1990", ITE Journal, April 1991.

(13) "Implementation Strategy for the Clean Air Act Amendments of 1990", EPA Office of Air and Radiation, January 1991.

(14) "Protocol Document for Urban Airshed and EKMA Modeling in the Dallas-Fortworth Metroplex Area", September, 1988.

(15) "Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume II: Emission Inventory Requirements for Photochemical Air Quality Simulation Models, EPA, September 1979.

(16) Davis, Wayne T., Terry L. Miller and Arun Chatterjee, "Comprehensive Emission Inventory for Precursors of Ozone in the Nashville and Memphis Tennessee Areas", Civil Engineering Department, University of Tennessee, 1990.

(17) Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources, EPA, Office of Air Quality Planning and Standards, July, 1989.

(18) "User's Guide to MOBILE4 (Mobile Source Emissions Factor (Model)", U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources Emission Control Technology Division, Test and Evaluation Branch. EPA-AA-TEB-89-01, February, 1989.

(19) "Heavy Duty Vehicle Emission Conversion Factors, 1962-1997", U.S. EPA, EPA Publication Number EPA-AA-SDSB-84-1, August, 1984.

(20) Special Report 209, "Highway Capacity Manual", Transportation Research Council, Washington D.C., 1985.

(21) "Preparation of Highway Vehicle Emission Inventories", 1991 TRB Conference Paper 910672. John H. Suhrbier, Samuel T.

Lawton, Joseph A. Moriarty. Cambridge Systematics, Cambridge, MA.

(22) "Additional Techniques for Estimating MOBILE2 Variables", Energy and Environmental Analysis, Inc. Arlington VA. U.S. EPA publication number PB 83-183277.

(23) "Traffic Flow Maps of Tennessee Roads and Streets 1988 Average Daily Traffic." Tennessee Department of Transportation, Bureau of Planning and Development. Nashville, Tennessee,1988.

(24) "1988 Monthly Variation Factors, By Day Of Week". Tennessee Department of Transportation, Nashville, Tennessee.

(25) 1987 Annual Book of ASTM Standards (Section 5: Petroleum Products, Lubricants, and Fossil Fuels; Volume 05.01: Petroleum Products and Lubricants (I): D 56 - D 1947).

(26) Quick Response Urban Travel Estimation Techniques and Transferable Parameters User's Guide. National Cooperative Highway Research Program Report 187. Transportation Research Board, National Research Council,.

(27) "Travel Activity by Vehicle Type and Functional Class". Tennessee Department of Transportation Figure II-4, 1986.

(28) Transportation and Traffic Engineering Handbook, Second Edition. Institution of Transportation Engineers, Prentice-Hall, 1982 pp. 286-289.

(29) "Average Daily Operating Speed by Air Quality Analysis Zone and Functional Class." Nashville-Davidson County,Tennessee. Developed by the Tennessee Department of Transportation and the Metropolitan planning Commission, 1989.

(30) Characteristics of Urban Transportation Systems, U.S. Department of Transportation Urban Mass Transportation Administration, pp. 73-76 October, 1985.

(31) "Tube Velocity Program with 24 Hour Totals" 1987, 1988. This information obtained from Bonnie Brothers at Tennessee Department of Transportation, Nashville Tennessee.

(32) "Continuous Automatic Traffic Recorder (A.T.R.) Monthly Summaries" Tennessee Department of Transportation, 1988. This information obtained from Buddy McLean at Tennessee Department of Transportation, Nashville Tennessee (615-741-5787).

APPENDICES

APPENDIX 1

TABLE 1

TOTAL TRAFFIC DISTRIBUTION BY HOUR
(INTERSTATES)

	PERCENT OF ADT		
HOUR ENDING	RURAL*	URBAN FRINGE**	URBAN CORE**
1:00 A.M.	2.10	2.00	1.50
2:00 A.M.	1.73	1.50	1.00
3:00 A.M.	1.58	0.50	1.00
4:00 A.M.	1.48	0.50	1.00
5:00 A.M.	1.62	0.50	1.00
6:00 A.M.	2.16	1.00	3.00
7:00 A.M.	2.82	5.50	5.50
8:00 A.M.	3.16	10.00	7.50
9:00 A.M.	4.58	6.00	6.00
10:00 A.M.	5.80	4.50	5.00
11:00 A.M.	6.35	4.00	5.00
12:00 P.M.	6.45	4.00	4.50
1:00 P.M.	6.26	4.00	4.50
2:00 P.M.	6.24	4.00	4.50
3:00 P.M.	6.45	4.50	5.50
4:00 P.M.	6.50	7.50	7.00
5:00 P.M.	6.07	10.00	8.50
6:00 P.M.	5.63	9.00	7.50
7:00 P.M.	5.45	5.50	5.00
8:00 P.M.	4.63	4.50	4.50
9:00 P.M.	3.86	3.50	3.50
10:00 P.M.	3.45	3.00	3.00
11:00 P.M.	3.09	2.50	2.50
12:00 A.M.	2.54	2.00	2.00
	100.00%	100.00%	100.00%

Source: *"Continious Automatic Traffic Recorder (ATR) Monthly Summaries" Tennessee Department of Transportation, 1988.
**"Quick Response Urban Travel Estimation Techniques and Transferable Parameters User's Guide". National Cooperative Highway Research Program Report 187. Transportation Research Board, National Research Council.

TABLE 2

TOTAL TRAFFIC DISTRIBUTION BY HOUR
(MAJOR & MINOR ARTERIALS)

	PERCENT OF ADT	
HOUR ENDING	RURAL & URBAN FRINGE	URBAN CORE
1:00 A.M.	1.50	1.00
2:00 A.M.	0.50	1.00
3:00 A.M.	0.00	0.50
4:00 A.M.	0.50	0.50
5:00 A.M.	1.00	0.50
6:00 A.M.	2.00	2.00
7:00 A.M.	6.00	5.00
8:00 A.M.	6.50	7.00
9:00 A.M.	4.50	6.50
10:00 A.M.	4.00	5.00
11:00 A.M.	4.00	5.50
12:00 P.M.	4.50	5.50
1:00 P.M.	5.00	5.50
2:00 P.M.	5.00	5.50
3:00 P.M.	6.00	6.00
4:00 P.M.	7.00	8.00
5:00 P.M.	8.00	9.00
6:00 P.M.	8.50	6.50
7:00 P.M.	6.50	4.50
8:00 P.M.	5.50	4.00
9:00 P.M.	4.50	3.50
10:00 P.M.	4.00	3.00
11:00 P.M.	3.00	2.50
12:00 A.M.	2.00	2.00
	100.00%	100.00%

Source: "Quick Response Urban Travel Estimation Techniques and Transferable Parameters User's Guide". National Cooperative Highway Research Program Report 187. Transportation Research Board, National Research Council.

TABLE 3

TOTAL TRAFFIC DISTRIBUTION BY HOUR
(COLLECTORS & LOCALS)

	PERCENT OF ADT	
HOUR ENDING	RURAL & URBAN FRINGE	URBAN CORE
1:00 A.M.	1.00	1.00
2:00 A.M.	0.50	0.50
3:00 A.M.	0.50	0.50
4:00 A.M.	0.50	0.50
5:00 A.M.	0.50	0.50
6:00 A.M.	2.00	1.50
7:00 A.M.	5.50	5.50
8:00 A.M.	6.50	8.50
9:00 A.M.	4.50	6.00
10:00 A.M.	4.00	5.50
11:00 A.M.	4.50	5.50
12:00 P.M.	5.00	6.50
1:00 P.M.	5.50	6.00
2:00 P.M.	5.50	6.50
3:00 P.M.	6.00	7.50
4:00 P.M.	7.50	8.00
5:00 P.M.	8.00	7.50
6:00 P.M.	8.00	5.50
7:00 P.M.	6.50	3.50
8:00 P.M.	5.50	4.00
9:00 P.M.	4.50	3.50
10:00 P.M.	3.50	2.00
11:00 P.M.	2.50	2.00
12:00 A.M.	2.00	2.00
	100.00%	100.00%

Source: "Quick Response Urban Travel Estimation Techniques and Transferable Parameters User's Guide". National Cooperative Highway Research Program Report 187. Transportation Research Board, National Research Council.

TABLE 4

PERCENT OF TRAFFIC THAT IS LARGE TRUCKS(T)

	AREA TYPE	
FUNCTIONAL CLASS	Urban	Rural
Interstate	7.70%	29.14%*
Principal Arterial	5.20%	6.80%
Minor Arterial	3.60%	5.10%
Collector	5.40%	1.60%
Local	0.00%	0.00%

Source: "Travel Activity by Vehicle Type and Functional Class". Tennessee Department of Transportation Figure II-4, 1986.

*"Continious Automatic Traffic Recorder (ATR) Monthly Summaries" Tennessee Department of Transportation, 1988.

TABLE 5

HOURLY DISTRIBUTION OF LARGE TRUCKS
(RURAL & URBAN ROADWAYS)

	PERCENT OF DAILY TRUCKS	
HOUR ENDING	ARTERIALS & COLLECTORS*	INTERSTATES**
1:00 A.M.	0.04	3.80
2:00 A.M.	0.04	3.30
3:00 A.M.	0.04	3.00
4:00 A.M.	0.04	3.00
5:00 A.M.	0.04	3.00
6:00 A.M.	0.04	3.10
7:00 A.M.	3.50	3.40
8:00 A.M.	7.00	3.30
9:00 A.M.	10.90	3.80
10:00 A.M.	11.60	4.10
11:00 A.M.	11.40	4.70
12:00 P.M.	10.90	4.90
1:00 P.M.	7.50	4.50
2:00 P.M.	9.50	4.40
3:00 P.M.	8.80	4.80
4:00 P.M.	8.00	4.60
5:00 P.M.	6.40	4.40
6:00 P.M.	3.10	4.60
7:00 P.M.	1.00	5.00
8:00 P.M.	0.04	5.30
9:00 P.M.	0.04	5.00
10:00 P.M.	0.04	4.80
11:00 P.M.	0.04	5.00
12:00 A.M.	0.04	4.20
	100.00%	100.00%

Source: *"Transportation and Traffic Engineering Handbook," Second Edition. Institution of Transporation Engineers, Prentice-Hall, 1982.
**"Continious Automatic Traffic Recorder (ATR) Monthly Summaries" Tennessee Department of Transportation, 1988.

TABLE 6

URBAN CORE SPEED STUDY SUMMARY

	Peak Hour			Off Peak		
Functional Class	Time (minutes)	Distance (miles)	Average Speed (mph)	Time (minutes)	Distance (miles)	Average Speed (mph)
Local	99.8	16.2	9.7	74.6	15.7	12.6
Collector	61.0	22.0	21.6	52.7	19.5	22.1
Minor Arterial	52.9	18.1	20.4	89.5	32.0	21.4
Principal Arterial	73.4	32.1	26.2	105.5	42.7	24.3
Interstate	73.4	64.3	54.8	49.7	45.7	55.1

Source: Data collected by Jerry Everett in average travel speed runs made in Knoxville, Tn, 1991.

TABLE 7
SPEED PROFILES

URBAN FRINGE AND RURAL*
(MPH)

	INTERSTATE	PRINCIPAL ARTERIAL	MINOR ARTERIAL	COLLECTOR	LOCAL
1:00 A.M.	55.00	45.00	38.00	25.00	24.00
2:00 A.M.	55.00	45.00	38.00	25.00	24.00
3:00 A.M.	55.00	45.00	38.00	25.00	24.00
4:00 A.M.	55.00	45.00	38.00	25.00	24.00
5:00 A.M.	55.00	45.00	38.00	25.00	24.00
6:00 A.M.	55.00	45.00	38.00	25.00	24.00
7:00 A.M.	50.00	35.00	31.00	23.00	22.00
8:00 A.M.	50.00	35.00	31.00	23.00	22.00
9:00 A.M.	55.00	40.00	34.00	23.00	22.00
10:00 A.M.	55.00	40.00	34.00	23.00	22.00
11:00 A.M.	55.00	40.00	34.00	23.00	22.00
12:00 P.M.	55.00	40.00	34.00	23.00	22.00
1:00 P.M.	55.00	40.00	34.00	23.00	22.00
2:00 P.M.	55.00	40.00	34.00	23.00	22.00
3:00 P.M.	55.00	40.00	34.00	23.00	22.00
4:00 P.M.	50.00	35.00	31.00	23.00	22.00
5:00 P.M.	50.00	35.00	31.00	23.00	22.00
6:00 P.M.	55.00	45.00	38.00	25.00	22.00
7:00 P.M.	55.00	45.00	38.00	25.00	24.00
8:00 P.M.	55.00	45.00	38.00	25.00	24.00
9:00 P.M.	55.00	45.00	38.00	25.00	24.00
10:00 P.M.	55.00	45.00	38.00	25.00	24.00
11:00 P.M.	55.00	45.00	38.00	25.00	24.00
12:00 A.M.	55.00	45.00	38.00	25.00	24.00

Source: *Compliation of data from references 29-32 of this thesis

URBAN CORE**
(MPH)

	INTERSTATE	PRINCIPAL ARTERIAL	MINOR ARTERIAL	COLLECTOR	LOCAL
1:00 A.M.	55.00	24.00	21.00	22.00	13.00
2:00 A.M.	55.00	24.00	21.00	22.00	13.00
3:00 A.M.	55.00	24.00	21.00	22.00	13.00
4:00 A.M.	55.00	24.00	21.00	22.00	13.00
5:00 A.M.	55.00	24.00	21.00	22.00	13.00
6:00 A.M.	55.00	24.00	21.00	22.00	13.00
7:00 A.M.	55.00	26.00	20.00	22.00	10.00
8:00 A.M.	55.00	26.00	20.00	22.00	10.00
9:00 A.M.	55.00	24.00	21.00	22.00	13.00
10:00 A.M.	55.00	24.00	21.00	22.00	13.00
11:00 A.M.	55.00	24.00	21.00	22.00	13.00
12:00 P.M.	55.00	24.00	21.00	22.00	13.00
1:00 P.M.	55.00	24.00	21.00	22.00	13.00
2:00 P.M.	55.00	24.00	21.00	22.00	13.00
3:00 P.M.	55.00	24.00	21.00	22.00	13.00
4:00 P.M.	55.00	26.00	20.00	22.00	10.00
5:00 P.M.	55.00	26.00	20.00	22.00	10.00
6:00 P.M.	55.00	24.00	21.00	22.00	13.00
7:00 P.M.	55.00	24.00	21.00	22.00	13.00
8:00 P.M.	55.00	24.00	21.00	22.00	13.00
9:00 P.M.	55.00	24.00	21.00	22.00	13.00
10:00 P.M.	55.00	24.00	21.00	22.00	13.00
11:00 P.M.	55.00	24.00	21.00	22.00	13.00
12:00 A.M.	55.00	24.00	21.00	22.00	13.00

Source: **Data collected by Jerry Everett in average travel speed runs made in Knoxville, Tn, 1991.

TABLE 8

PERCENT OF TOTAL DAILY VMT FOR RUTHERFORD COUNTY

BY AREA TYPE AND FUNCTIONAL CLASS

	Functional Class				
Area Type	Interstate	Principal Arterial	Minor Arterial	Collector	Local
Urban Fringe	36%	76%	47%	57%	82%
Rural	64%	24%	53%	43%	18%
	100%	100%	100%	100%	100%

TABLE 9
FUNCTIONAL CLASS VMT DISTRIBUTION
FOR RUTHERFORD COUNTY BY AREA TYPE

	Area Type	
Functional Class	Urban Fringe	Rural
Interstate	19.00%	46.00%
Principal Arterial	39.00%	17.00%
Minor Arterial	5.00%	8.00%
Collector	25.00%	25.00%
Local	12.00%	4.00%
	100.00%	100.00%

TABLE 10

DIFFERENCES IN EMISSIONS

BETWEEN UTK AND FTP APPROACHES

	Pollutants					
	CO		HC		NOx	
Area Type	DIFFERENCE	% DIFFERENCE	DIFFERENCE	% DIFFERENCE	DIFFERENCE	% DIFFERENCE
RURAL	-30475	-48%	-3418	-31%	2580	63%
URBAN FRINGE	-30758	-36%	-3087	-21%	724	13%
COUNTYWIDE	-61233	-41%	6505	-25%	3304	34%

APPENDIX 2

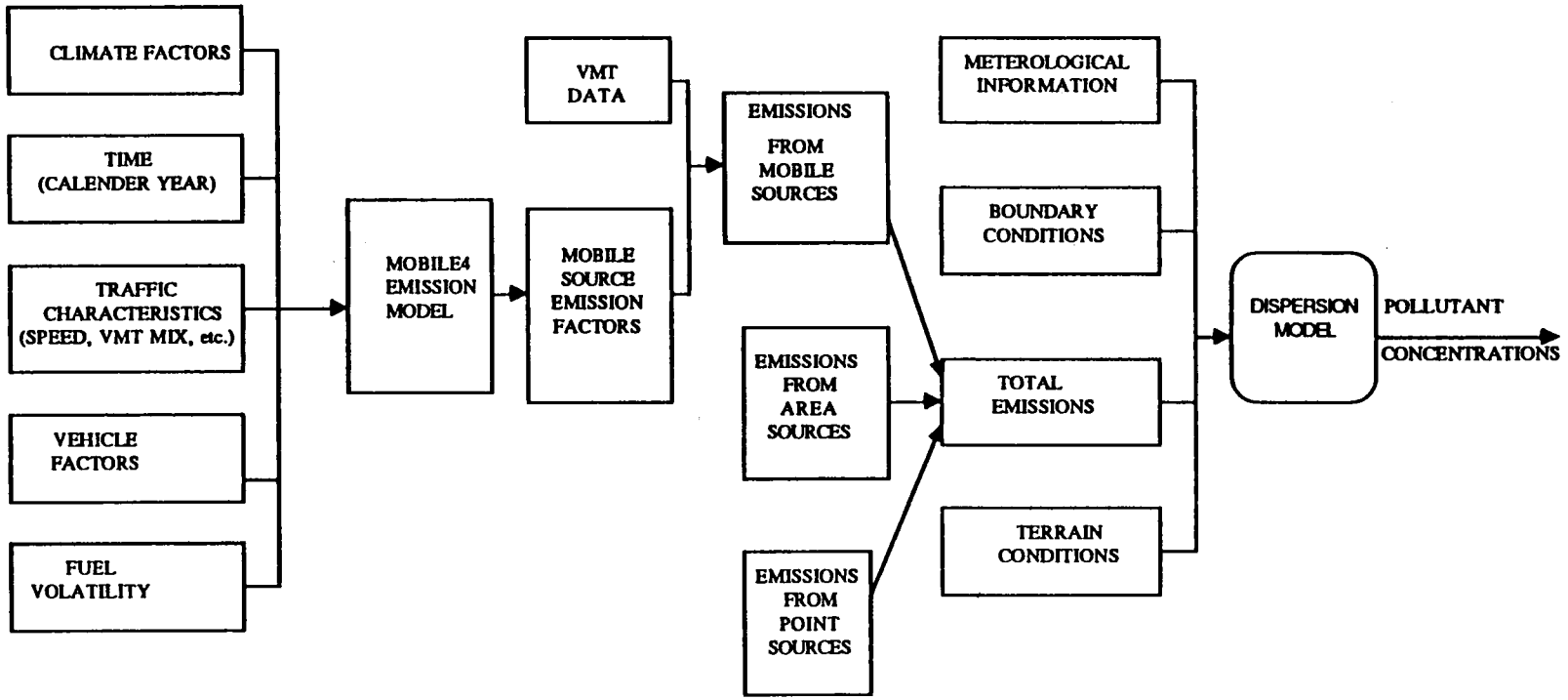


FIGURE 1

THE AIR POLLUTION MODELING PROCESS

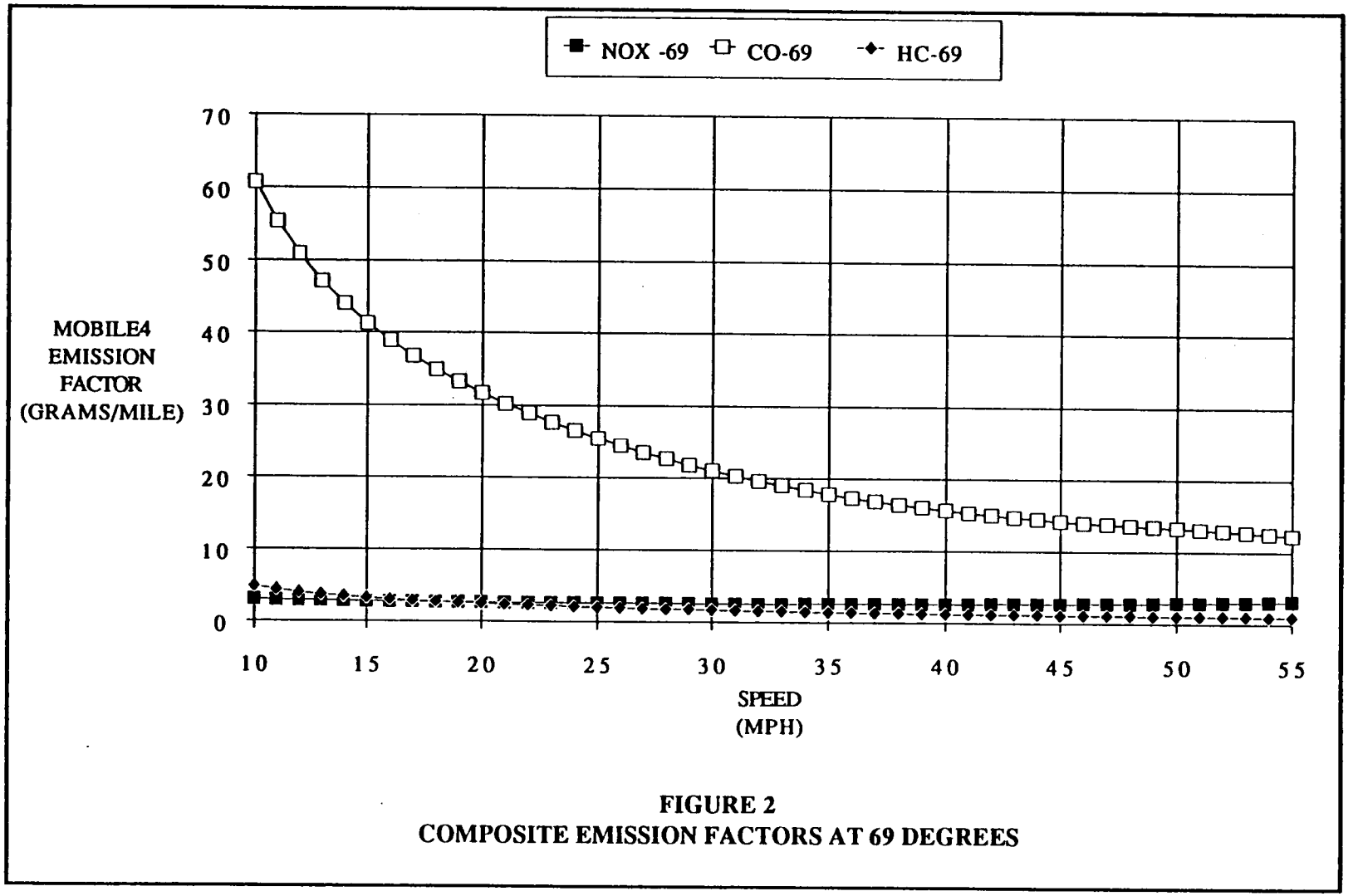


FIGURE 2
COMPOSITE EMISSION FACTORS AT 69 DEGREES

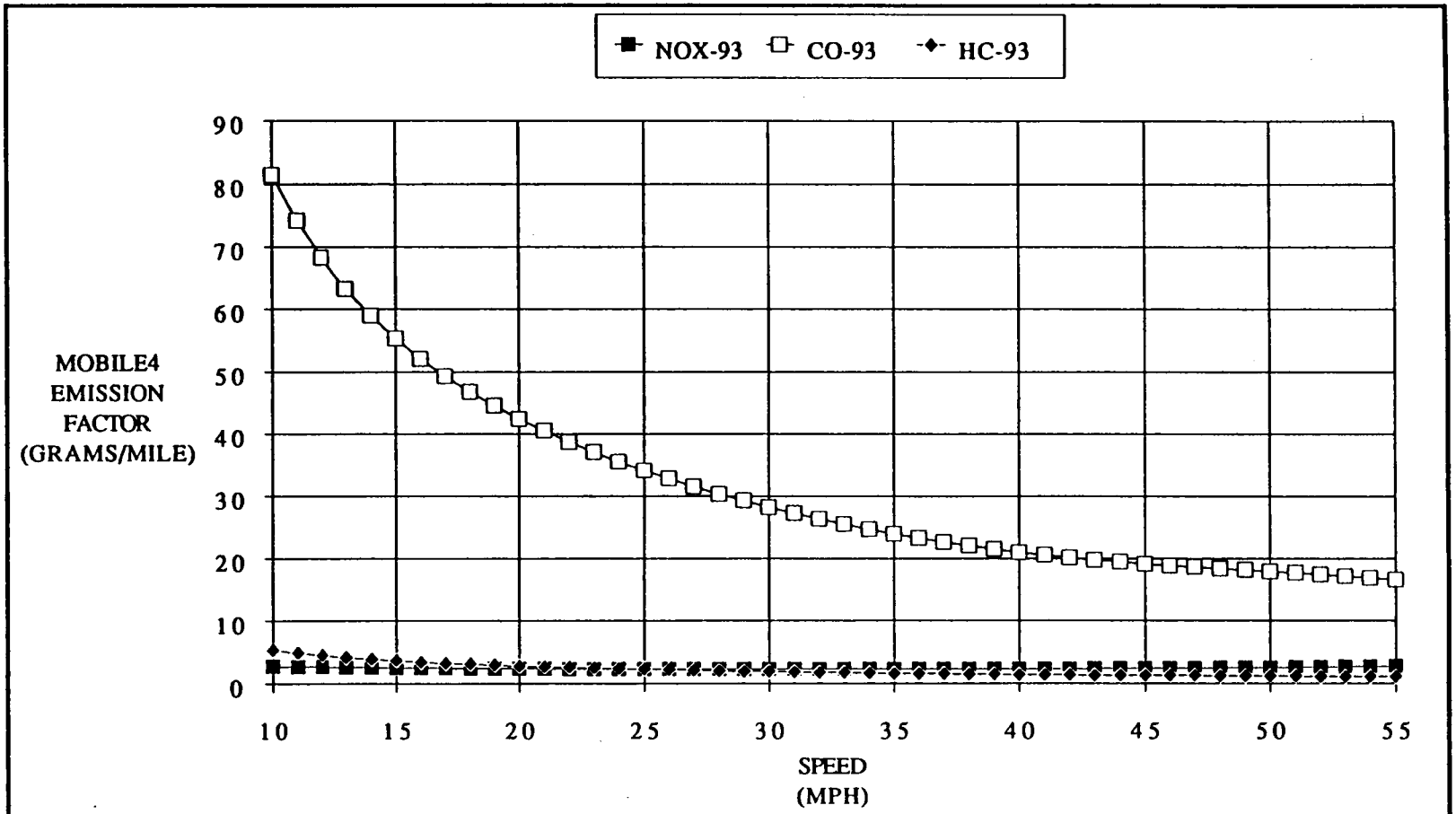


FIGURE 3
COMPOSITE EMISSION FACTORS AT 93 DEGREES

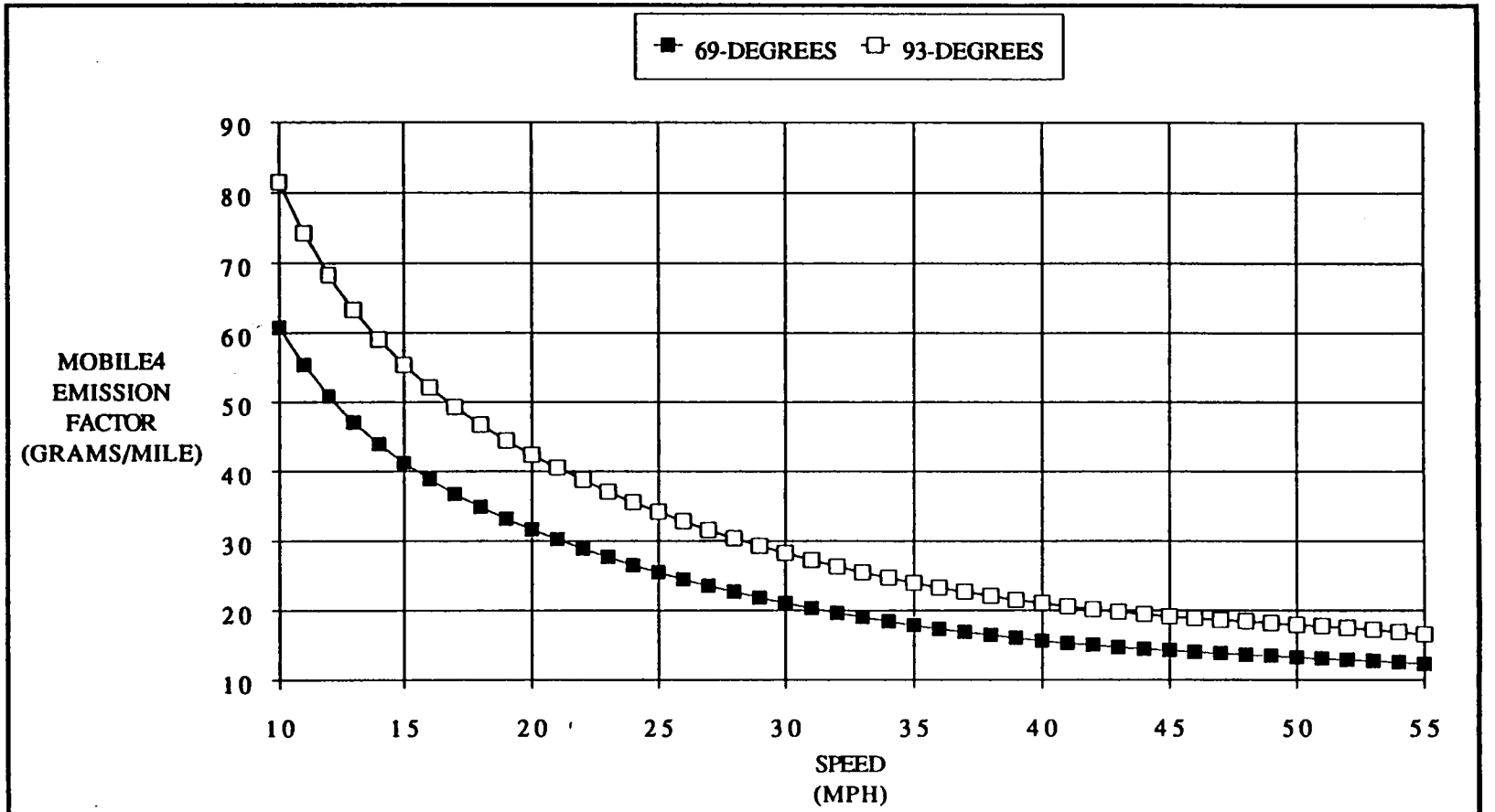


FIGURE 4
CO EMISSION FACTORS
COMPOSITE OF ALL VEHICLES

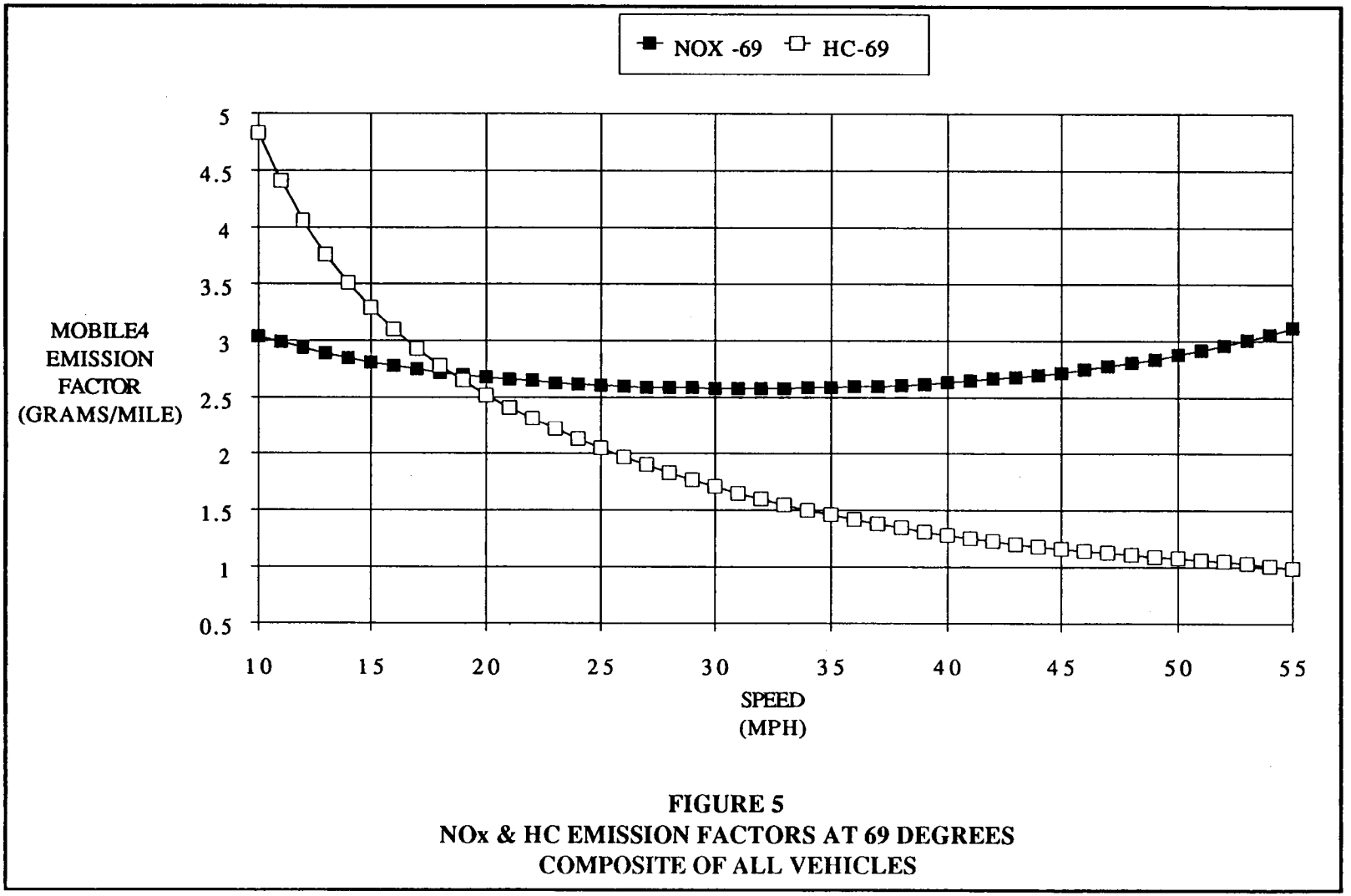


FIGURE 5
NOx & HC EMISSION FACTORS AT 69 DEGREES
COMPOSITE OF ALL VEHICLES

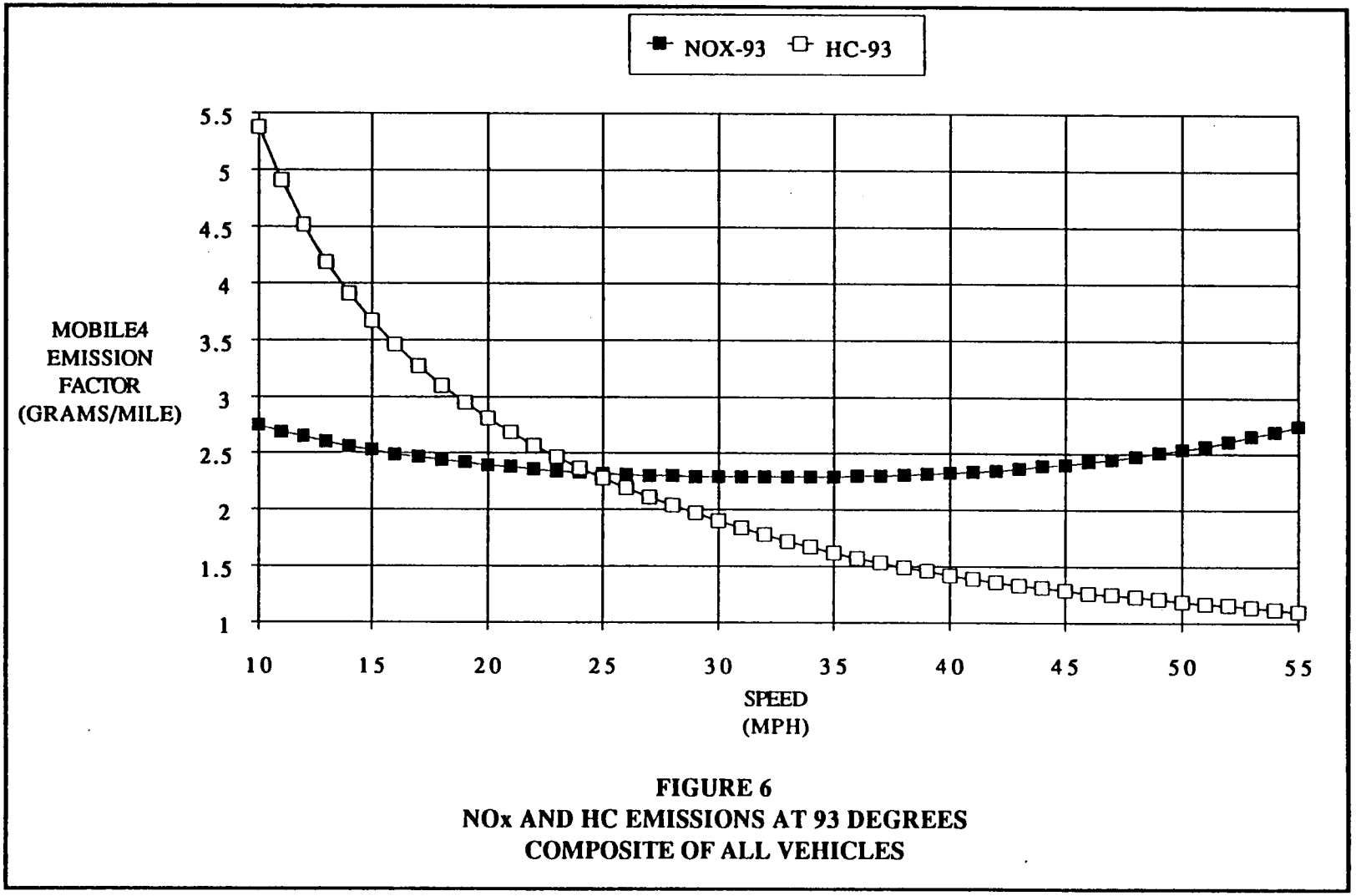


FIGURE 6
NOx AND HC EMISSIONS AT 93 DEGREES
COMPOSITE OF ALL VEHICLES

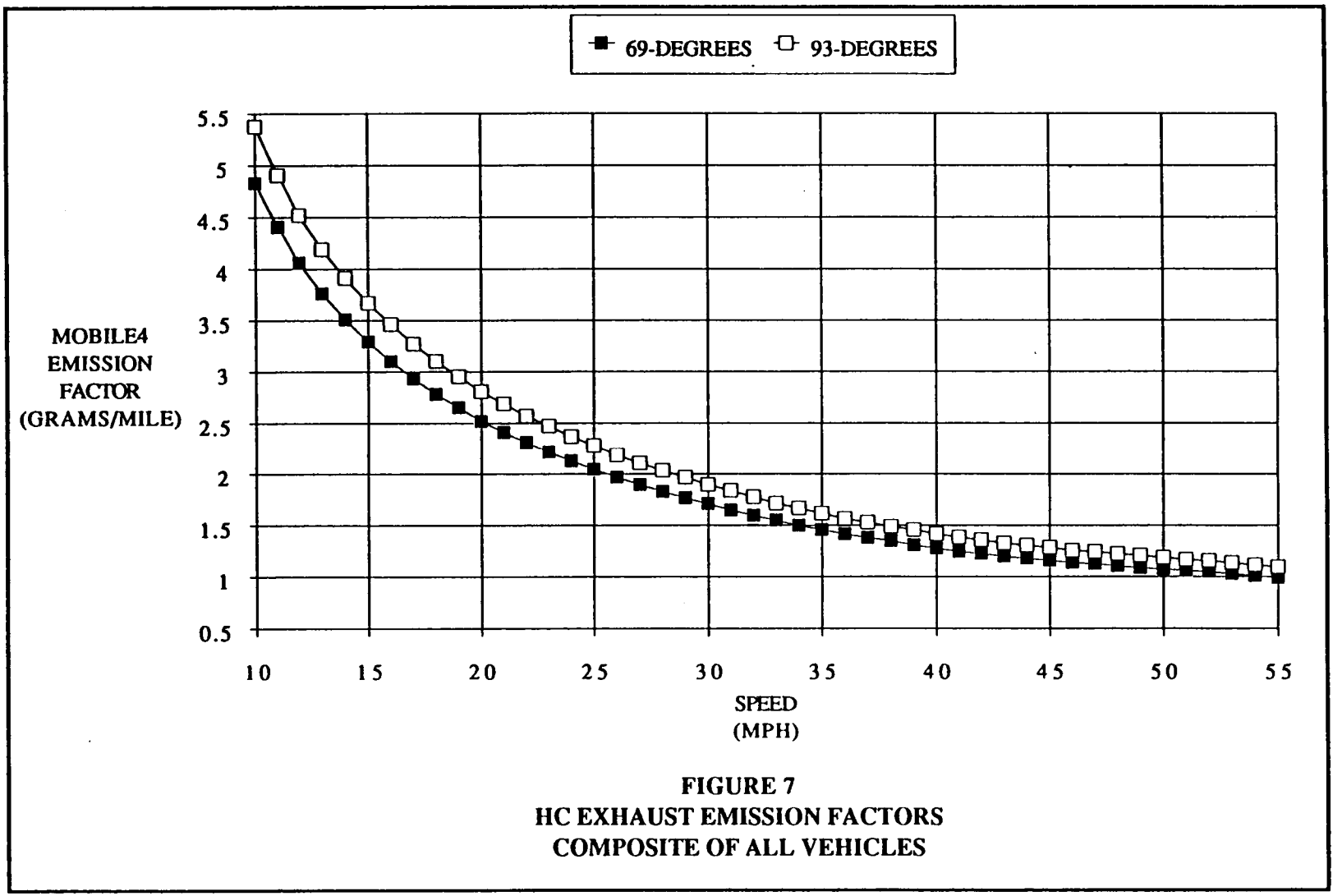


FIGURE 7
HC EXHAUST EMISSION FACTORS
COMPOSITE OF ALL VEHICLES

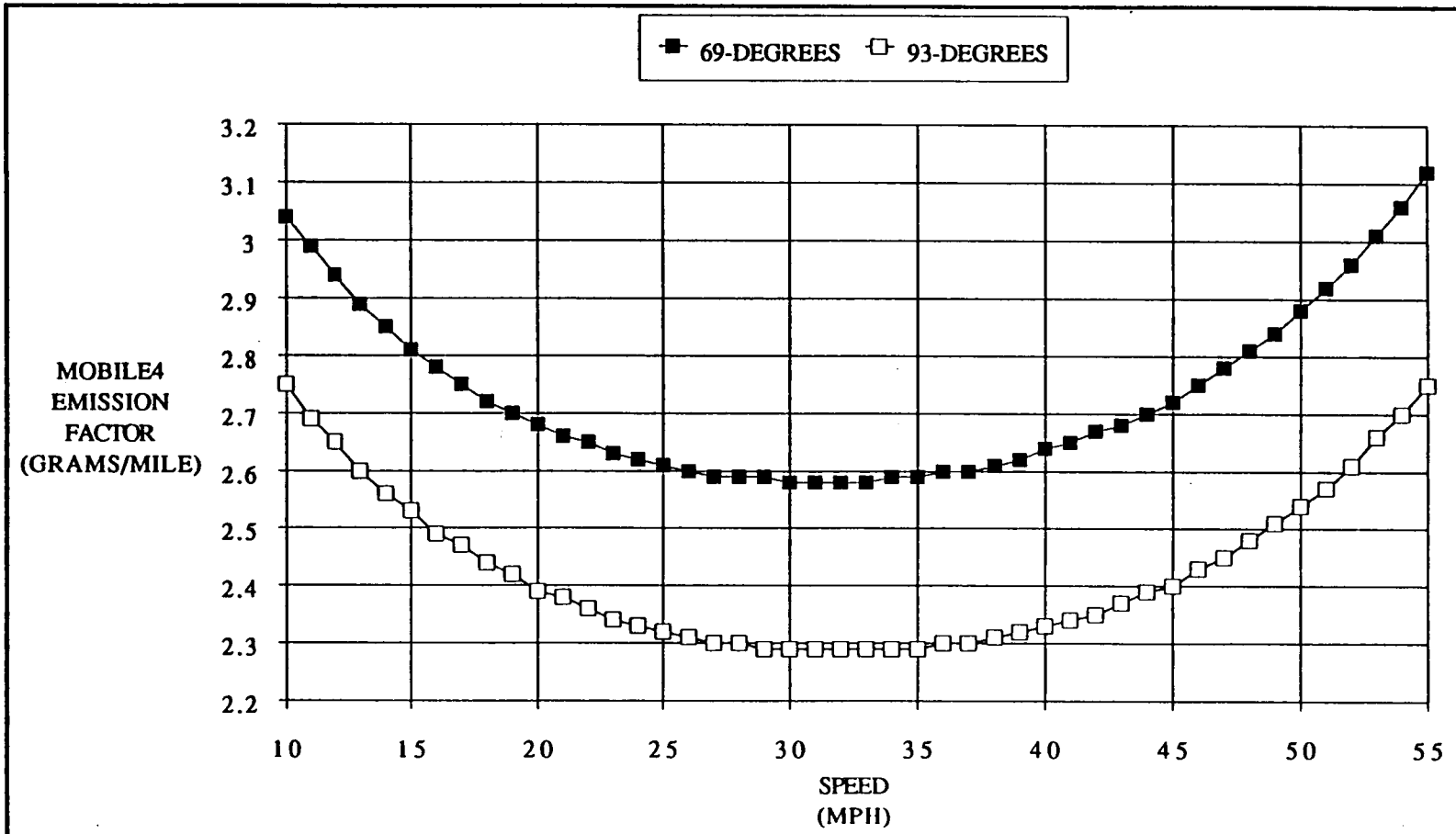


FIGURE 8
NOx EXHAUST EMISSION FACTORS
COMPOSITE OF ALL VEHICLES

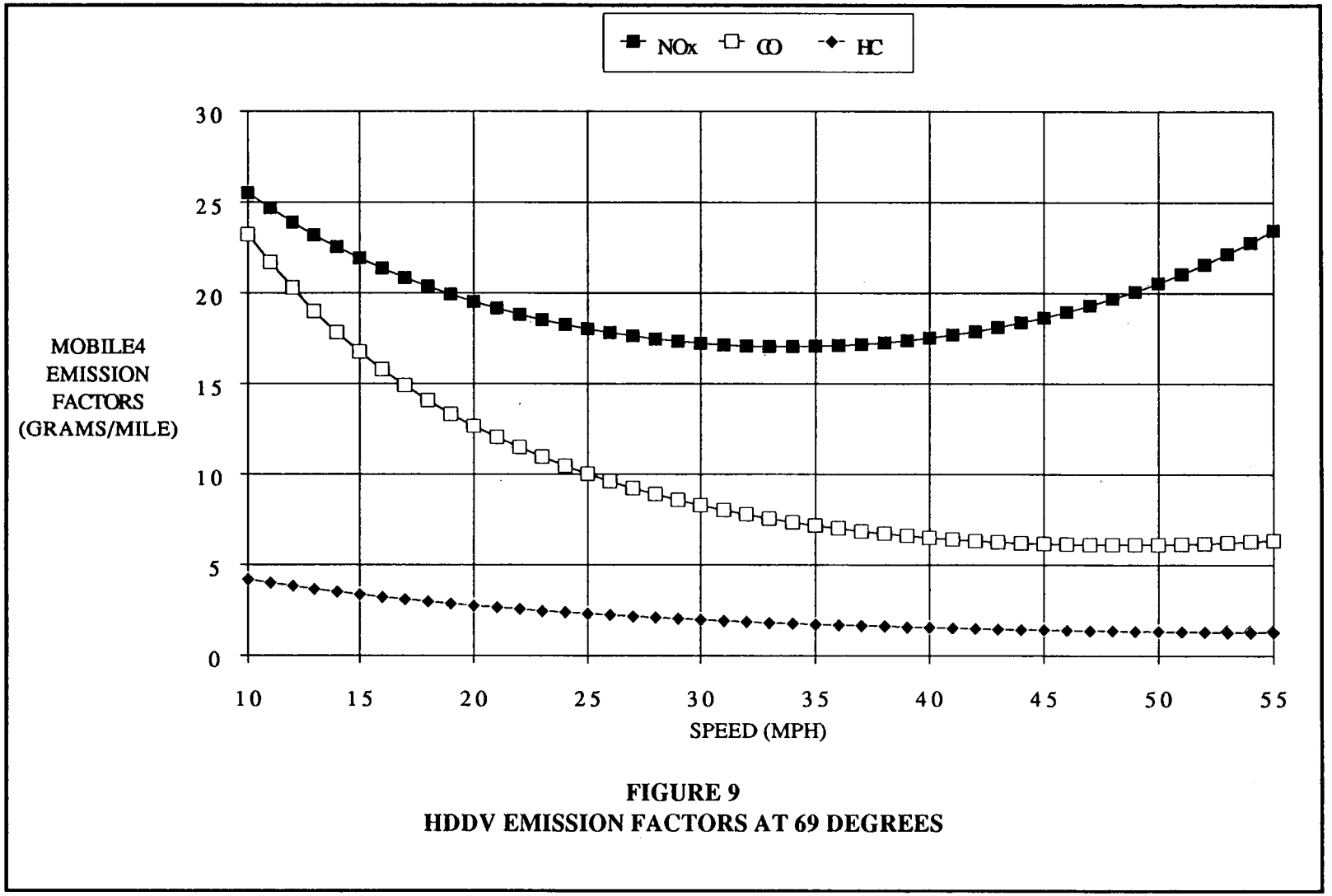


FIGURE 9
HDDV EMISSION FACTORS AT 69 DEGREES

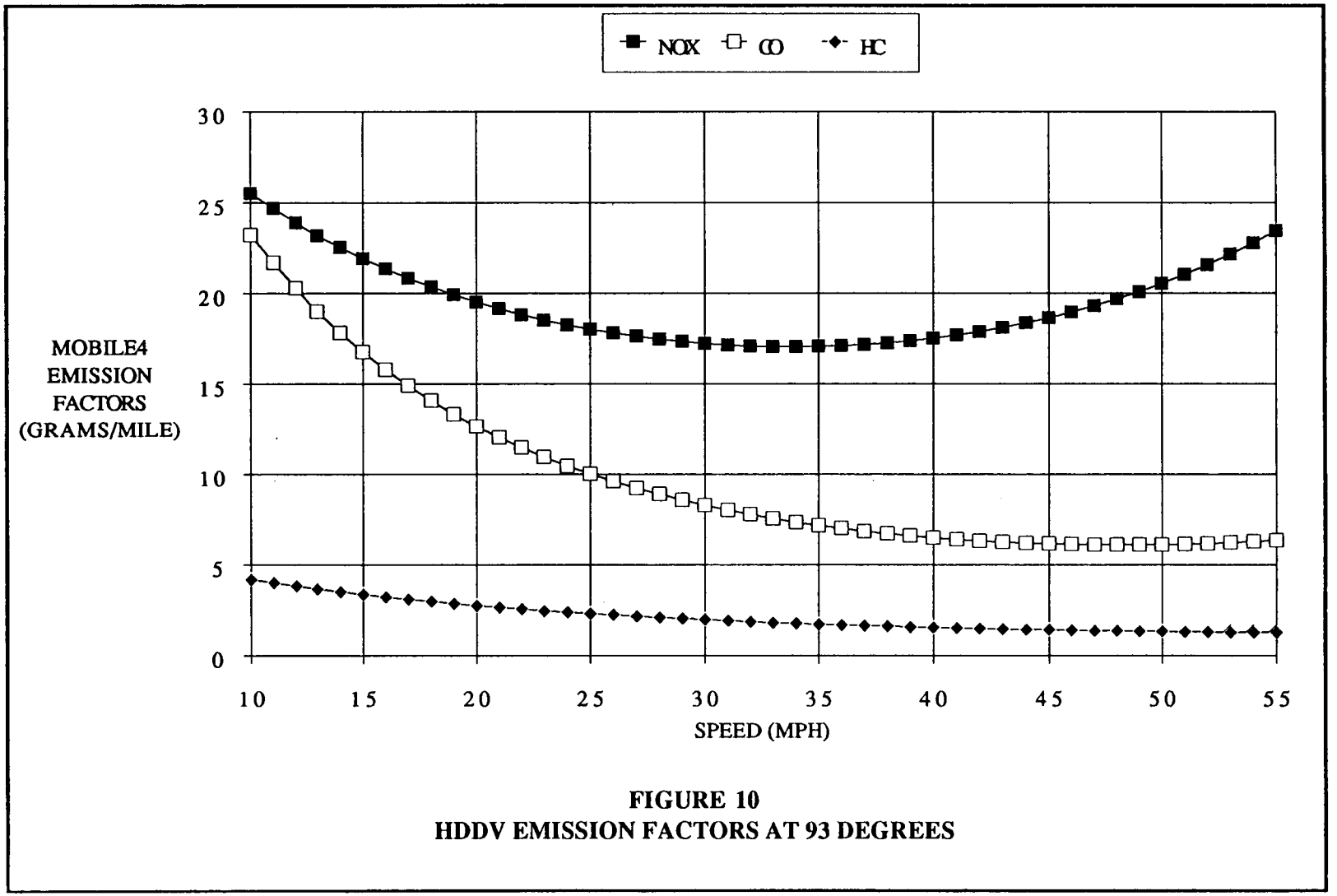


FIGURE 10
HDDV EMISSION FACTORS AT 93 DEGREES

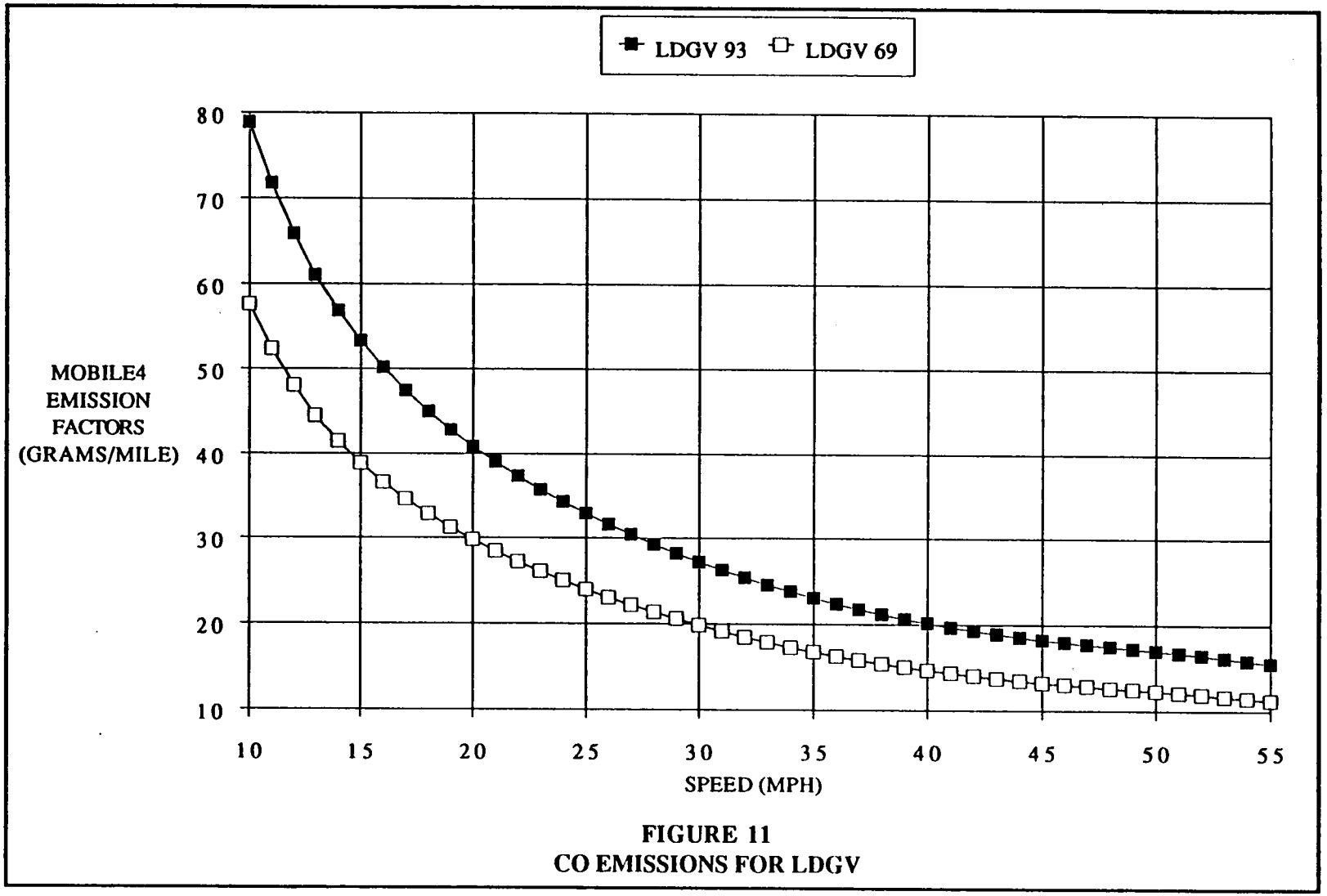


FIGURE 11
CO EMISSIONS FOR LDGV

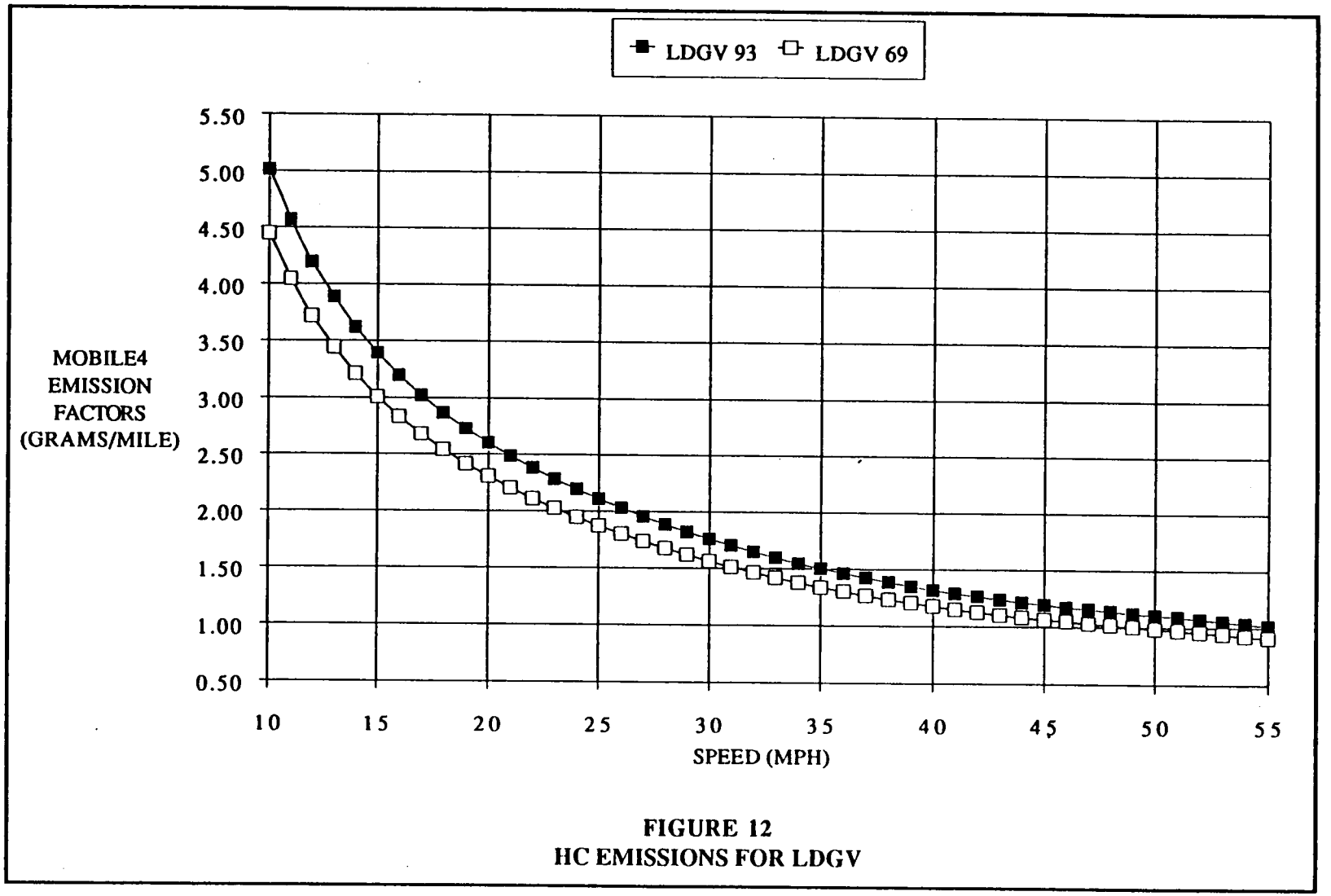


FIGURE 12
HC EMISSIONS FOR LDGV

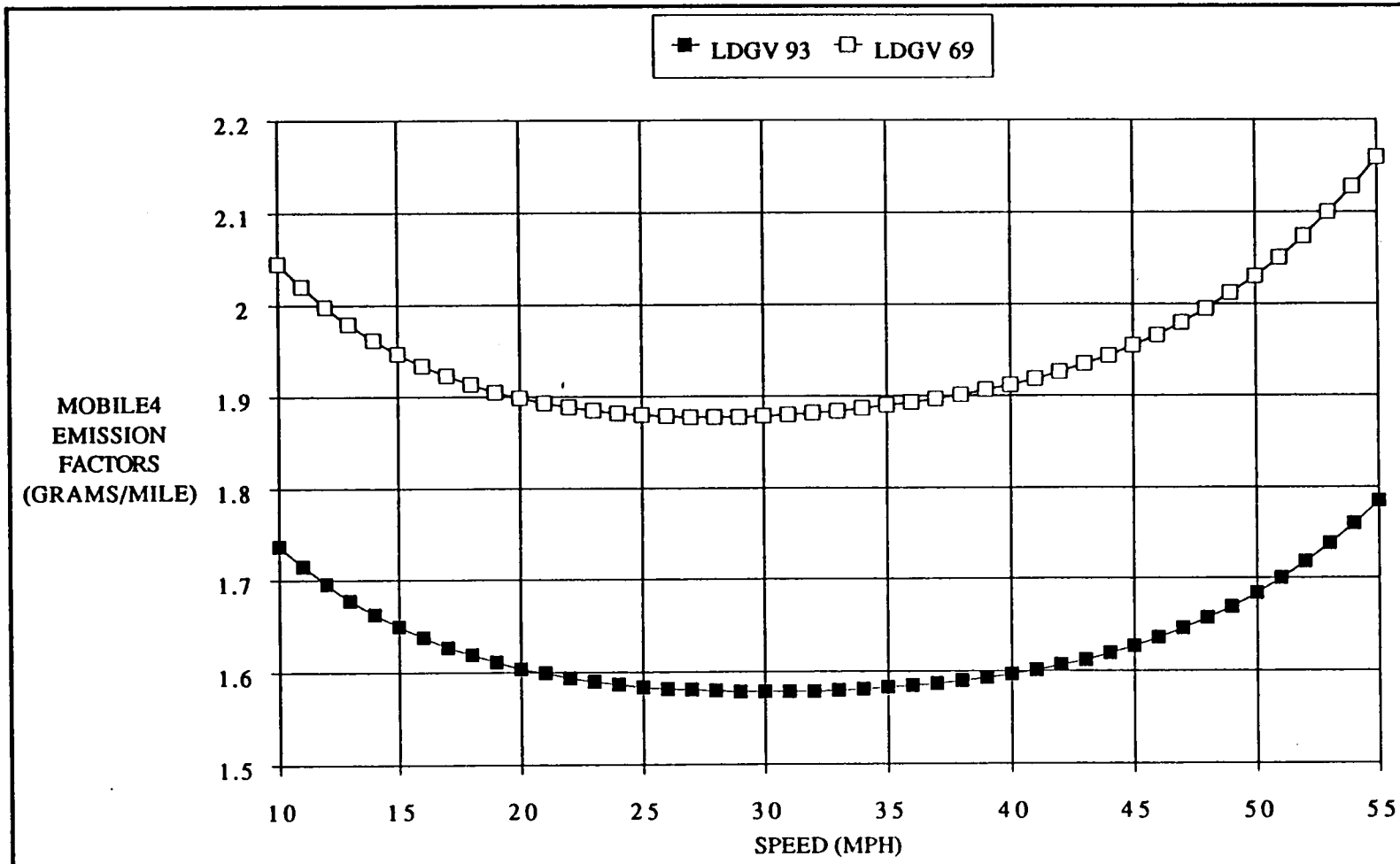


FIGURE 13
NOx EMISSIONS FOR LDGV

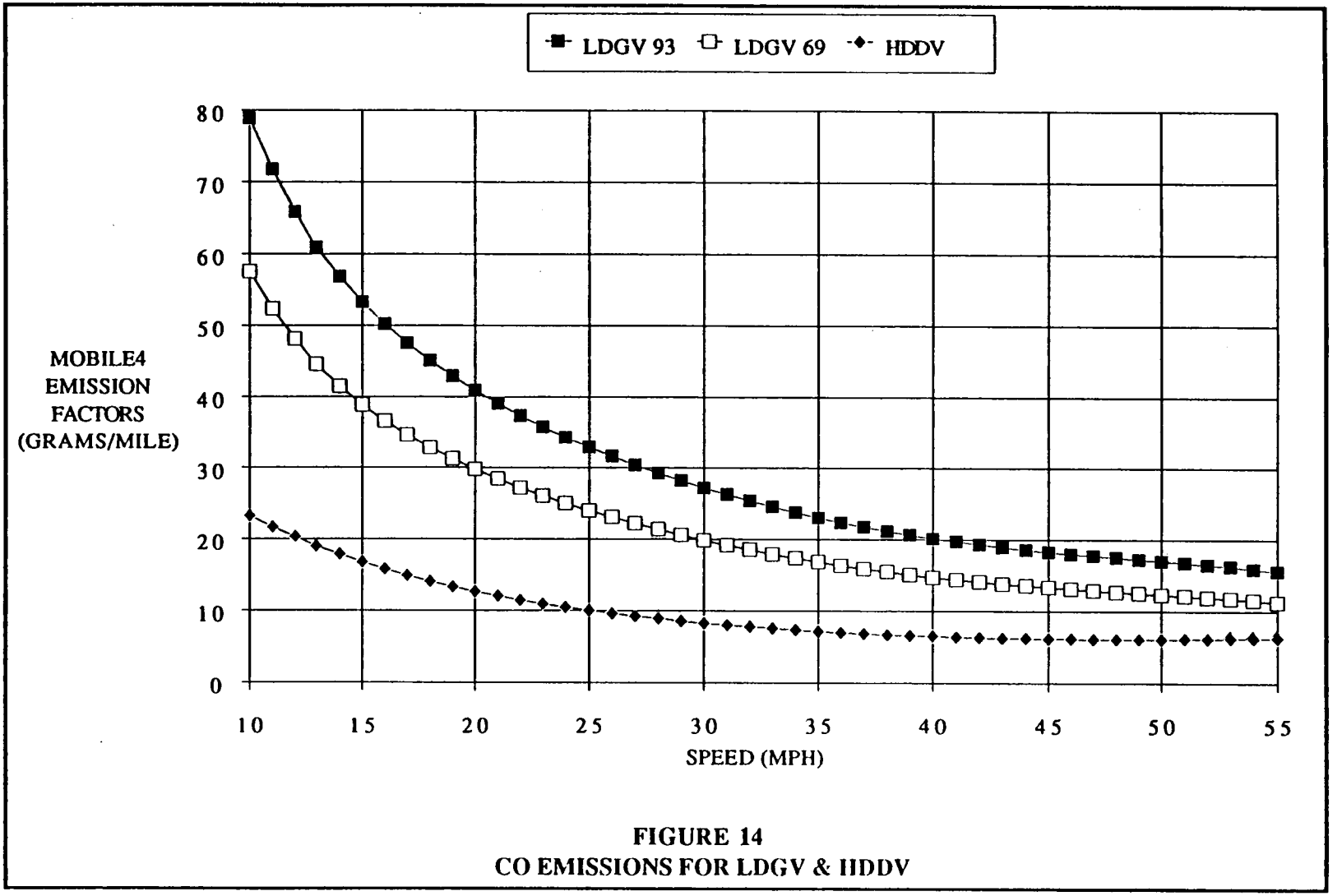


FIGURE 14
CO EMISSIONS FOR LDGV & HDDV

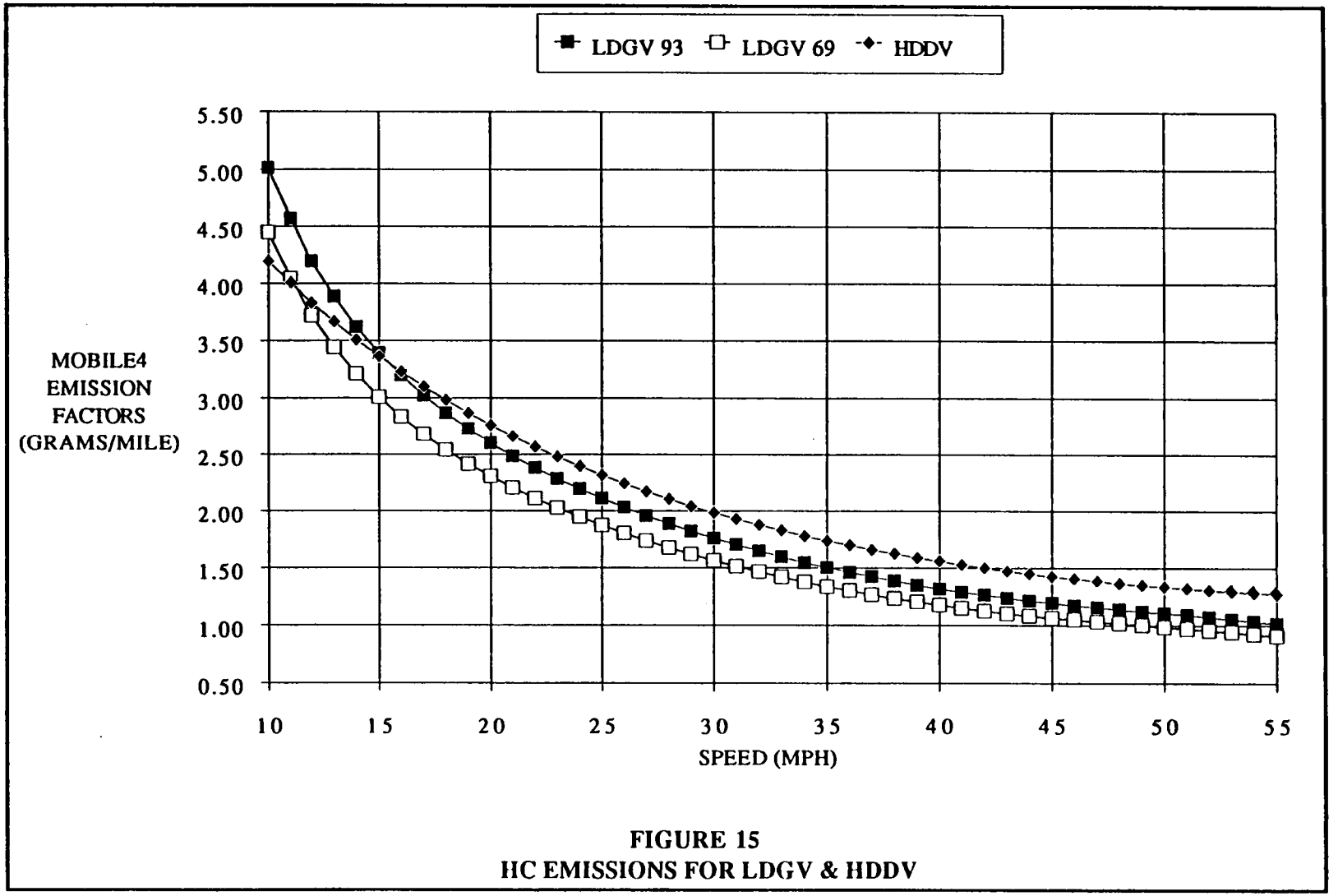


FIGURE 15
HC EMISSIONS FOR LDGV & HDDV

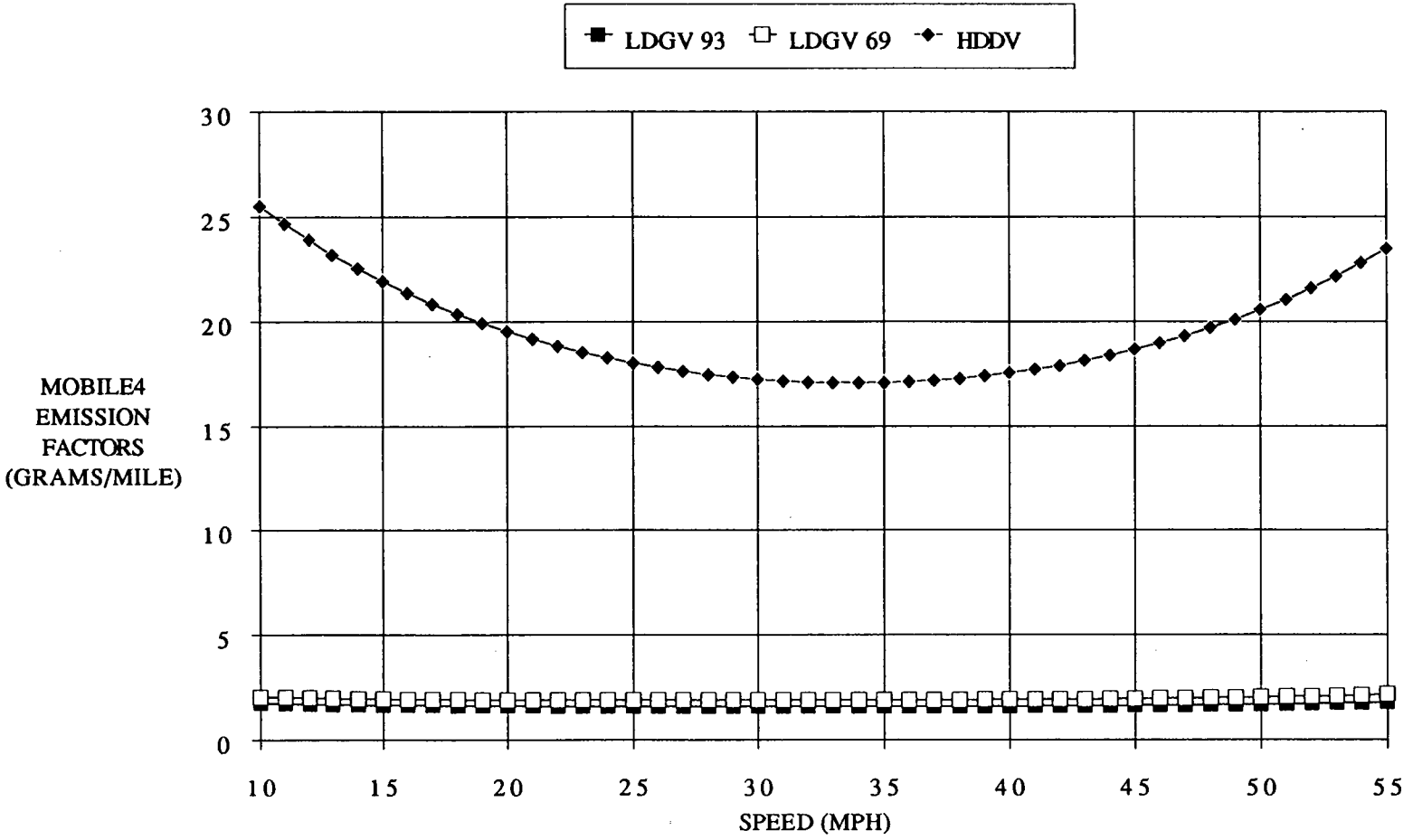


FIGURE 16
NOx EMISSIONS FOR LDGV & HDDV

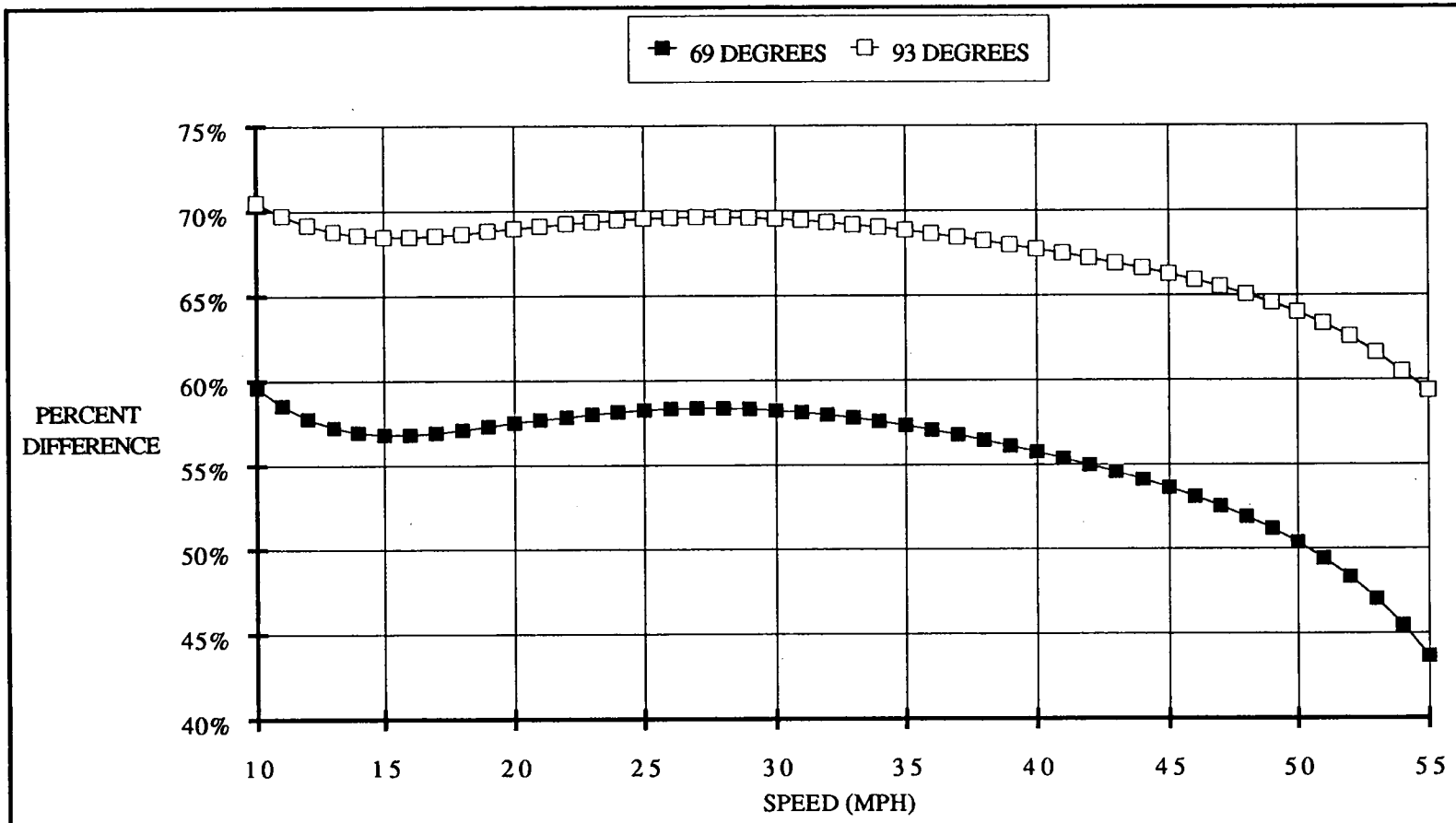


FIGURE 17
PERCENT DIFFERENCE IN MOBILE4 CO EMISSION FACTORS BETWEEN LDGV AND HDDV

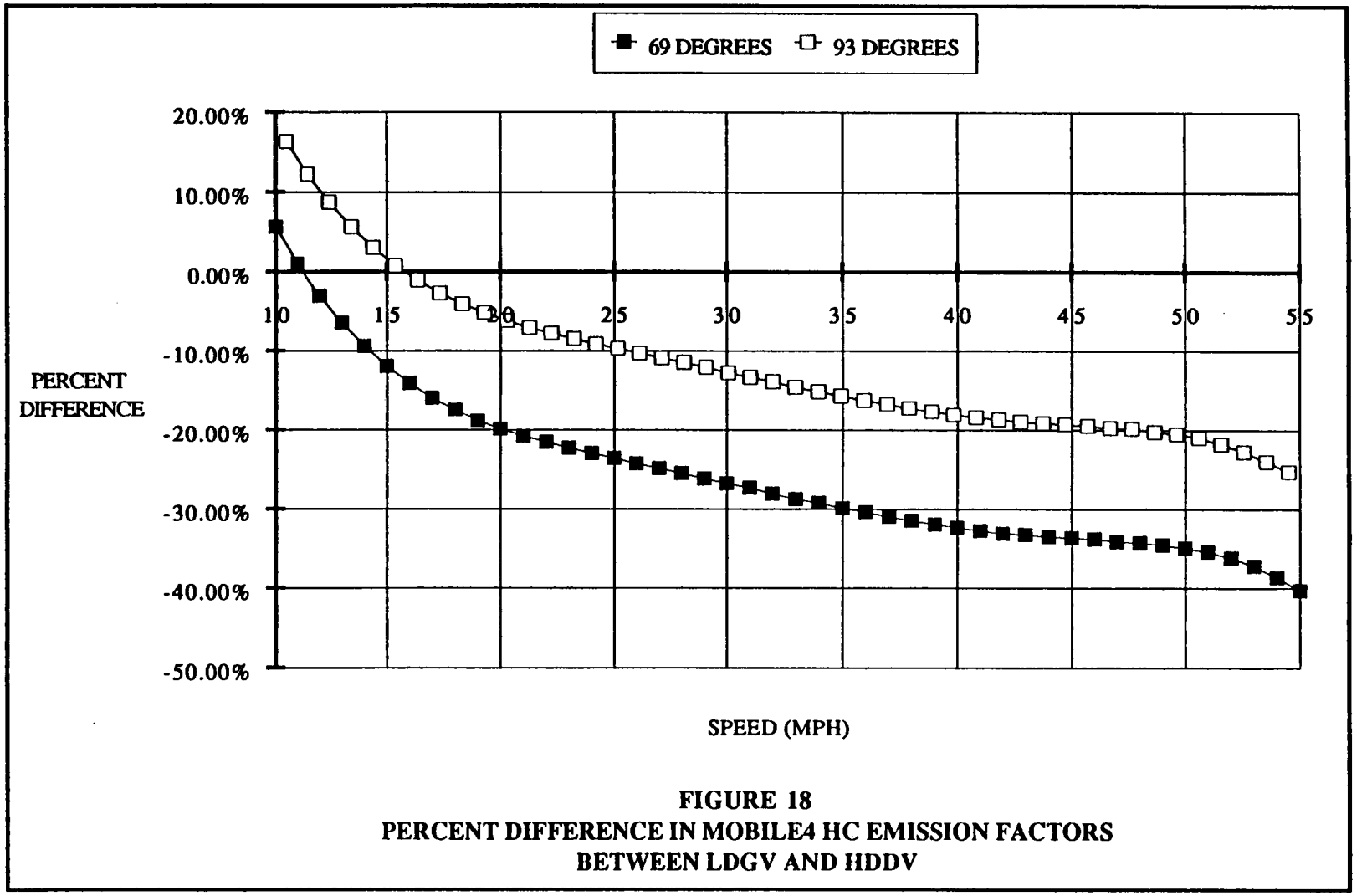


FIGURE 18
PERCENT DIFFERENCE IN MOBILE4 HC EMISSION FACTORS BETWEEN LDGV AND HDDV

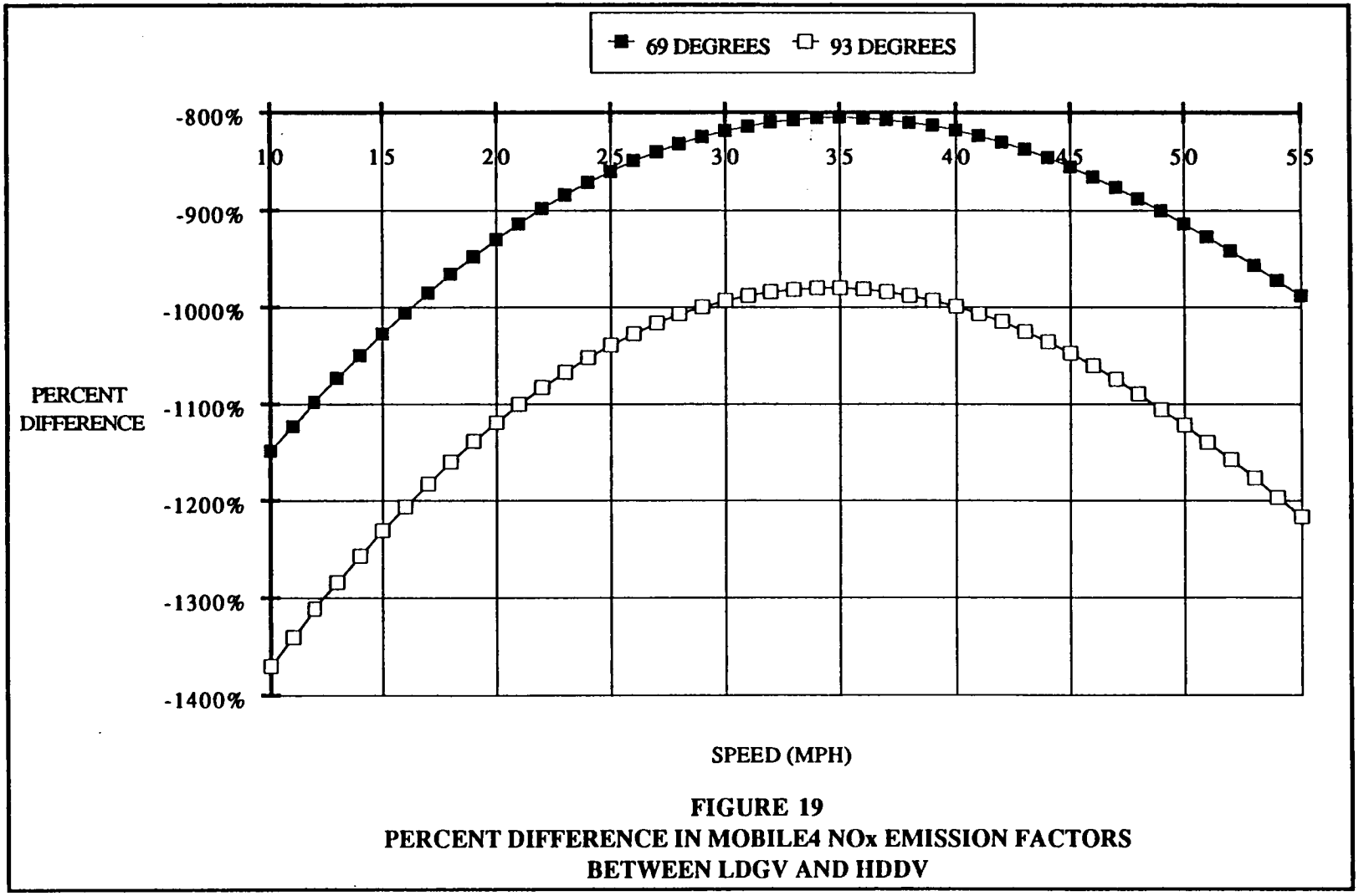


FIGURE 19
PERCENT DIFFERENCE IN MOBILE4 NOx EMISSION FACTORS BETWEEN LDGV AND HDDV

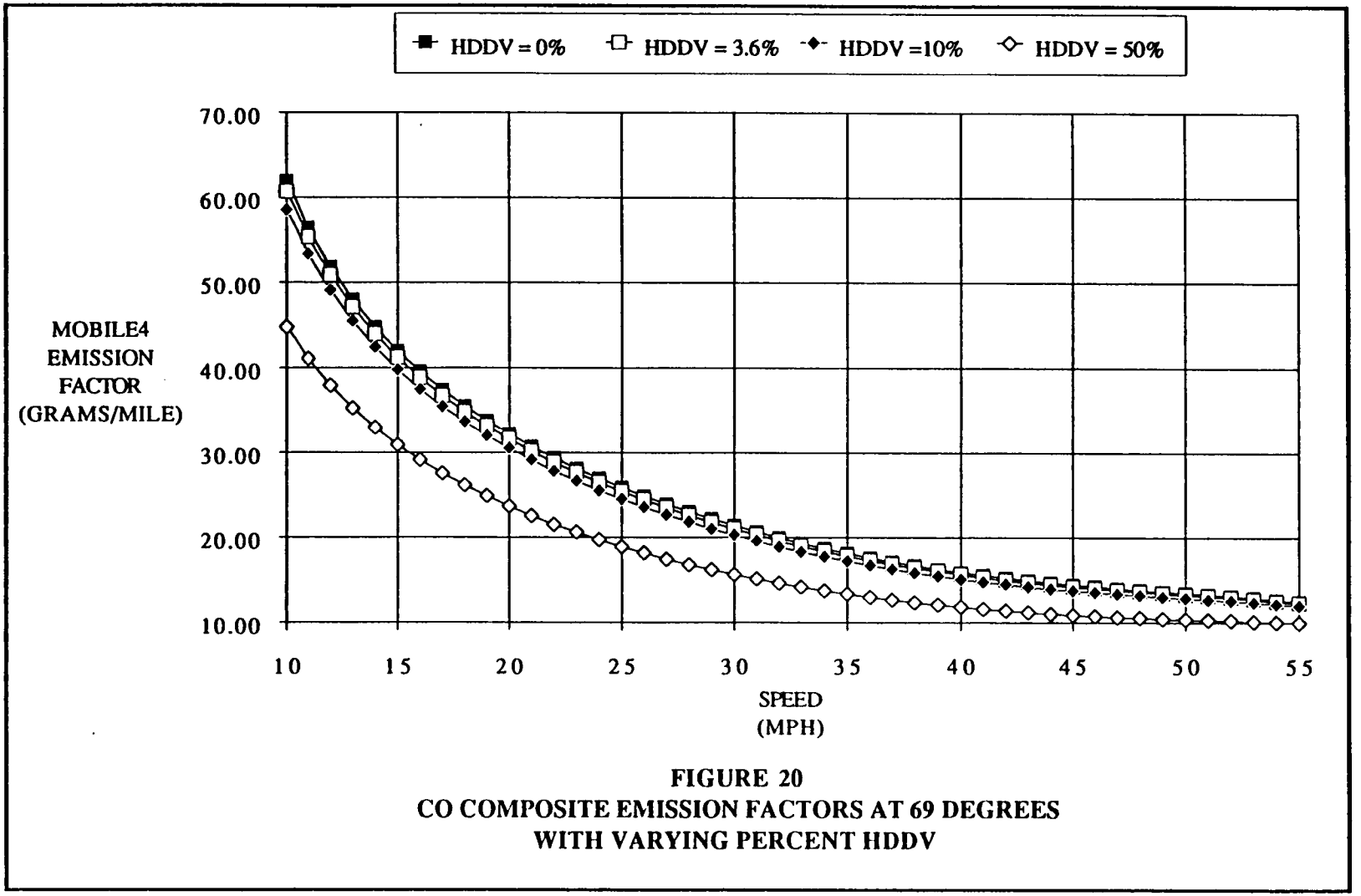


FIGURE 20
CO COMPOSITE EMISSION FACTORS AT 69 DEGREES WITH VARYING PERCENT HDDV

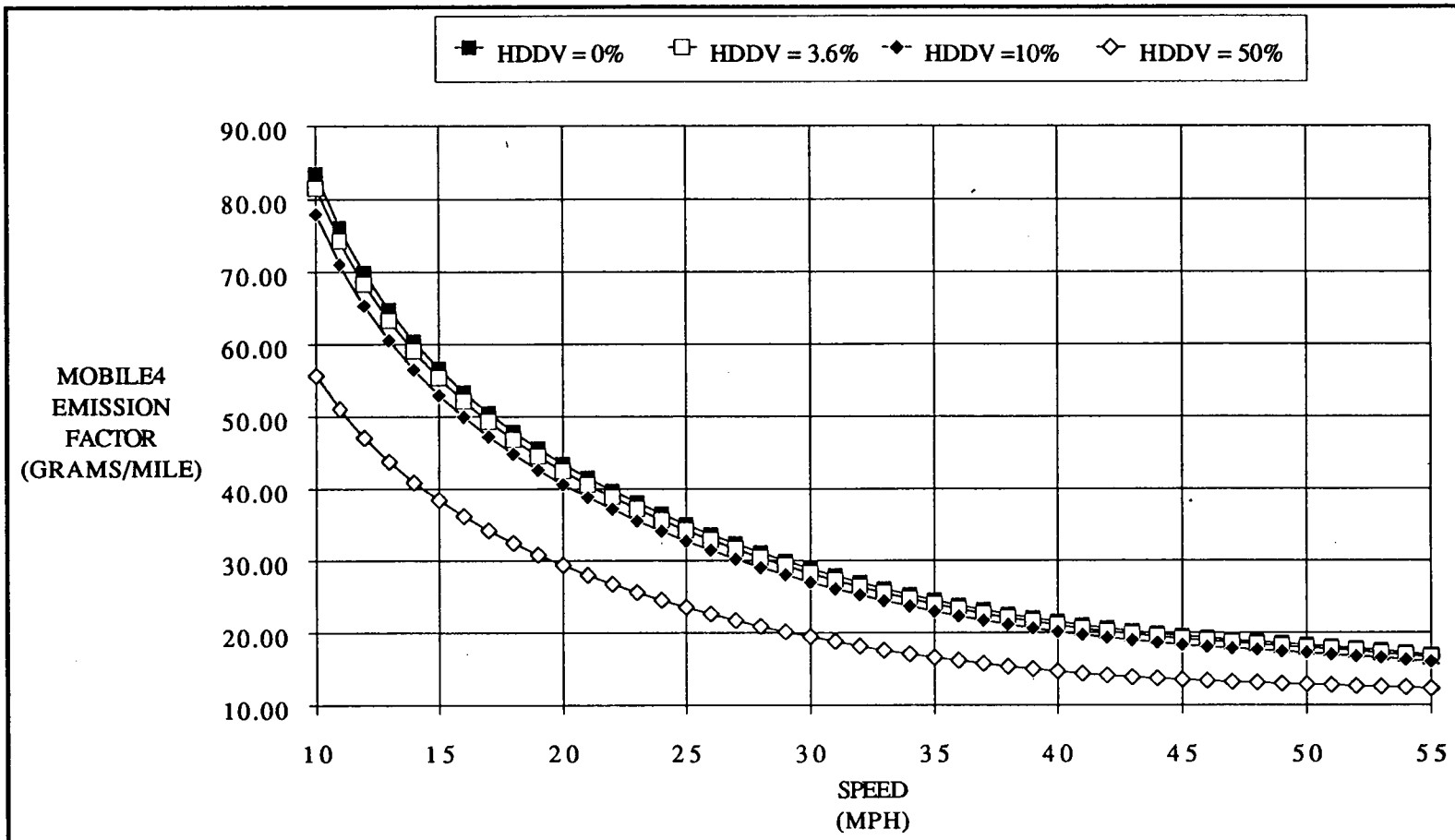


FIGURE 21
CO COMPOSITE EMISSION FACTORS AT 93 DEGREES WITH VARYING PERCENT HDDV

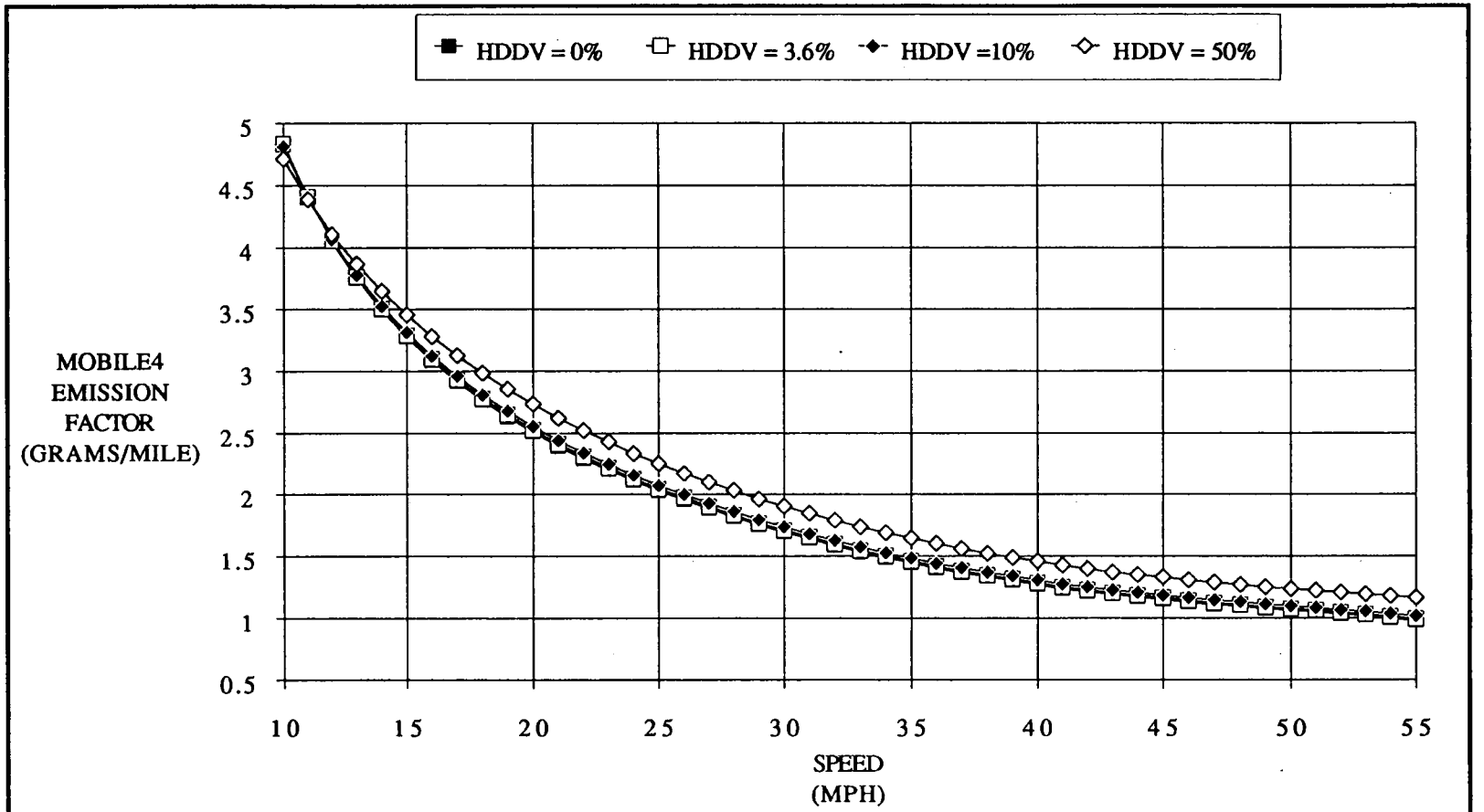


FIGURE 22
HC COMPOSITE EMISSION FACTORS AT 69 DEGREES WITH VARYING PERCENT HDDV

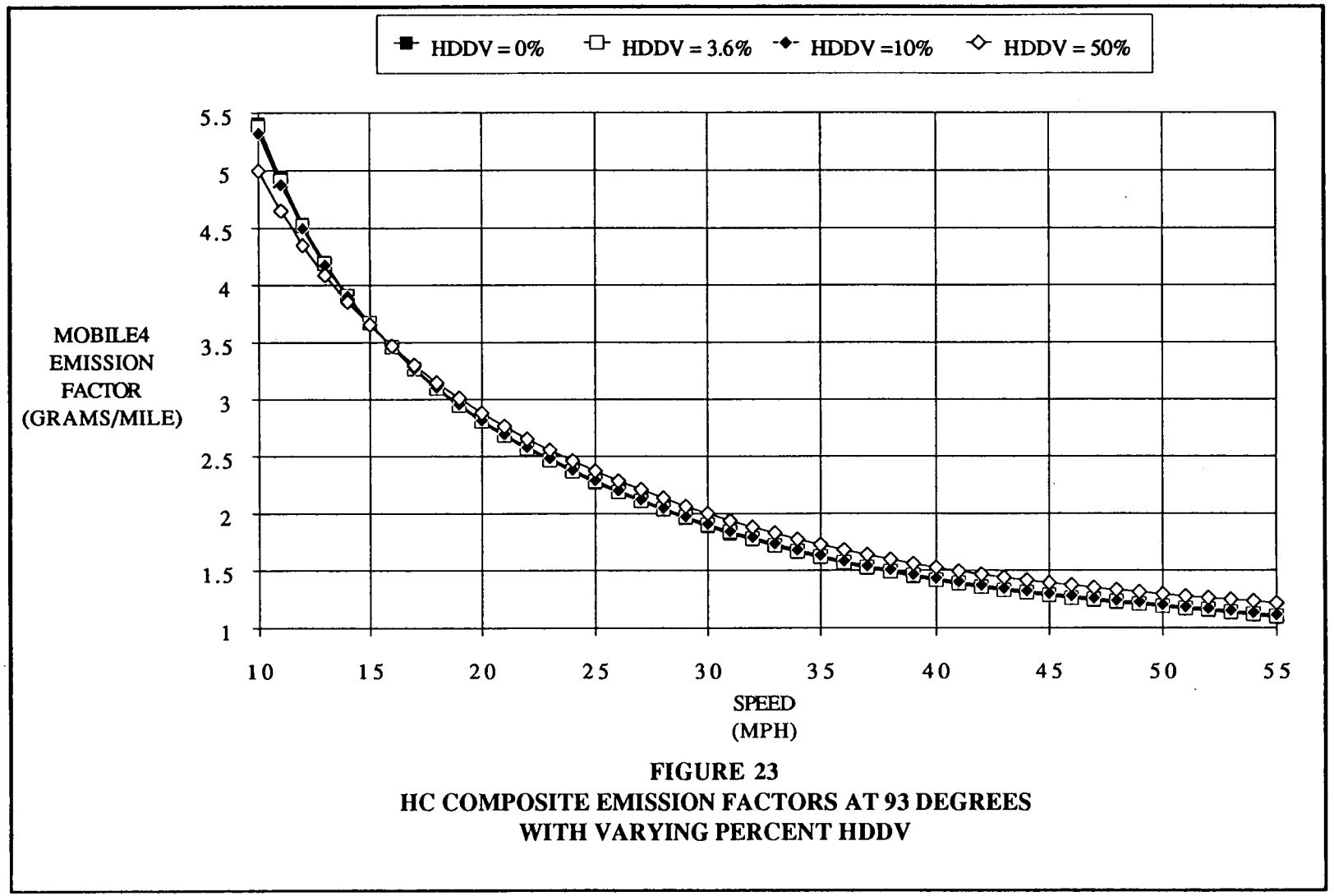


FIGURE 23
HC COMPOSITE EMISSION FACTORS AT 93 DEGREES WITH VARYING PERCENT HDDV

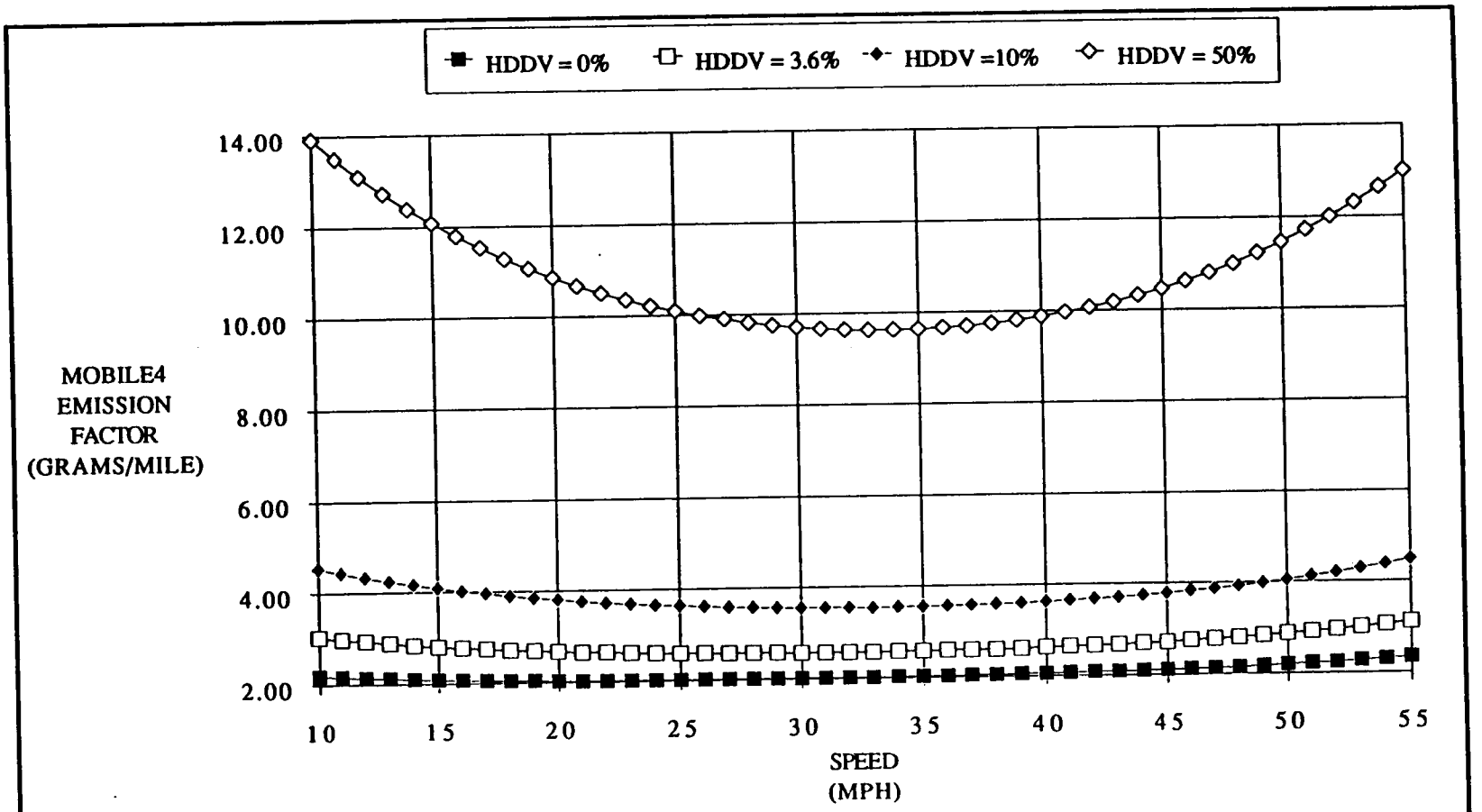


FIGURE 24
NOx COMPOSITE EMISSION FACTORS AT 69 DEGREES WITH VARYING PERCENT HDDV

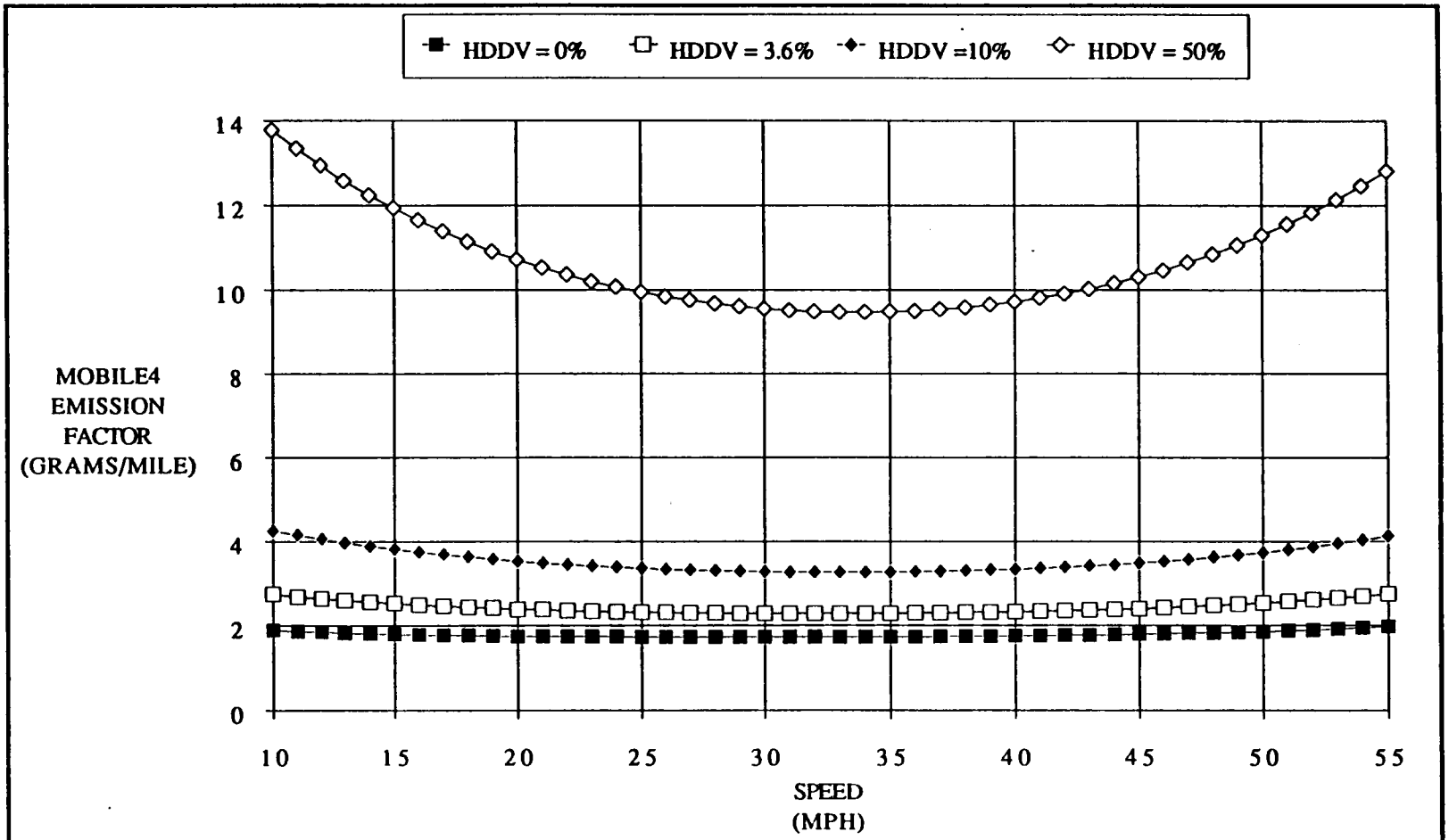


FIGURE 25
NOx COMPOSITE EMISSION FACTORS AT 93 DEGREES WITH VARYING PERCENT HDDV

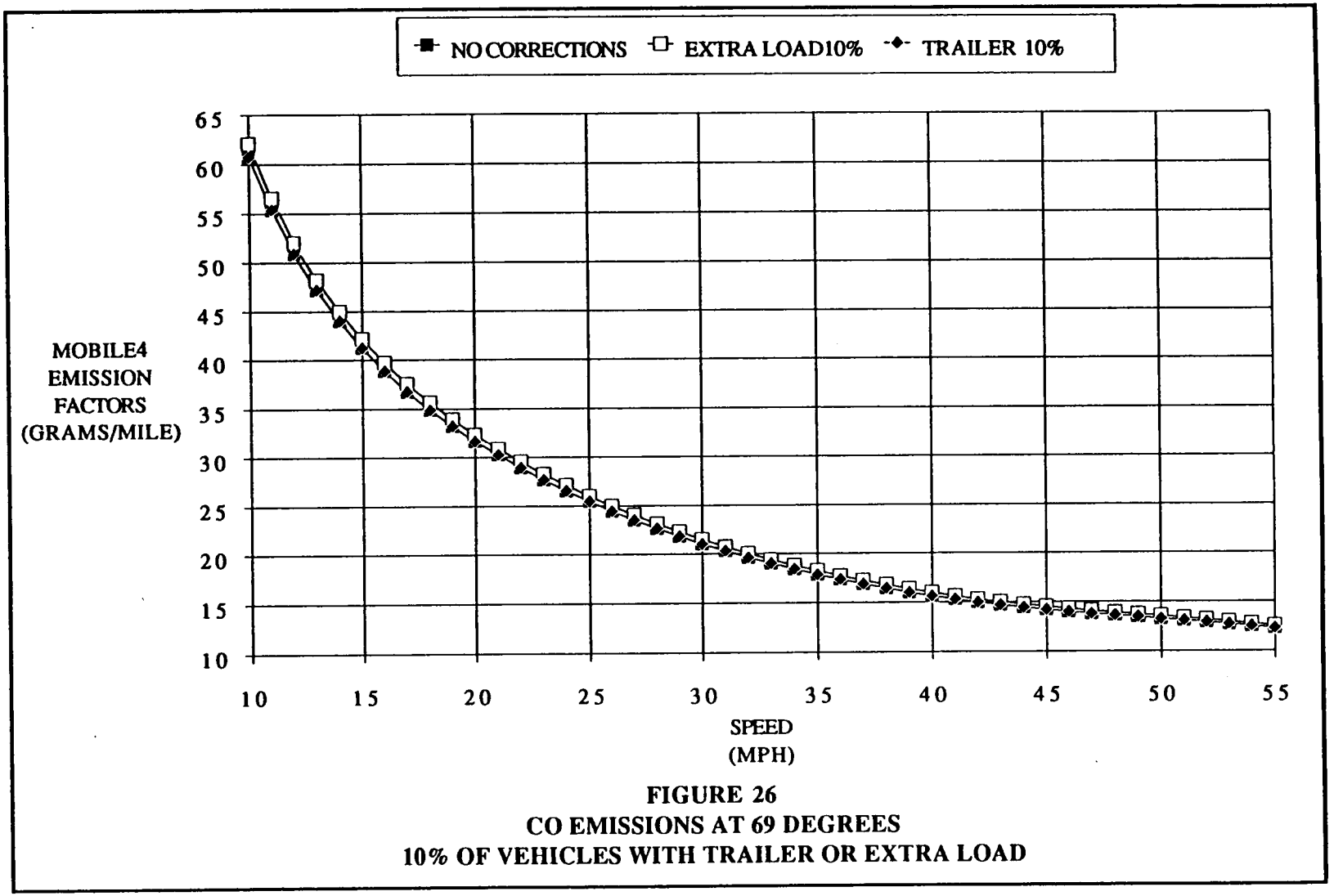


FIGURE 26
CO EMISSIONS AT 69 DEGREES
10% OF VEHICLES WITH TRAILER OR EXTRA LOAD

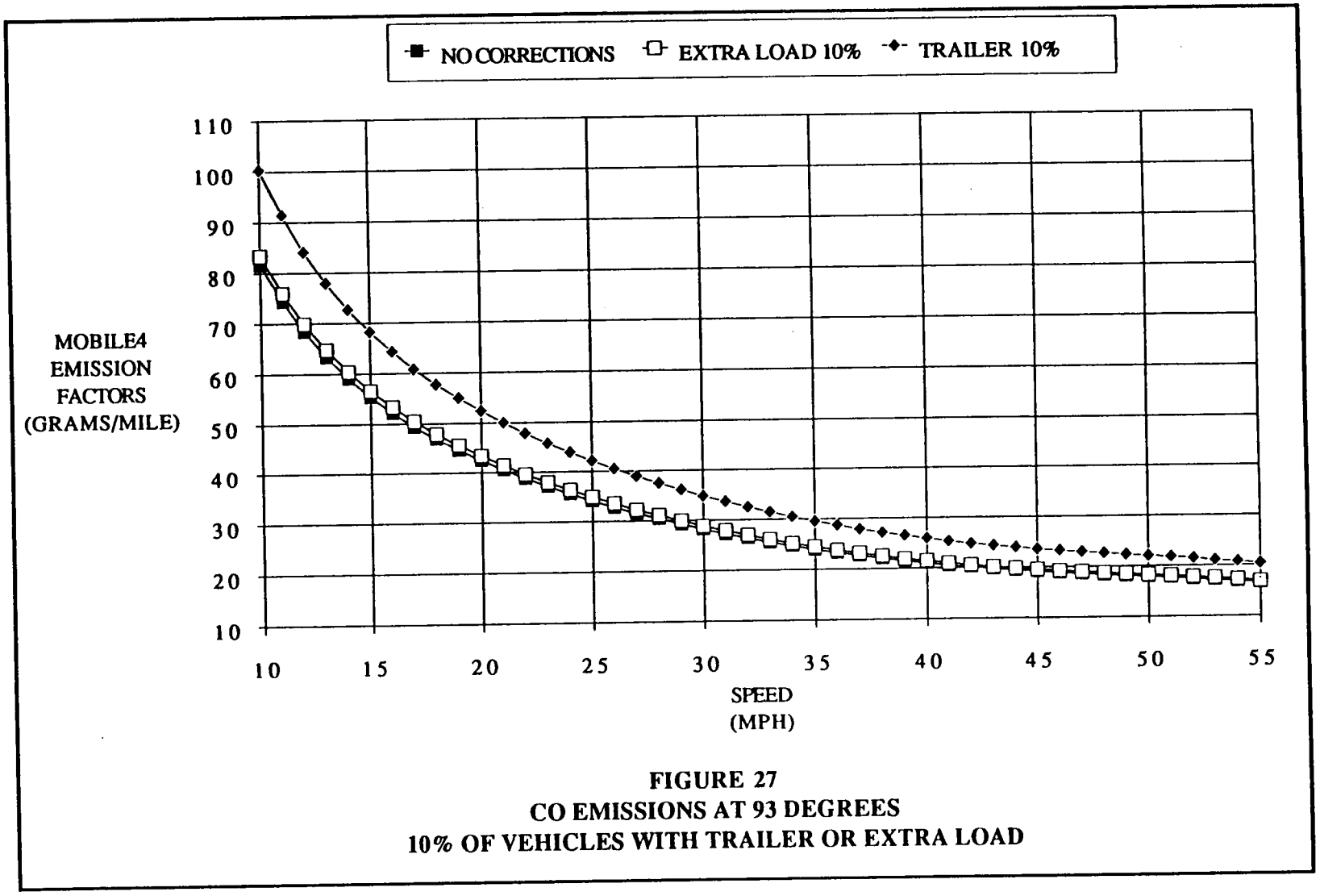


FIGURE 27
CO EMISSIONS AT 93 DEGREES
10% OF VEHICLES WITH TRAILER OR EXTRA LOAD

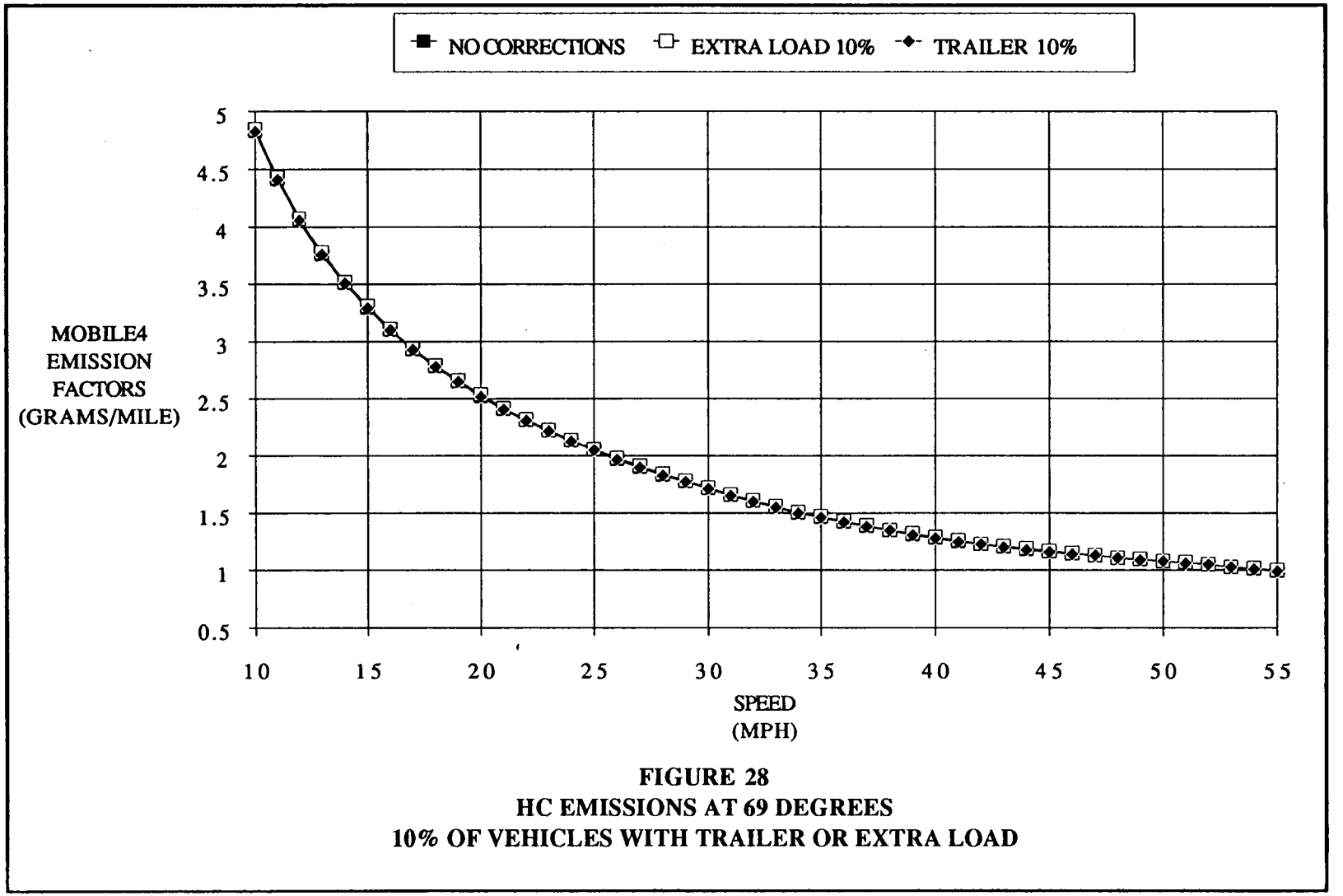


FIGURE 28
HC EMISSIONS AT 69 DEGREES
10% OF VEHICLES WITH TRAILER OR EXTRA LOAD

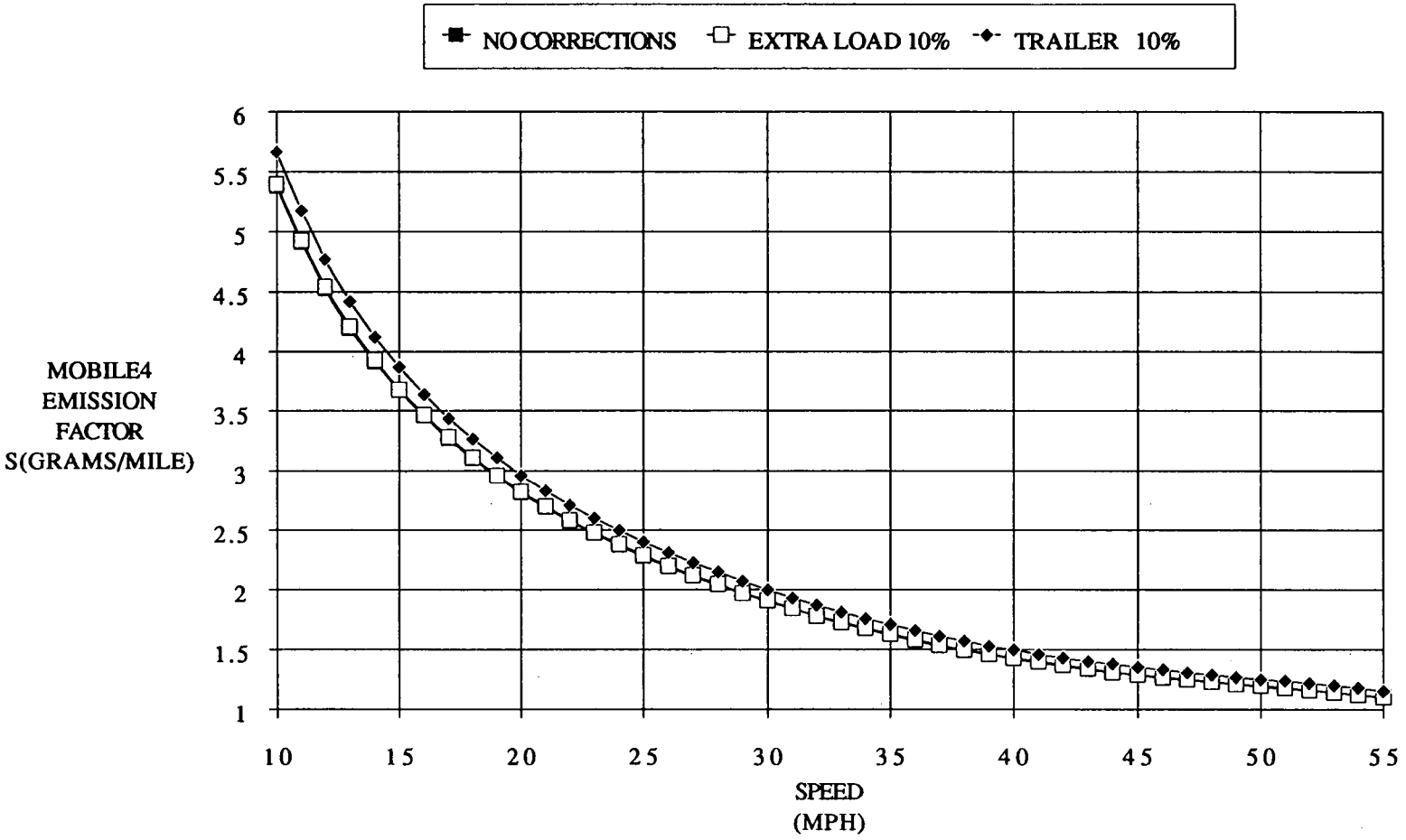


FIGURE 29
HC EMISSIONS AT 93 DEGREES
10% 0F VEHICLES WITH TRAILER OR EXTRA LOAD

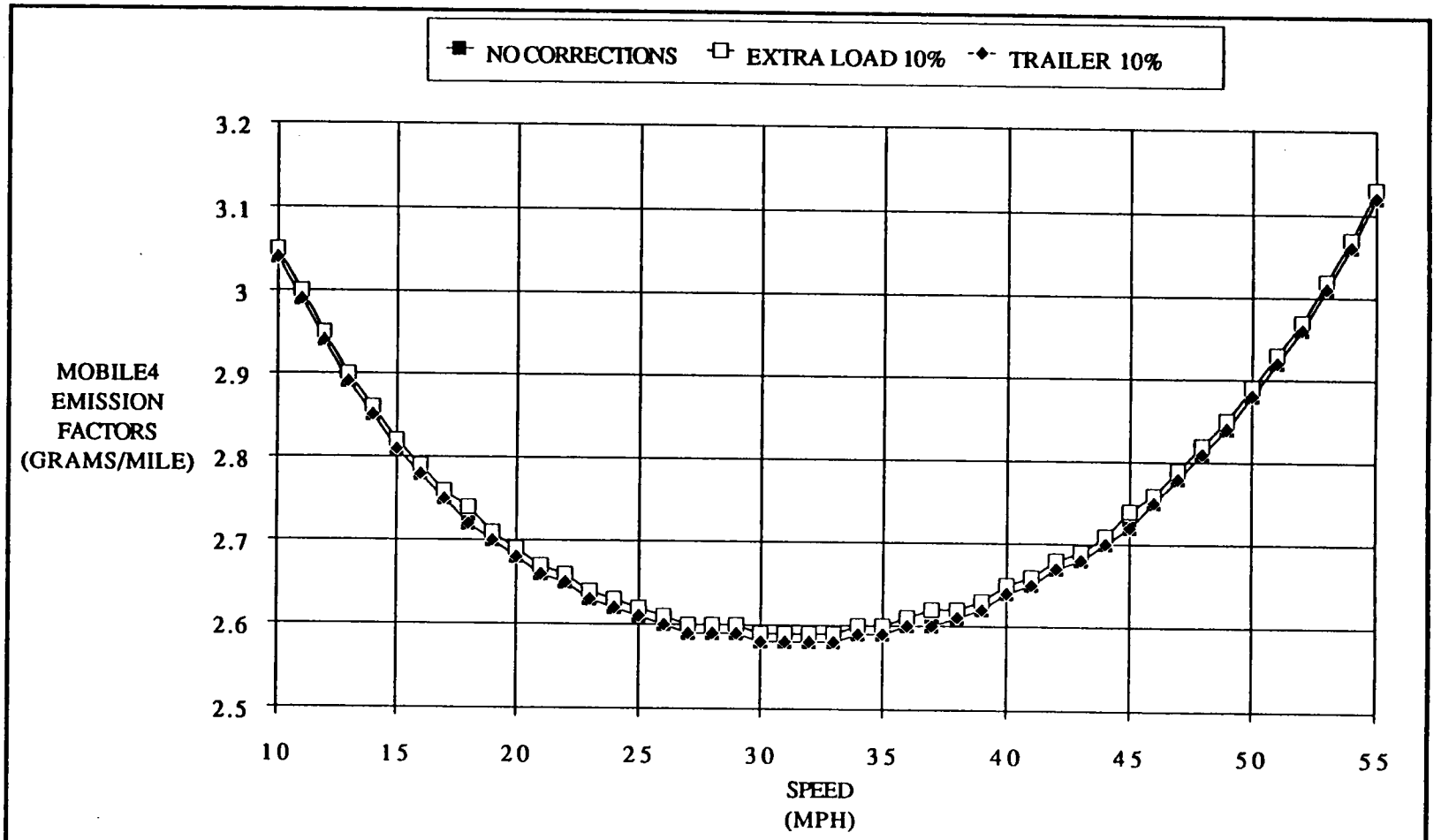


FIGURE 30
NOx EMISSIONS AT 69 DEGREES
10% 0F VEHICLES WITH TRAILER OR EXTRA LOAD

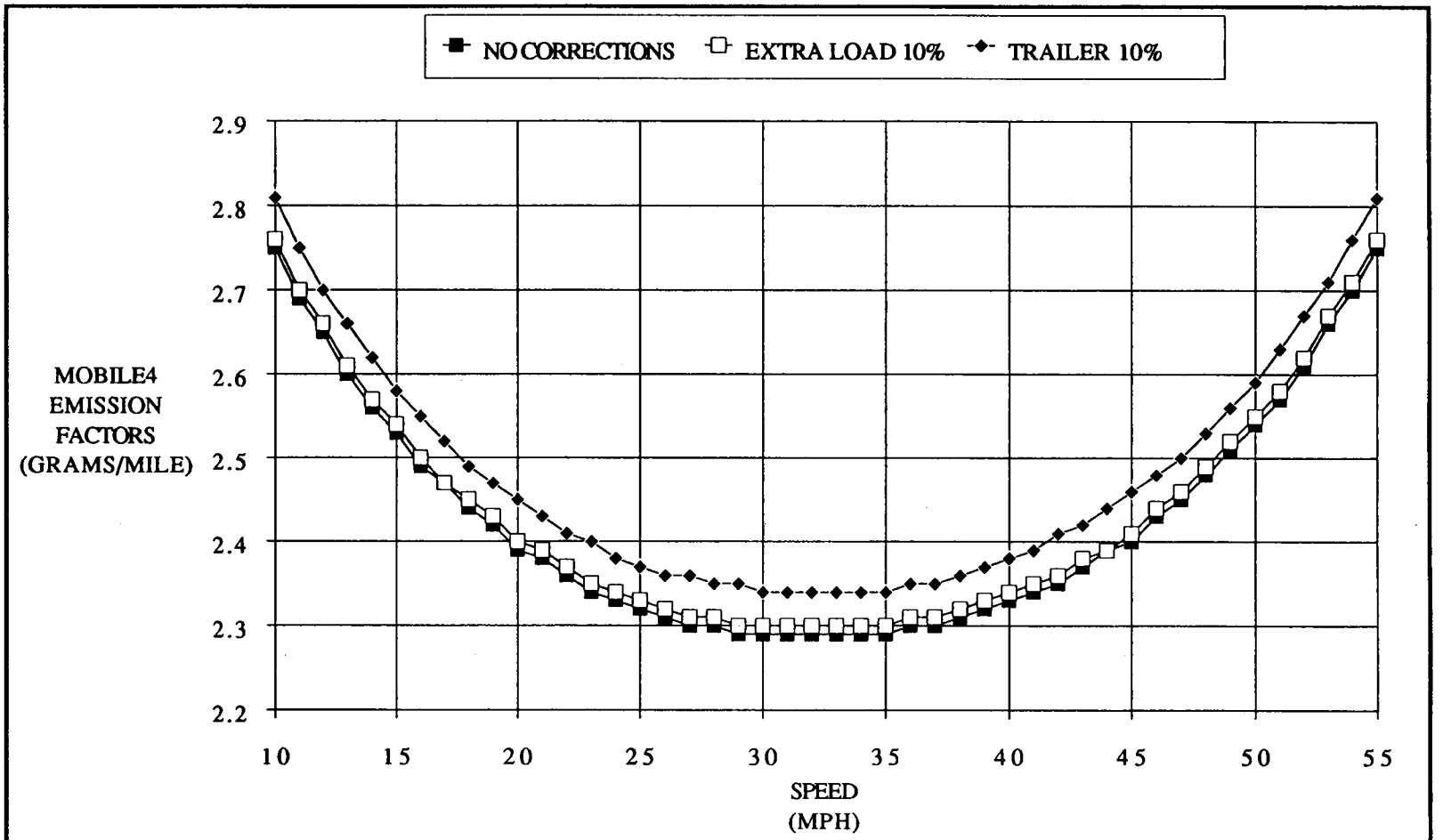


FIGURE 31
NOx EMISSIONS AT 93 DEGREES
10% OF VEHICLES WITH TRAILER OR EXTRA LOAD

ROADWAY TYPE	AREA TYPE		
	Urban Core	Urban Fringe	Rural
Interstate	Time of Day*		
Principal Arterial			
Minor Arterial			
Collector			
Local			

*Each of these cells are further categorized by time of day.

FIGURE 32
CATEGORIES FOR TRAFFIC PARAMETER PROFILES

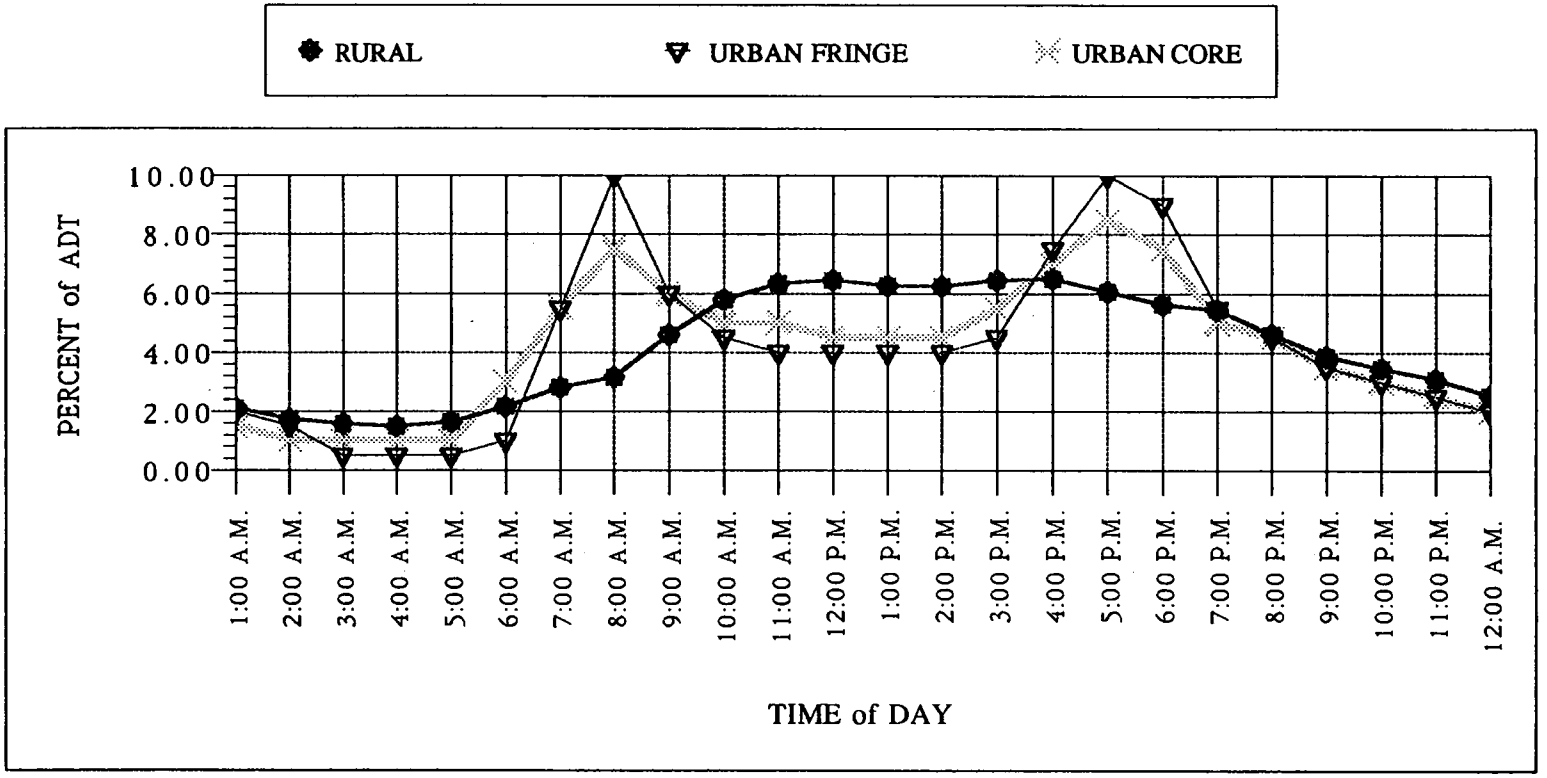


FIGURE 33
TOTAL TRAFFIC DISTRIBUTION BY HOUR FOR INTERSTATES

Source: Rural Interstates-"Continious Automatic Traffic Recorder (ATR) Monthly Summaries." Tennessee Department of Transporation, 1988. Urban Interstates-"Quick Response Urban Travel Estimation Techniques and Transferable Parameter's Users Guide" National Cooperative Highway Research Program Report 187.

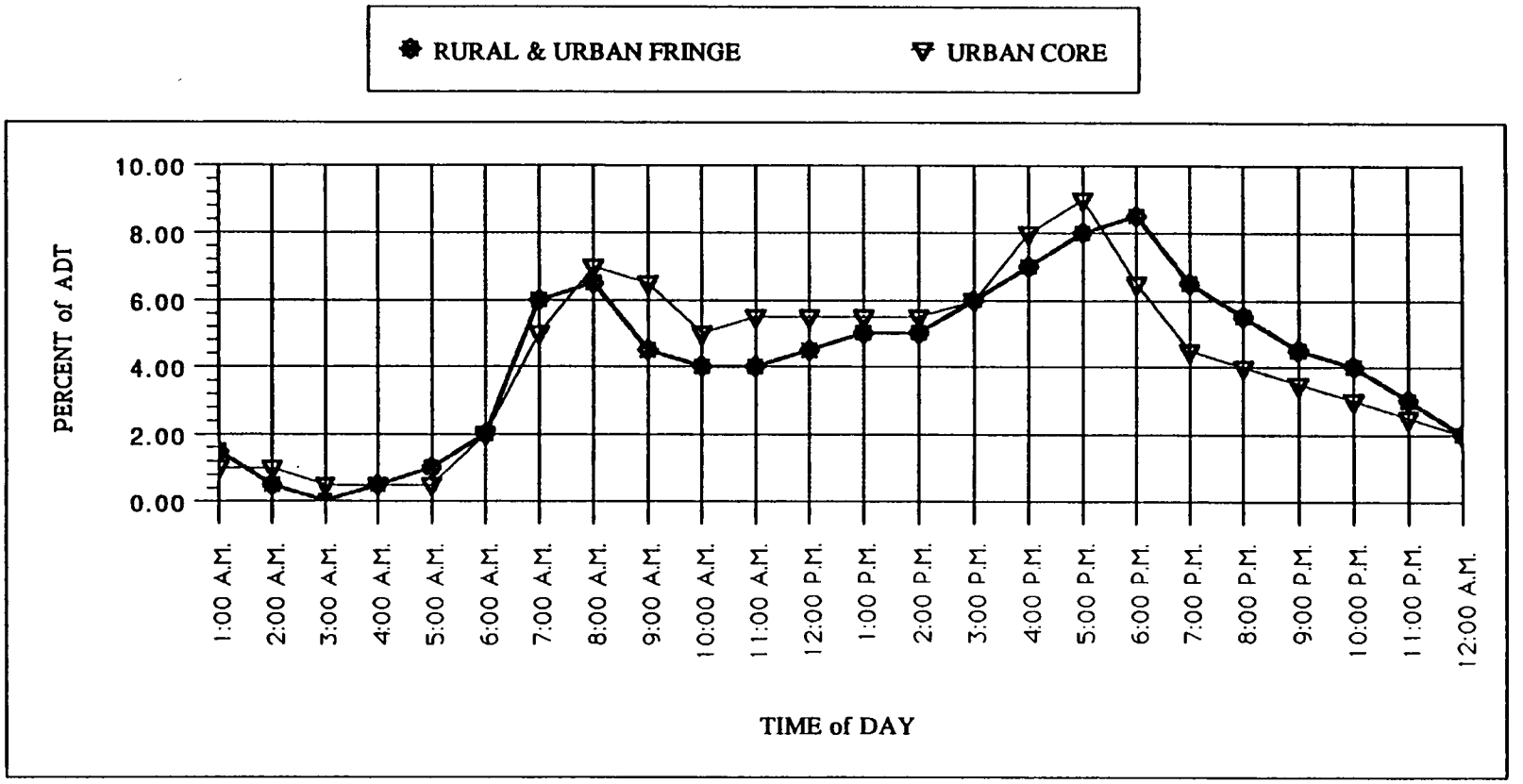


FIGURE 34
TOTAL TRAFFIC DISTRIBUTION BY HOUR FOR MAJOR AND MINOR ARTERIALS

Source: "Quick Response Urban Travel Estimation Techniques and Transferable Parameter's Users Guide" National Cooperative Highway Research Program Report 187.

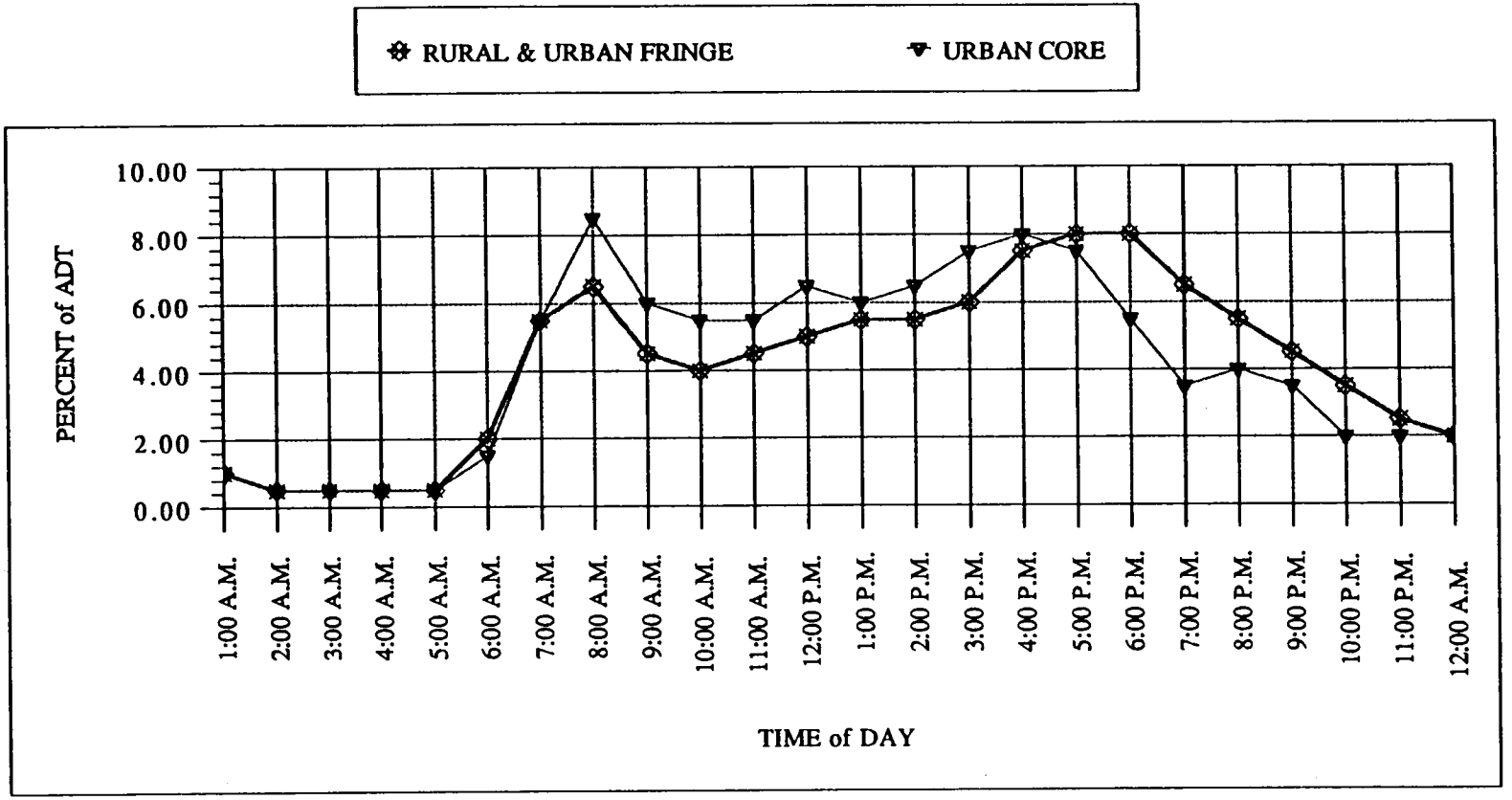


FIGURE 35
TOTAL TRAFFIC DISTRIBUTION BY HOUR FOR COLLECTORS AND LOCALS

Source: "Quick Response Urban Travel Estimation Techniques and Transferable Parameter's Users Guide" National Cooperative Highway Research Program Report 187.

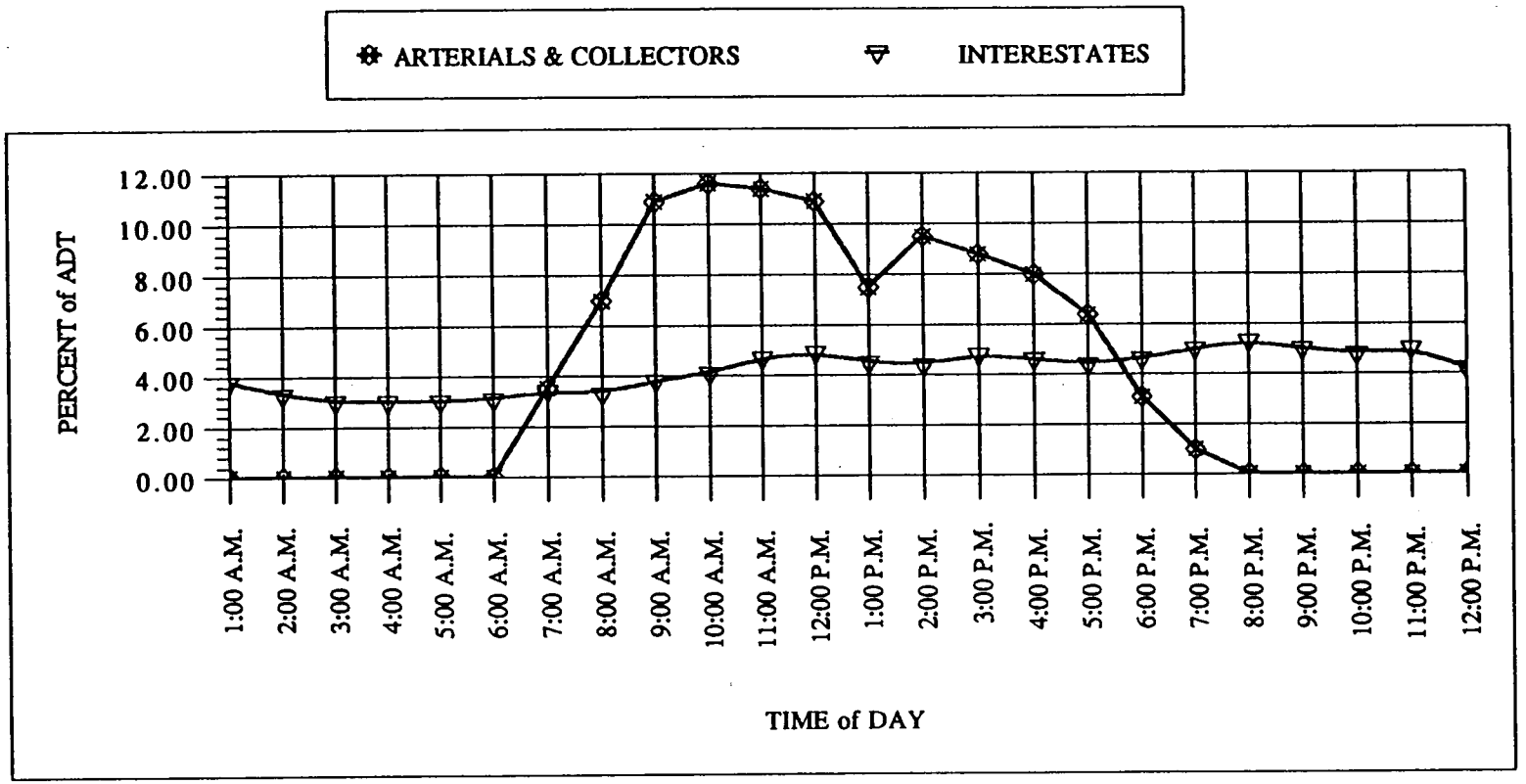


FIGURE 36
HOURLY DISTRIBUTION OF LARGE TRUCKS FOR URBAN AND RURAL ROADWAYS

Source: 1) "Travel Activity by Vehicle Type and Functional Class". Tennessee Department of Transporation, Figure II-4, 1986. 2) "Continious Automatic Traffic Recorder (ATR) Monthly Summaries." Tennessee Department of Transporation, 1988.

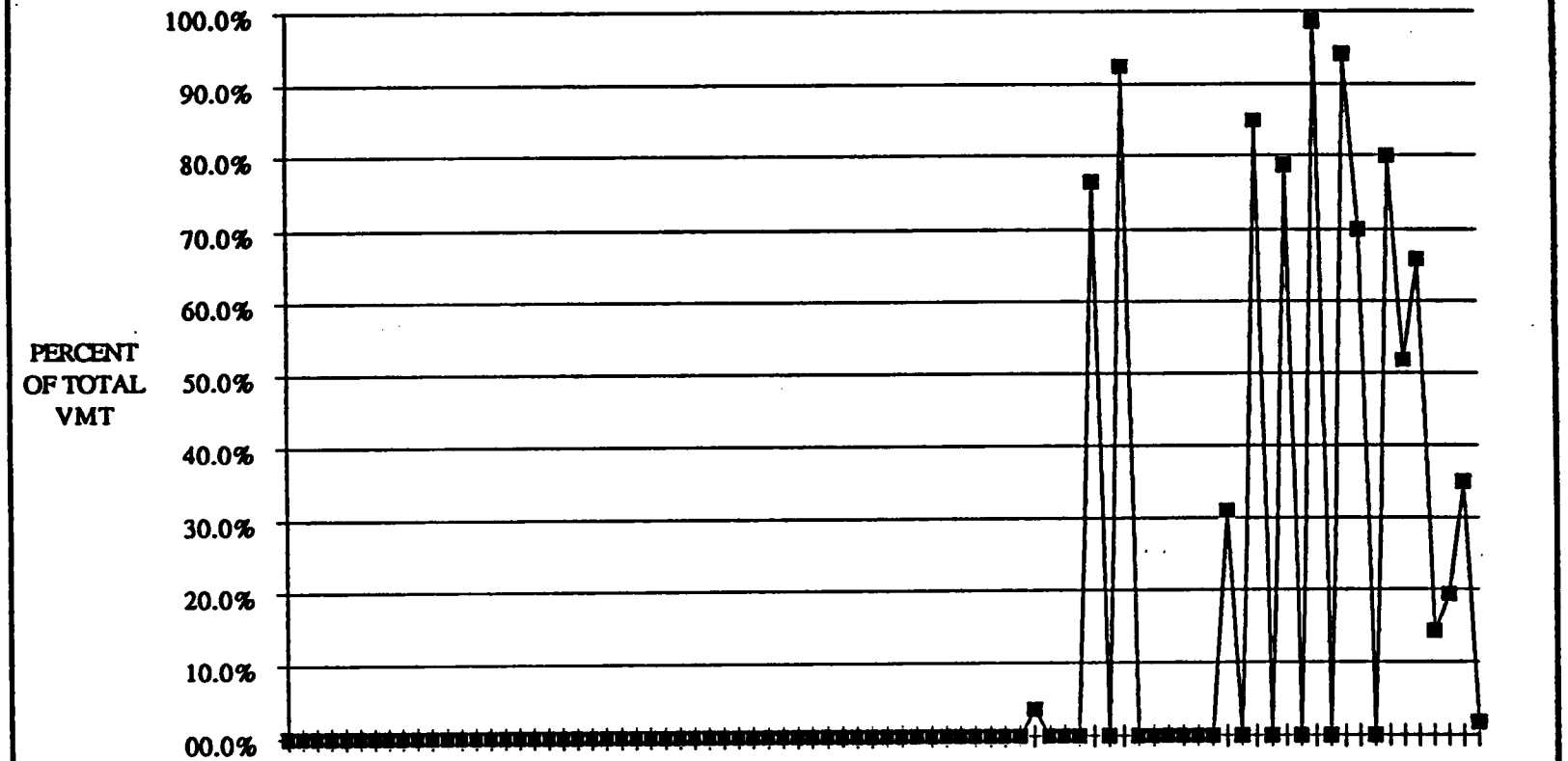


FIGURE 37
PERCENT OF TOTAL VMT BY GRID
ON INTERSTATES IN RUTHERFORD COUNTY

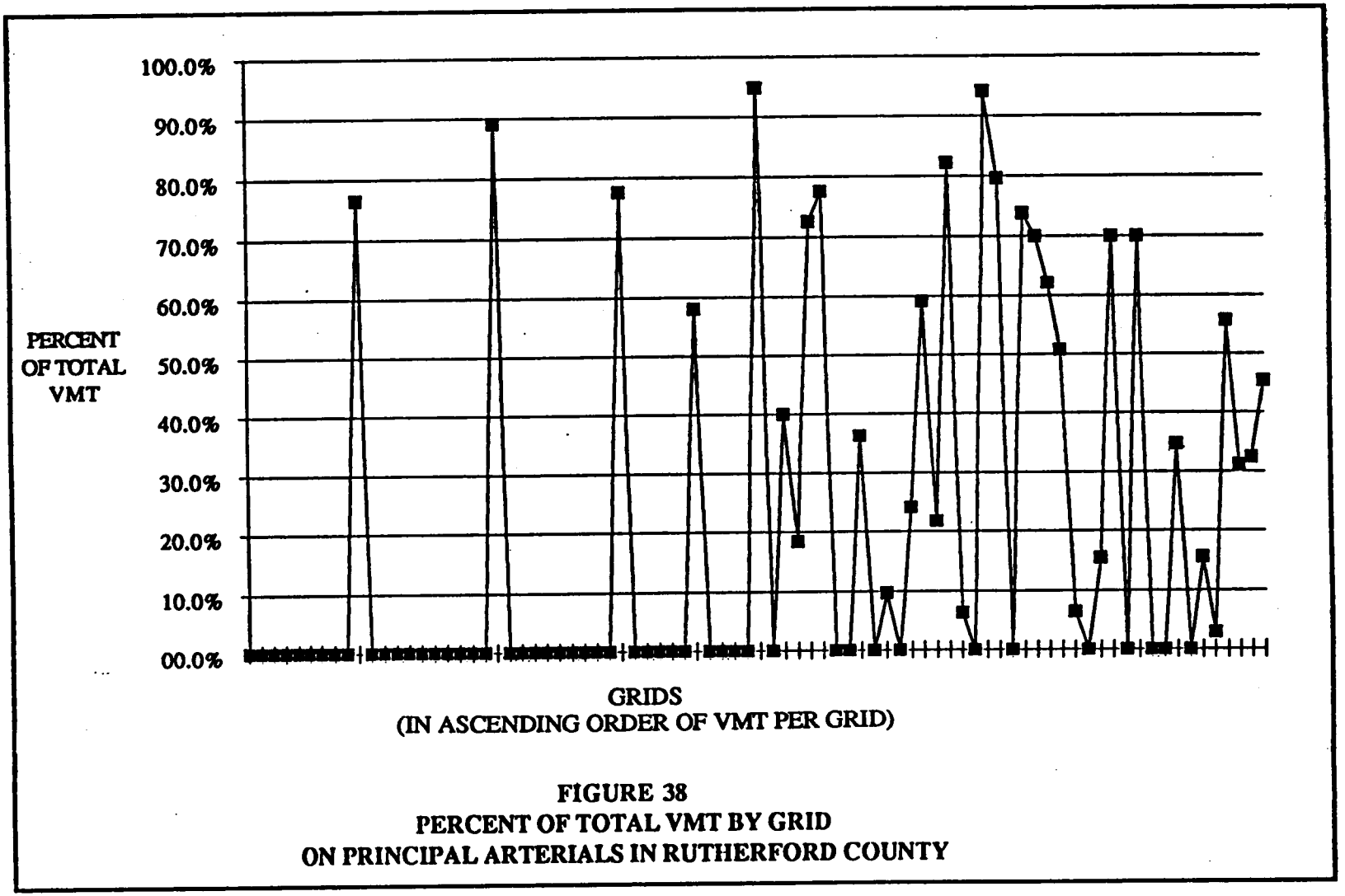


FIGURE 38
PERCENT OF TOTAL VMT BY GRID
ON PRINCIPAL ARTERIALS IN RUTHERFORD COUNTY

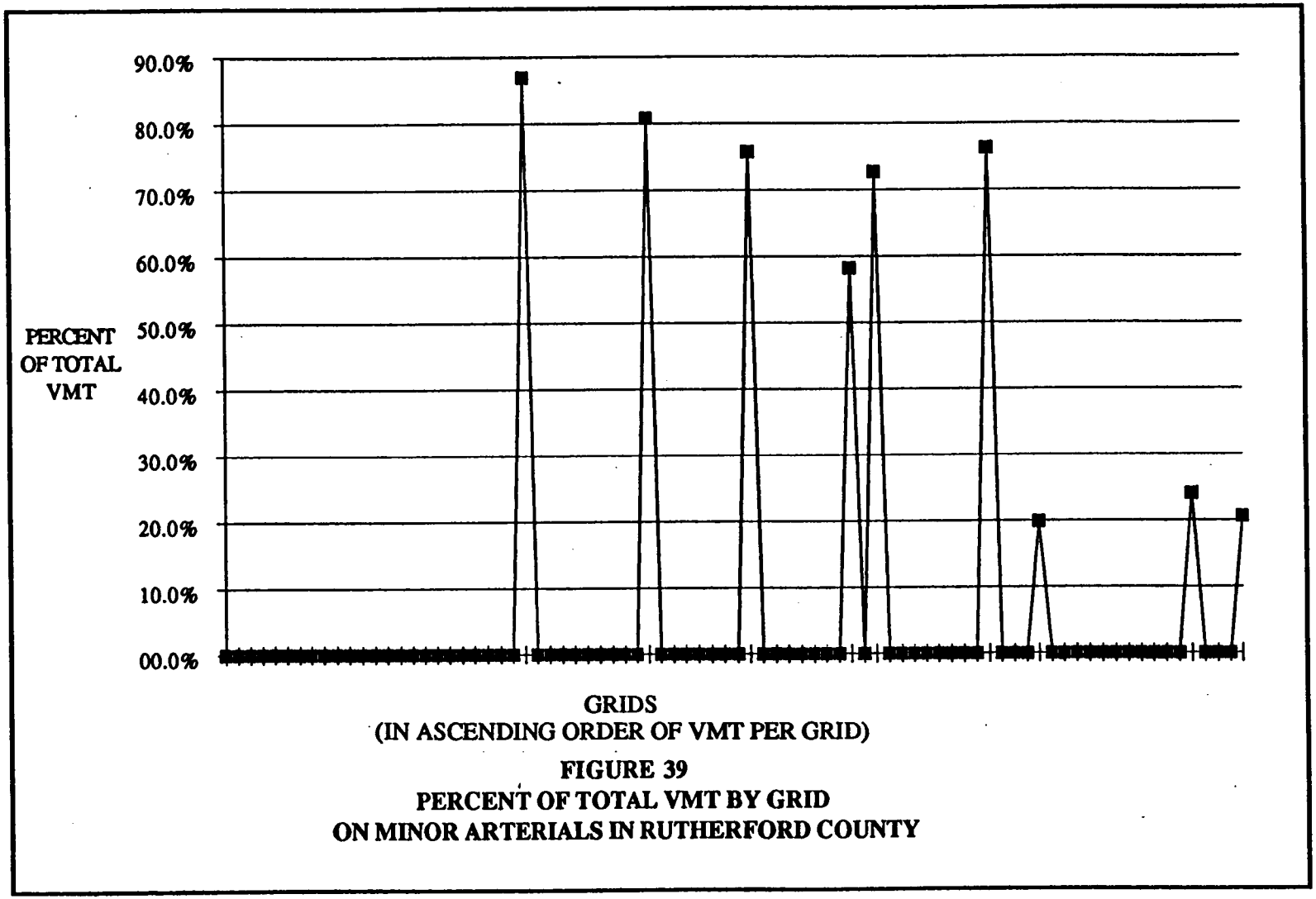


FIGURE 39
PERCENT OF TOTAL VMT BY GRID
ON MINOR ARTERIALS IN RUTHERFORD COUNTY

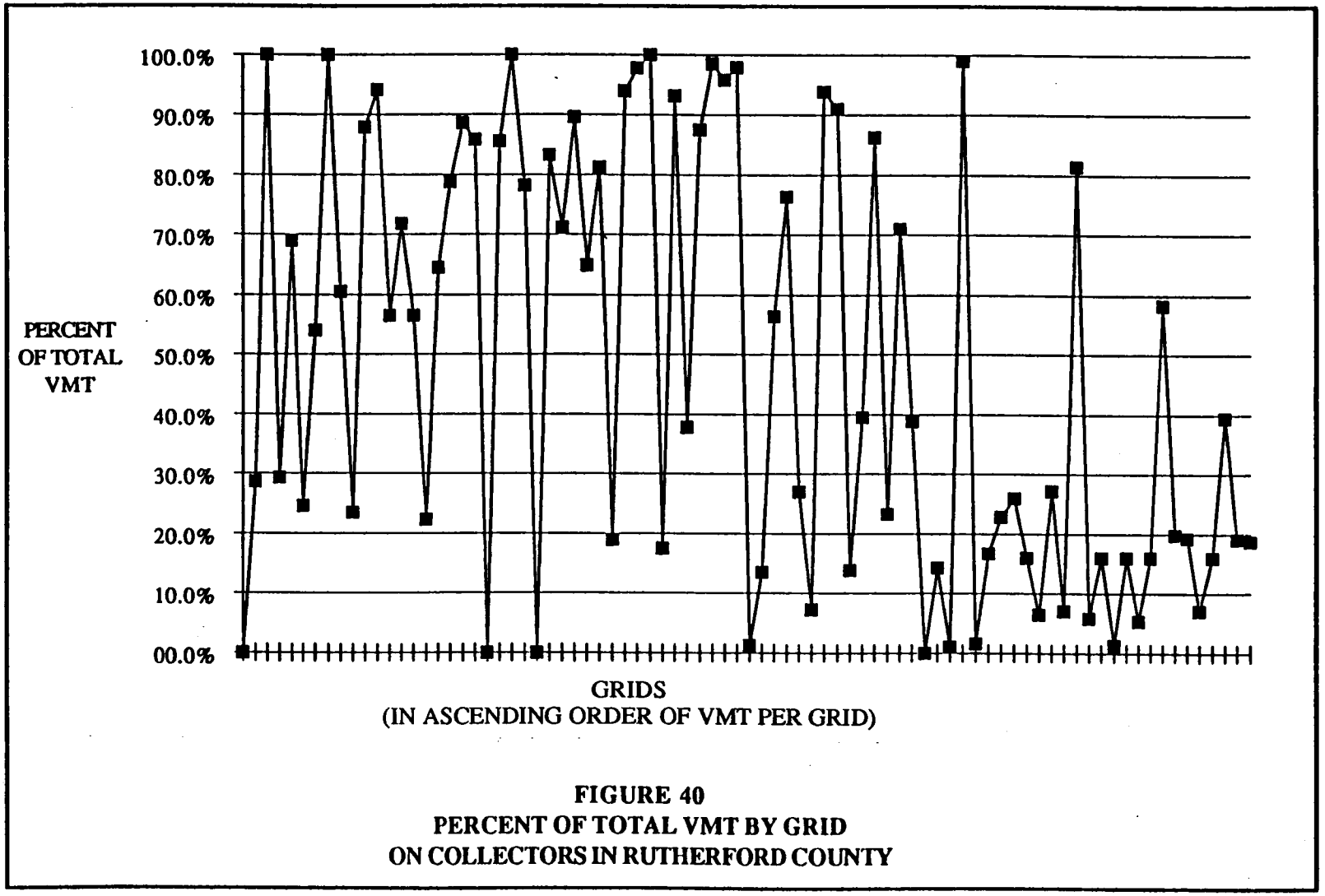


FIGURE 40
PERCENT OF TOTAL VMT BY GRID
ON COLLECTORS IN RUTHERFORD COUNTY

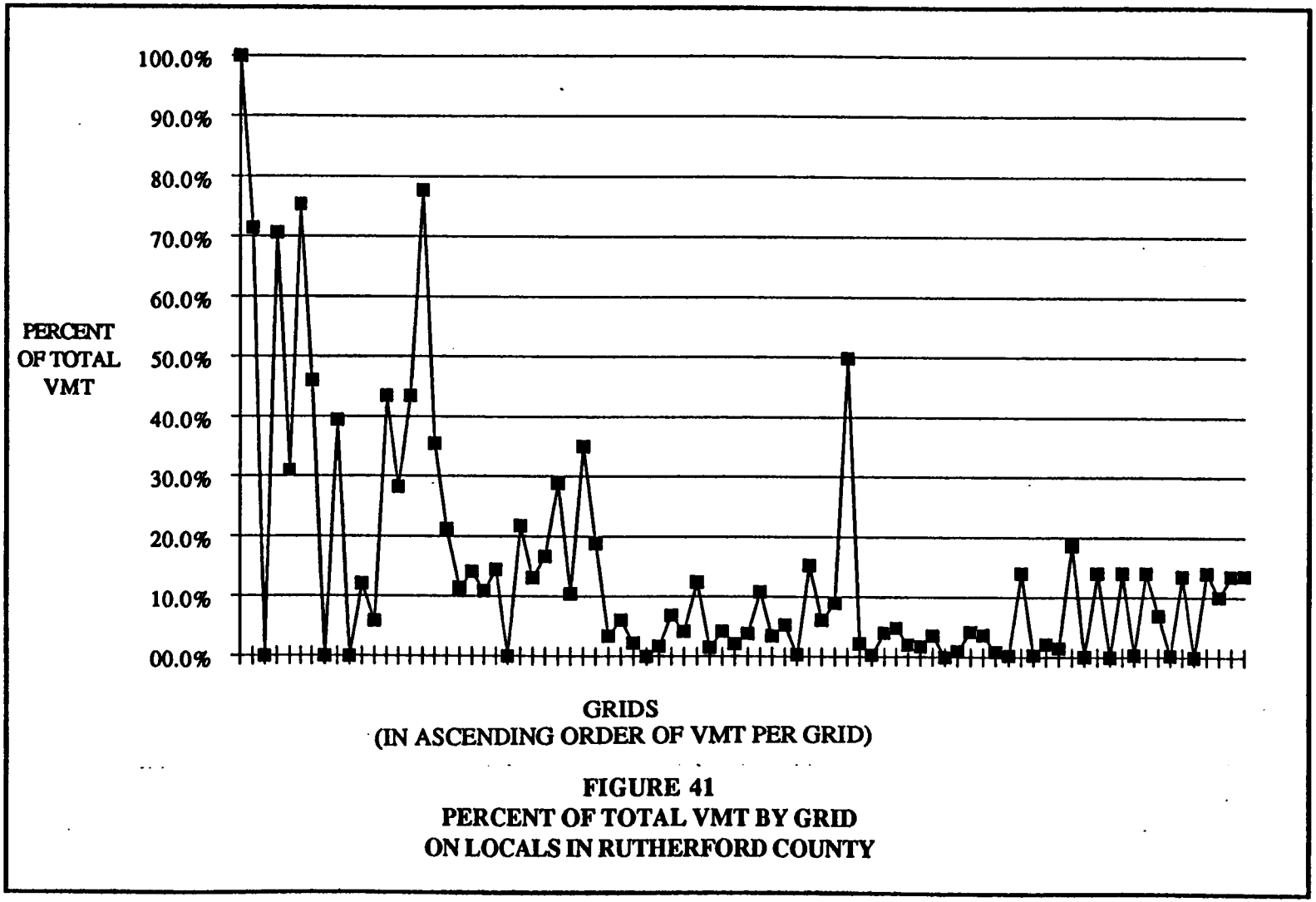


FIGURE 41
PERCENT OF TOTAL VMT BY GRID
ON LOCALS IN RUTHERFORD COUNTY

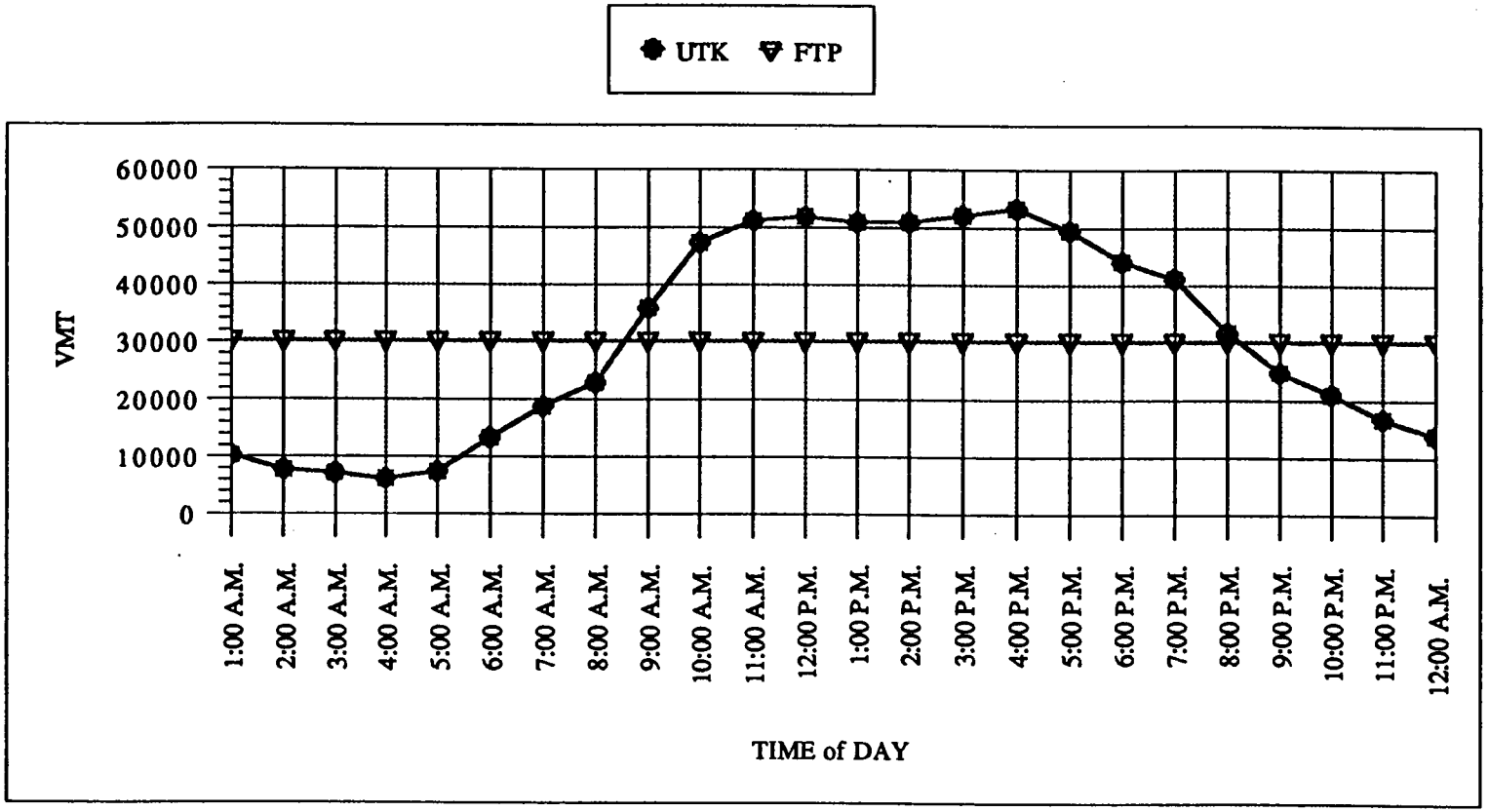


FIGURE 42
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY INTERSTATES
IN RURAL AREAS

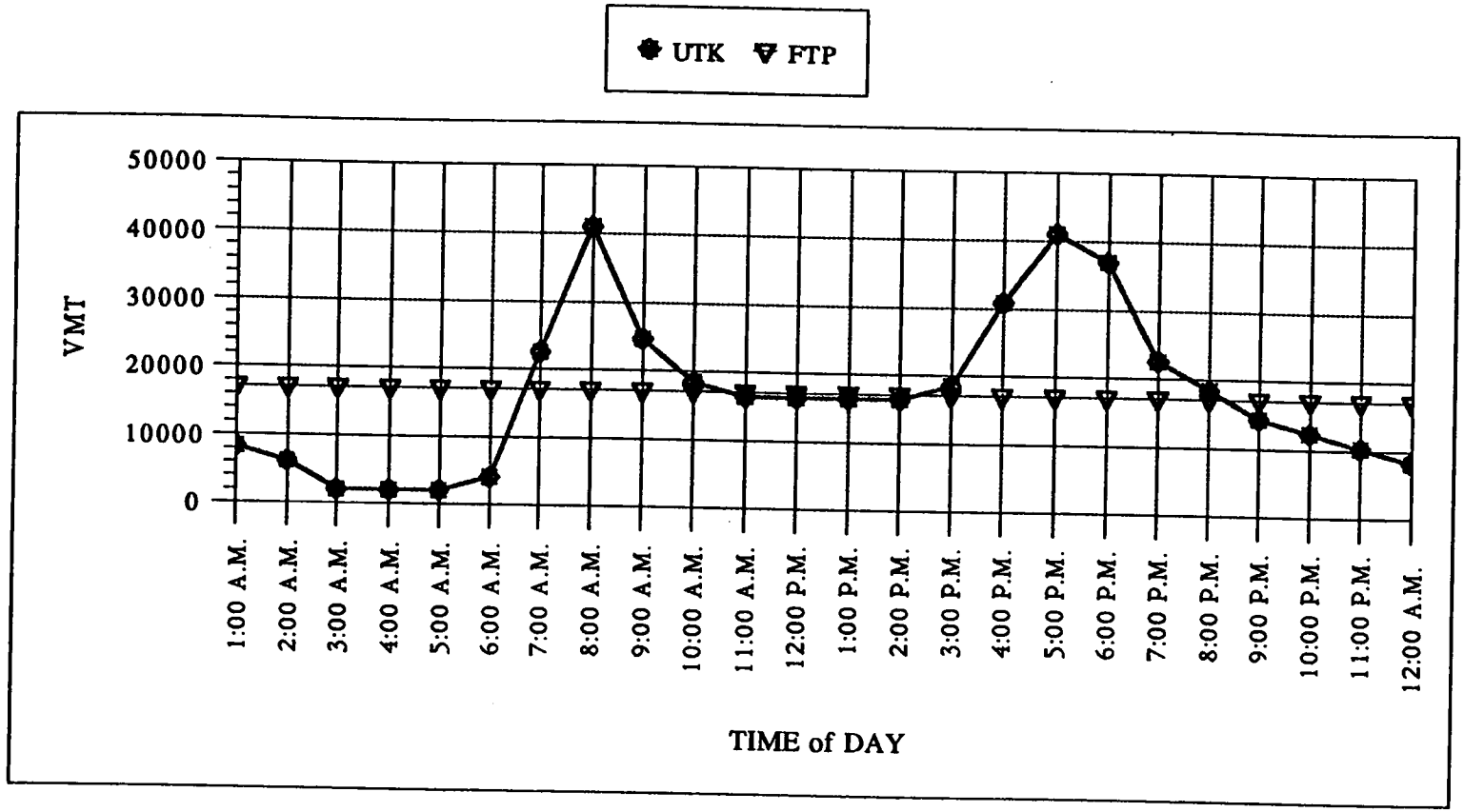


FIGURE 43
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY INTERSTATES
IN THE URBAN FRINGE

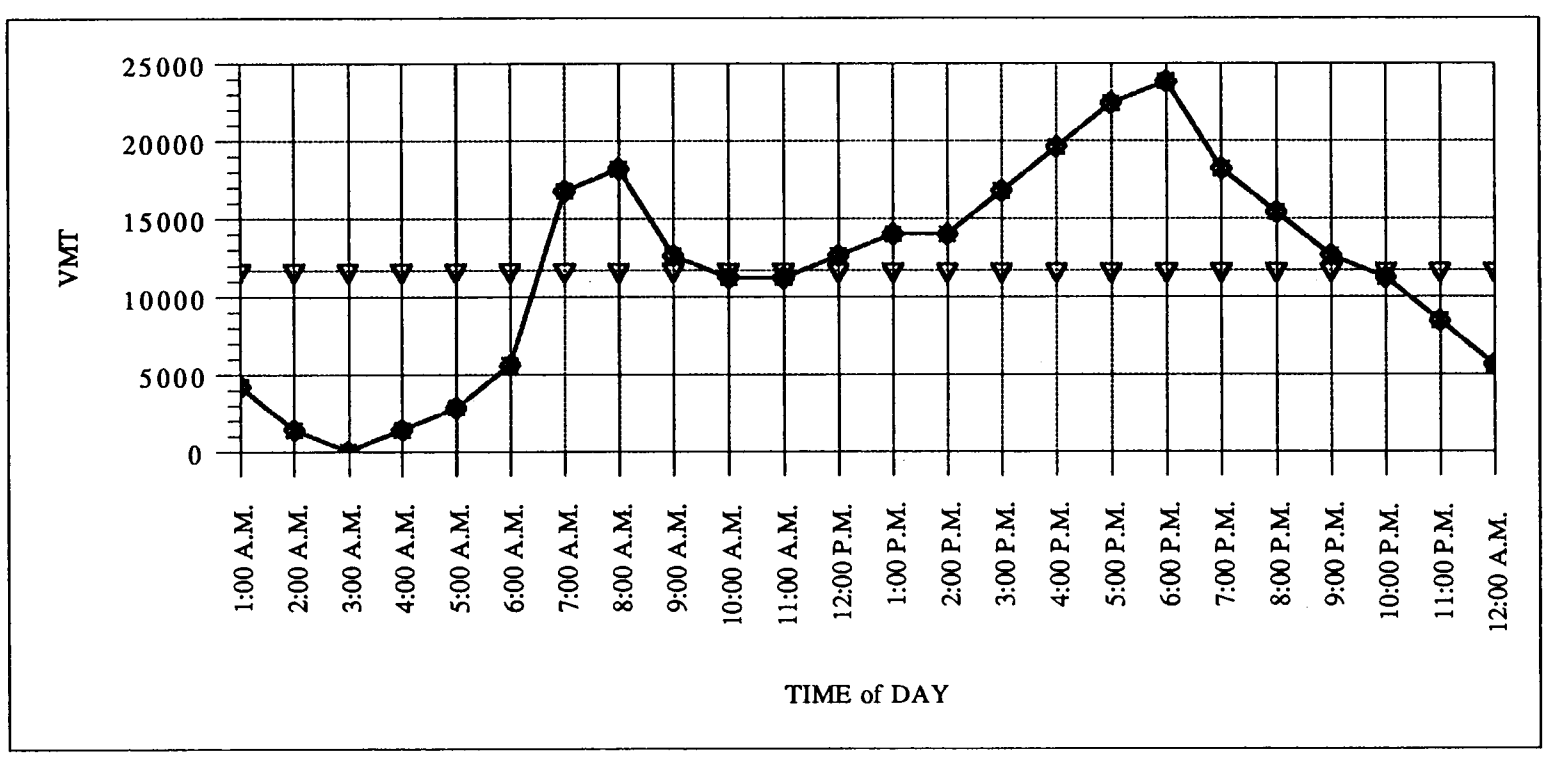


FIGURE 44
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY PRINCIPAL ARTERIALS
IN RURAL AREAS

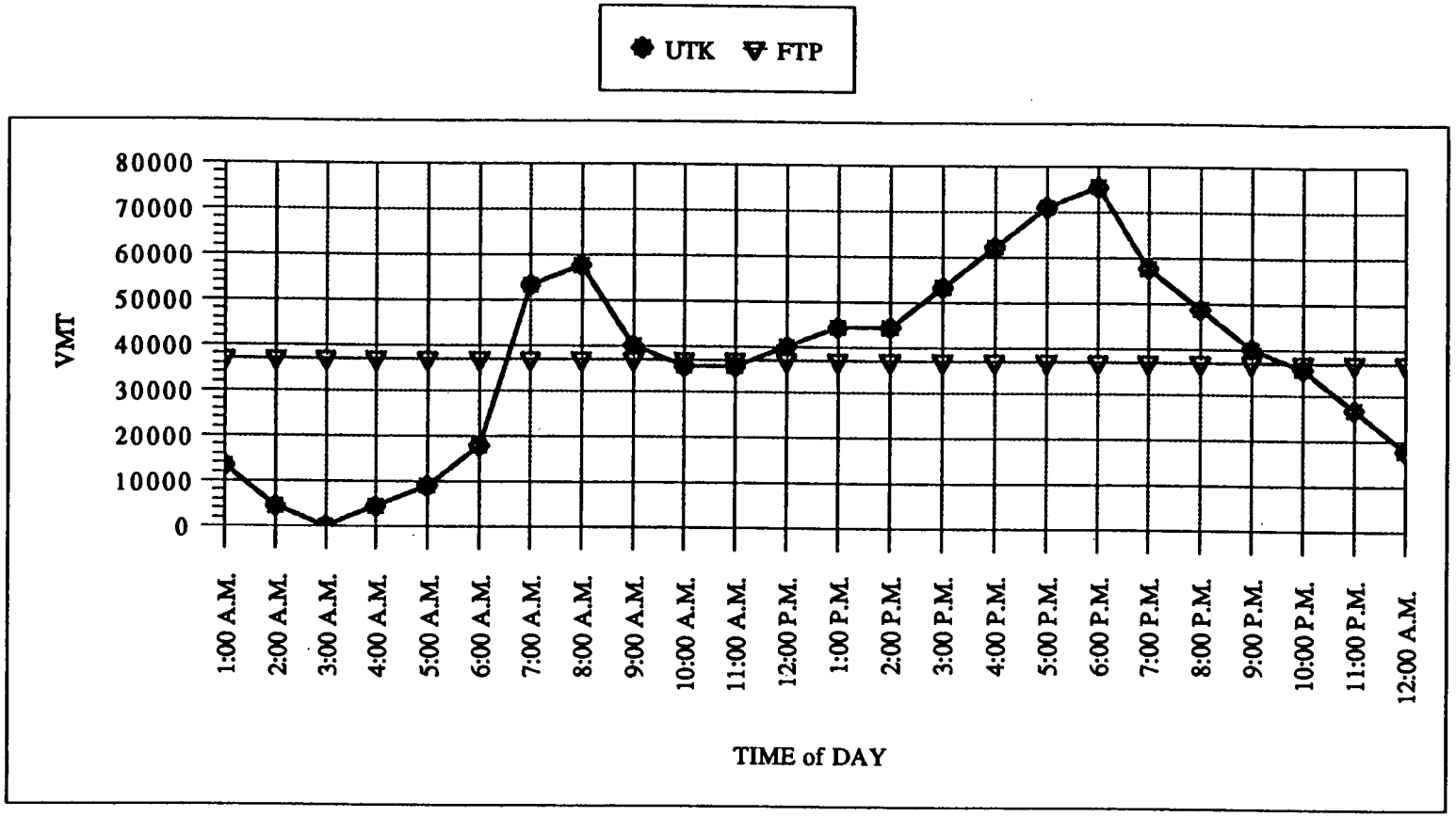


FIGURE 45
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY PRINCIPAL ARTERIALS
IN THE URBAN FRINGE

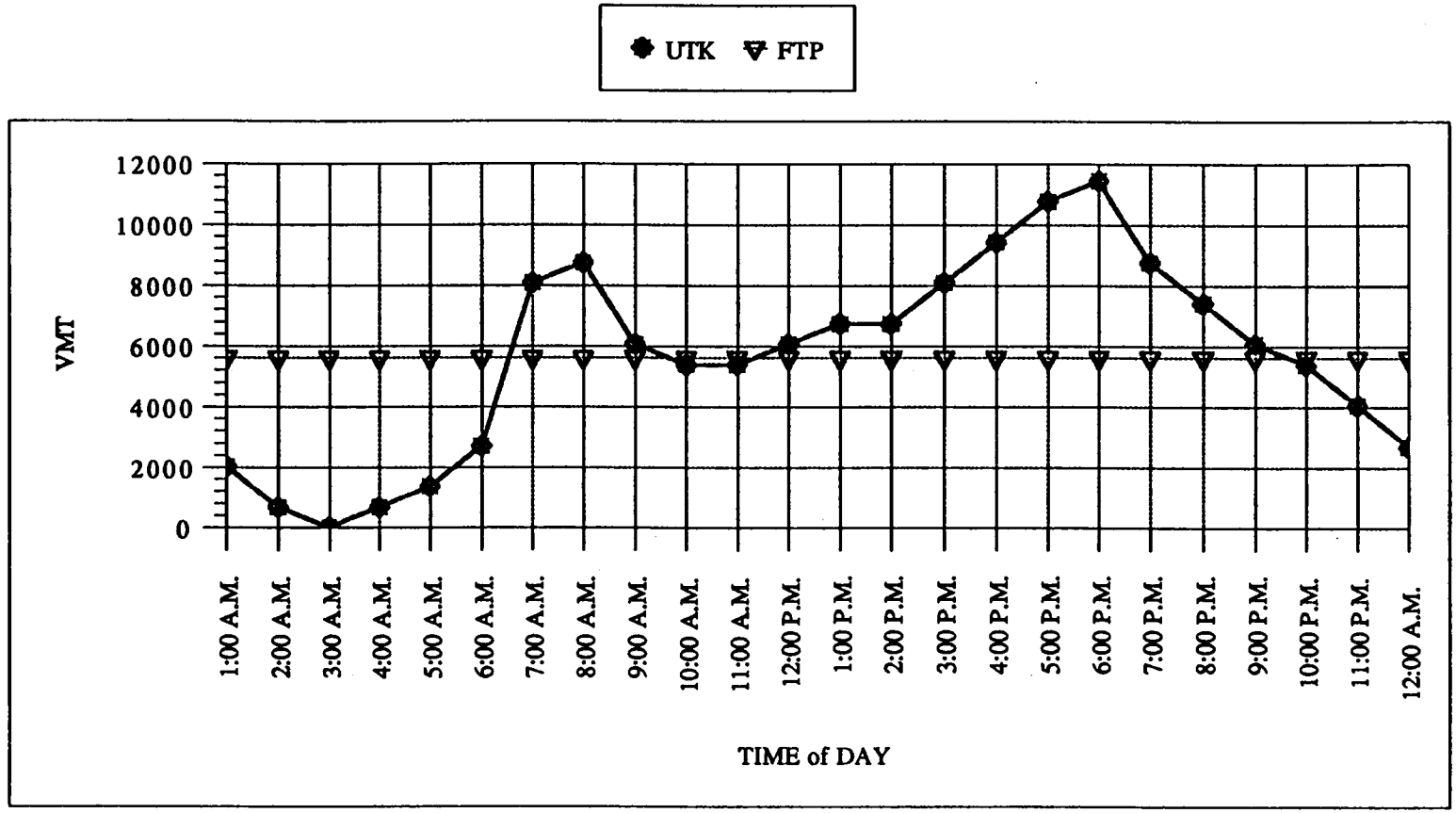


FIGURE 46
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY MINOR ARTERIALS
IN RURAL AREAS

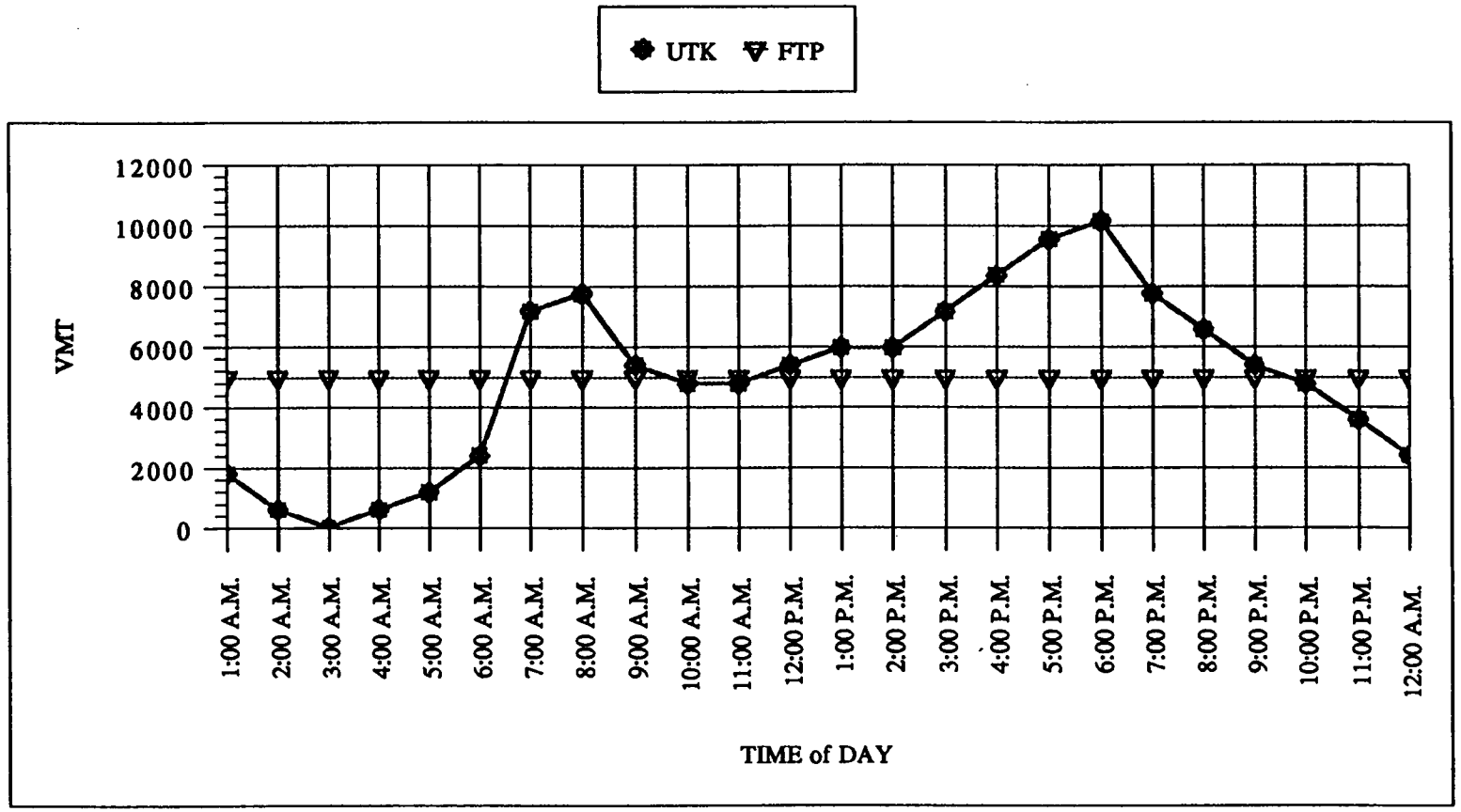


FIGURE 47
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY MINOR ARTERIALS
IN THE URBAN FRINGE

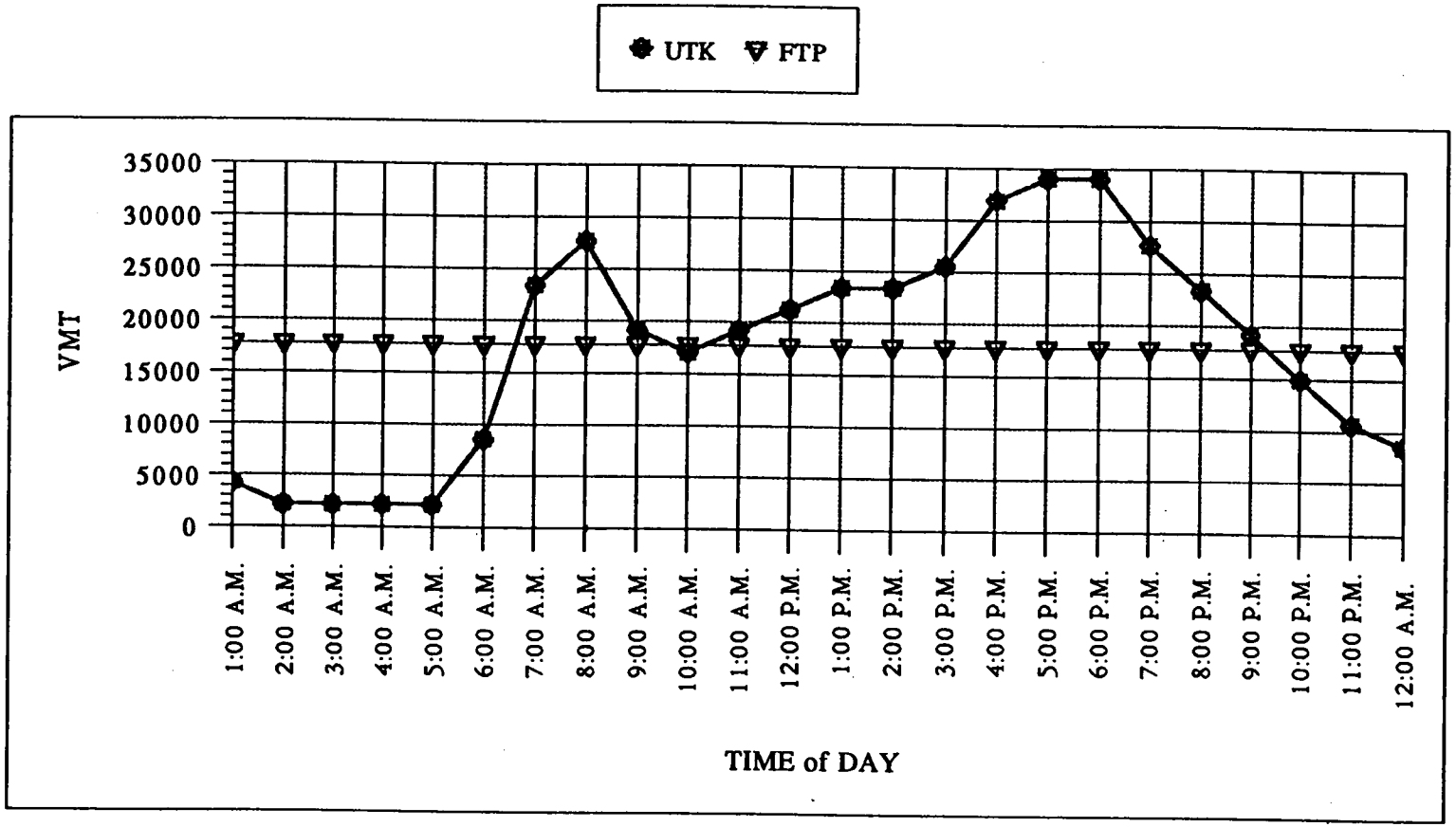


FIGURE 48
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY COLLECTORS
IN RURAL AREAS

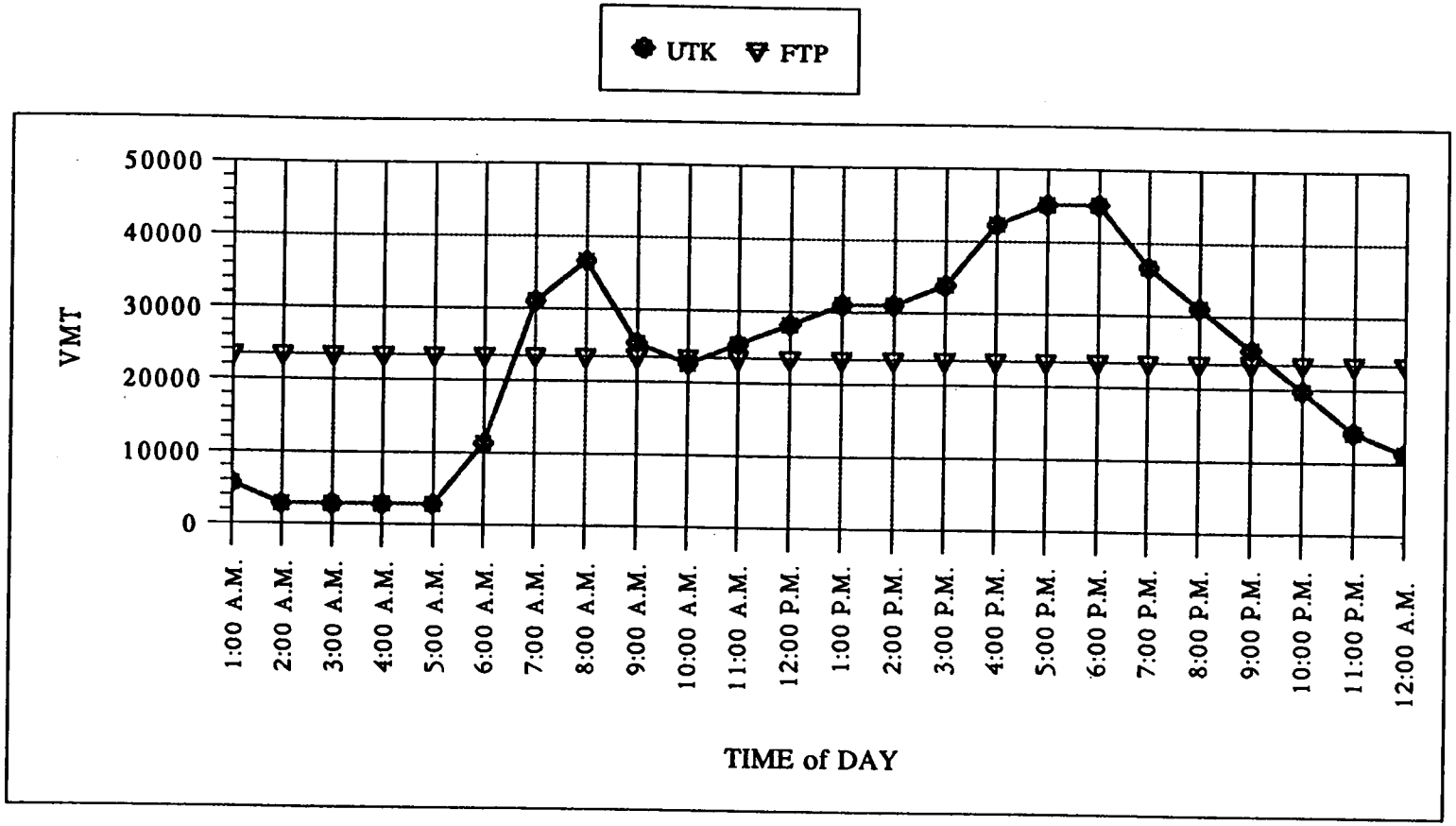


FIGURE 49
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY COLLECTORS
IN THE URBAN FRINGE

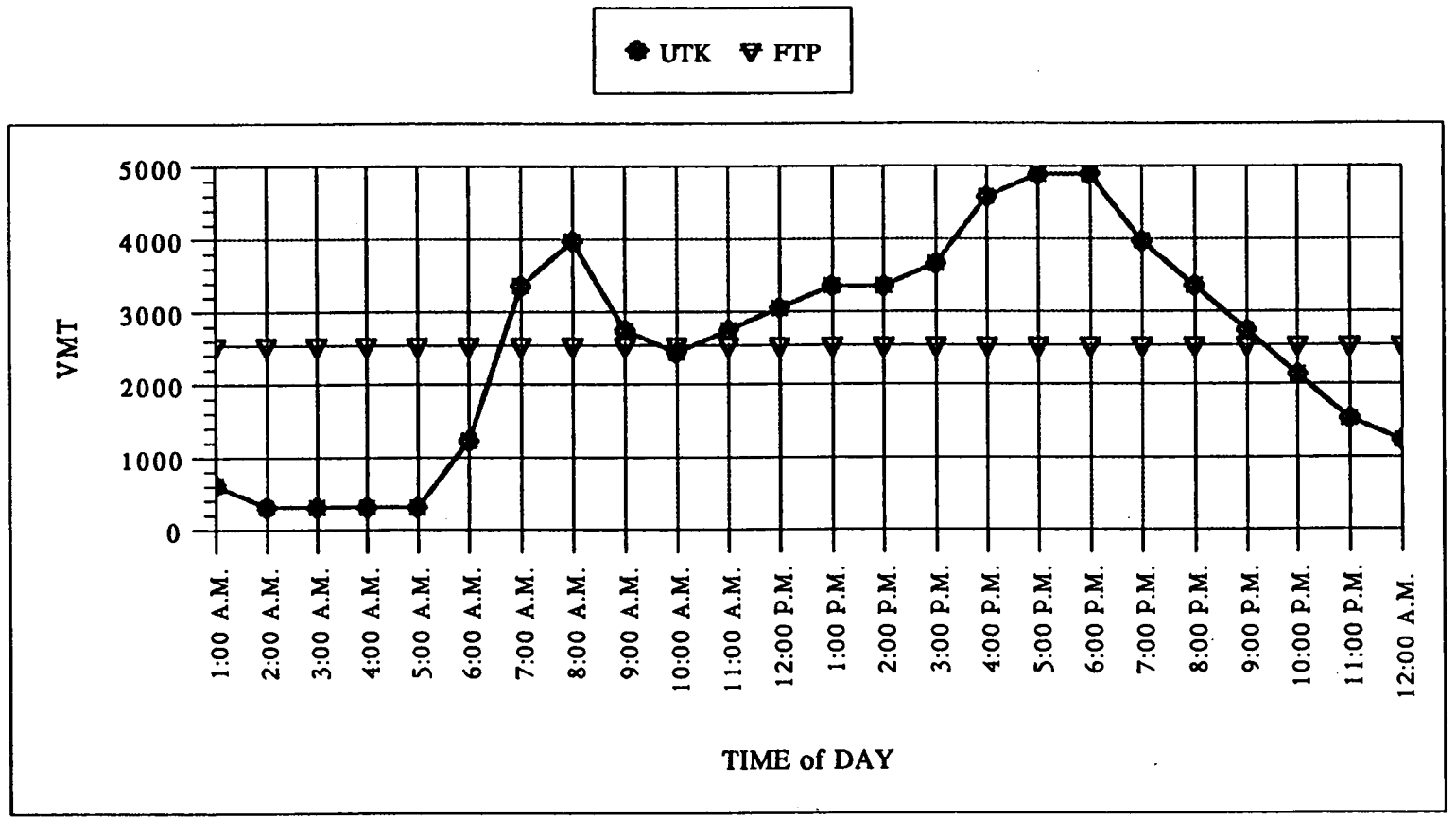


FIGURE 50
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY LOCALS
IN RURAL AREAS

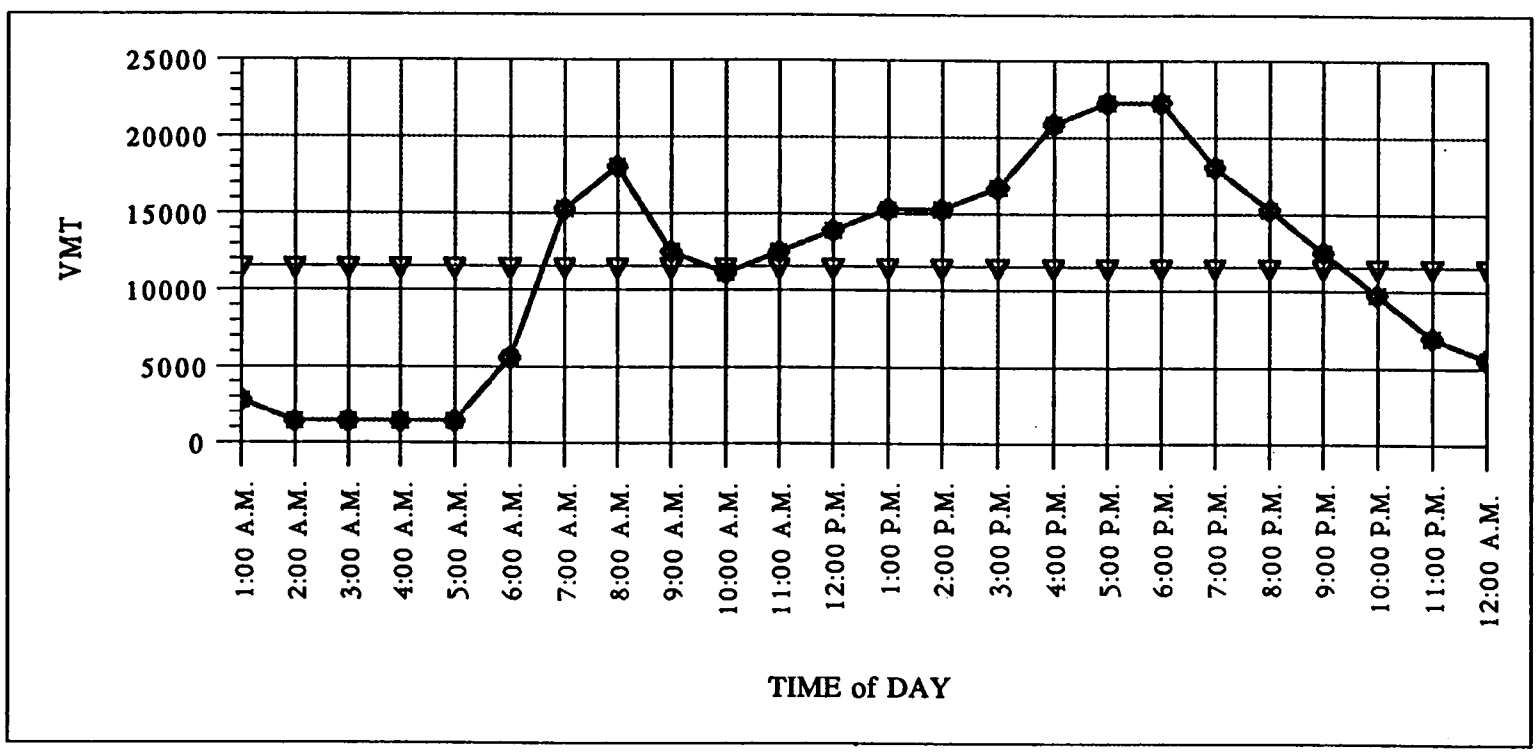


FIGURE 51
TOTAL TRAFFIC DISTRIBUTION BY HOUR
FOR RUTHERFORD COUNTY LOCALS
IN THE URBAN FRINGE

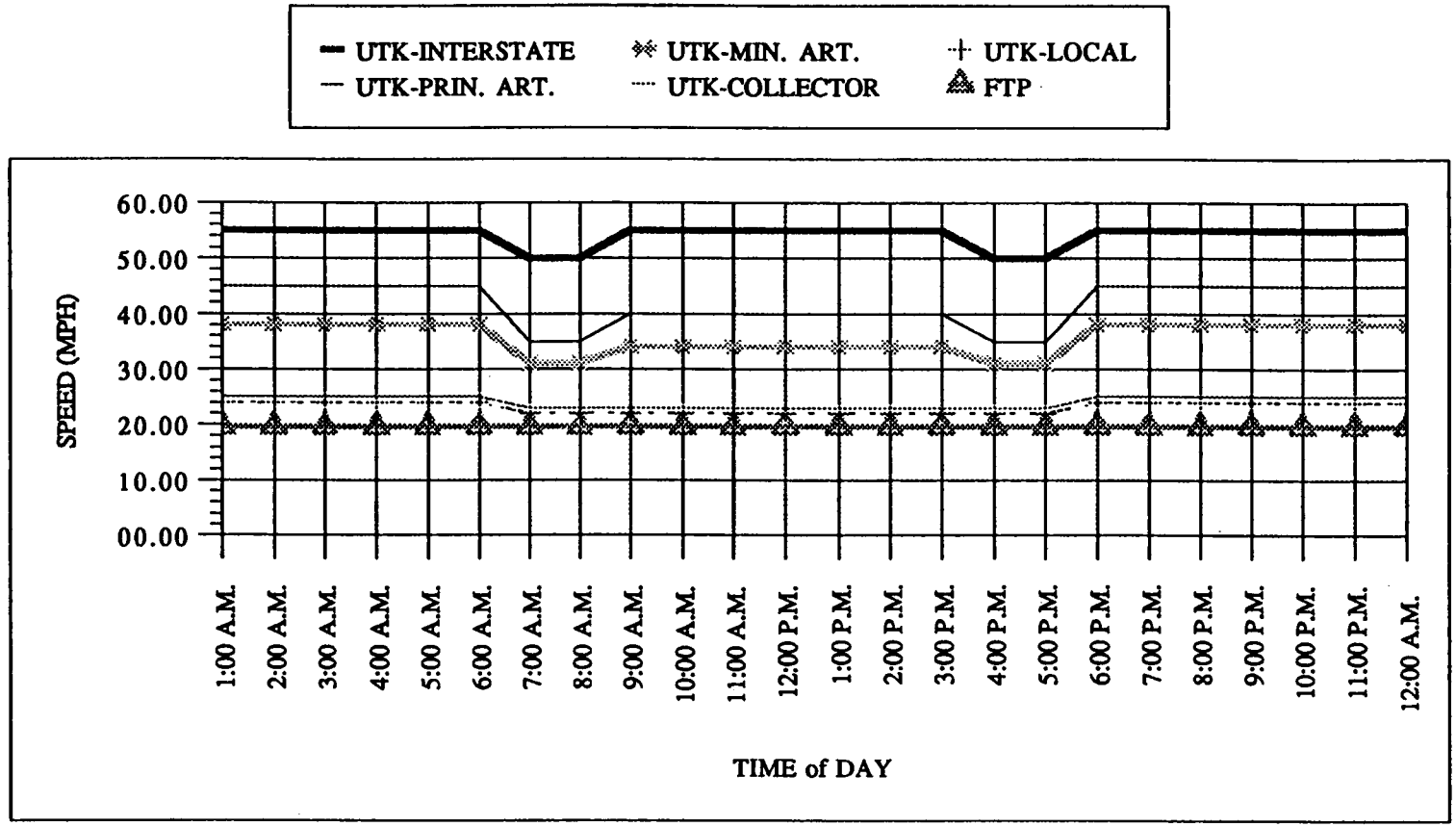


FIGURE 52
VEHICLE SPEED BY HOUR FOR RUTHERFORD COUNTY

Source: Compilation of data from references 29-32 of this thesis

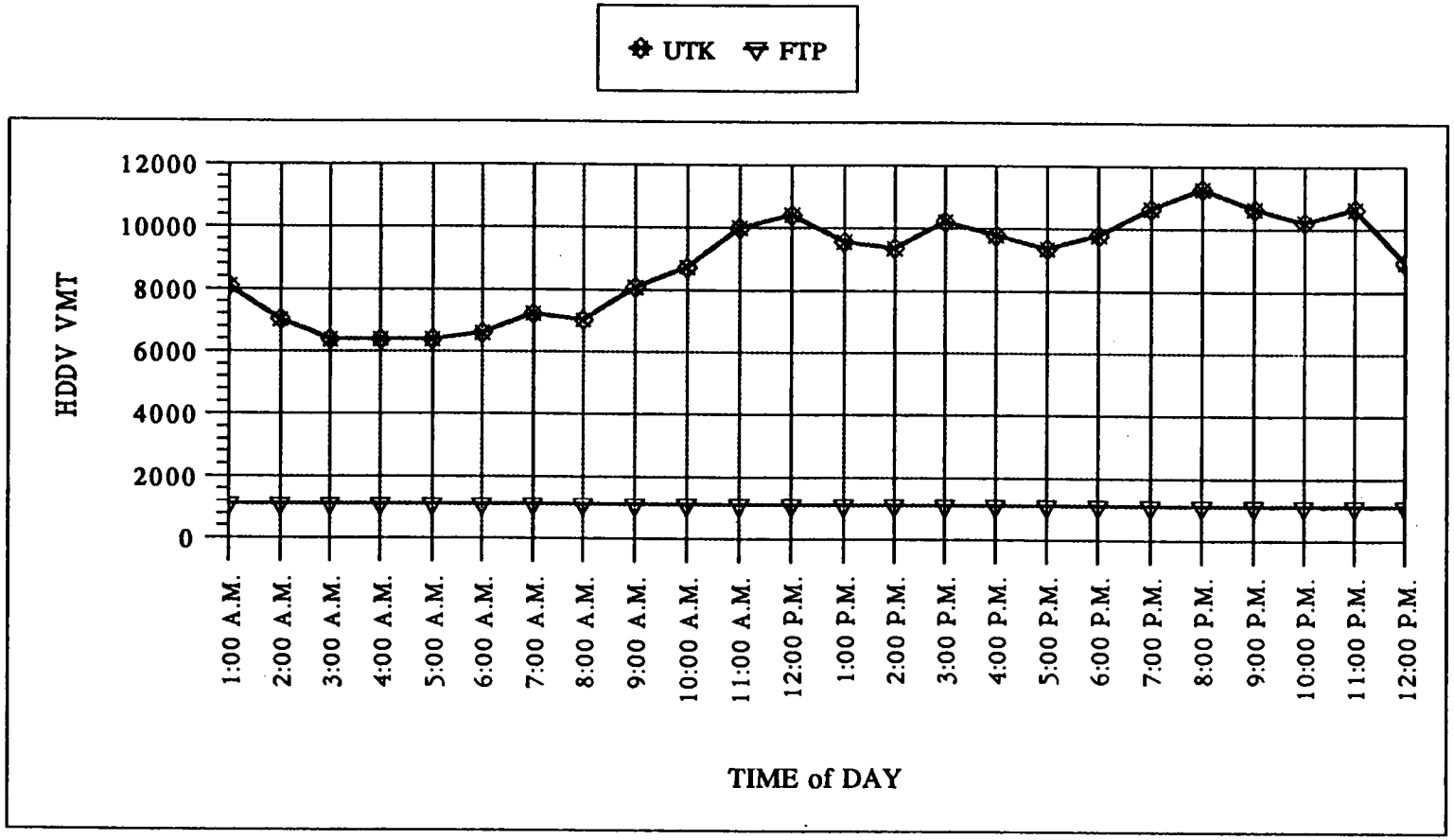


FIGURE 53
HOURLY DISTRIBUTION OF HDDV
ON RURAL INTERSTATES IN RUTHERFORD COUNTY

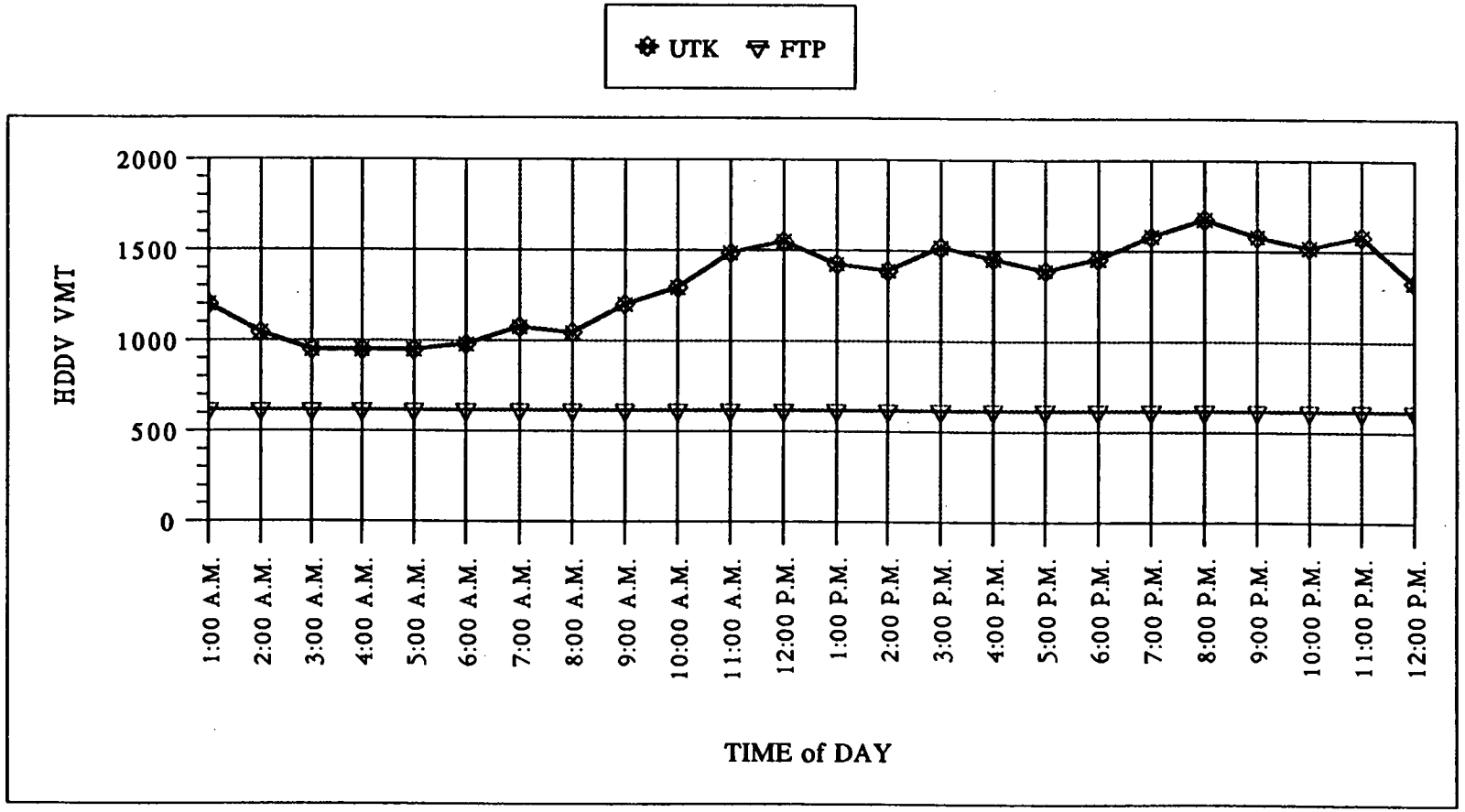


FIGURE 54
HOURLY DISTRIBUTION OF HDDV
ON URBAN FRINGE INTERSTATES IN RUTHERFORD COUNTY

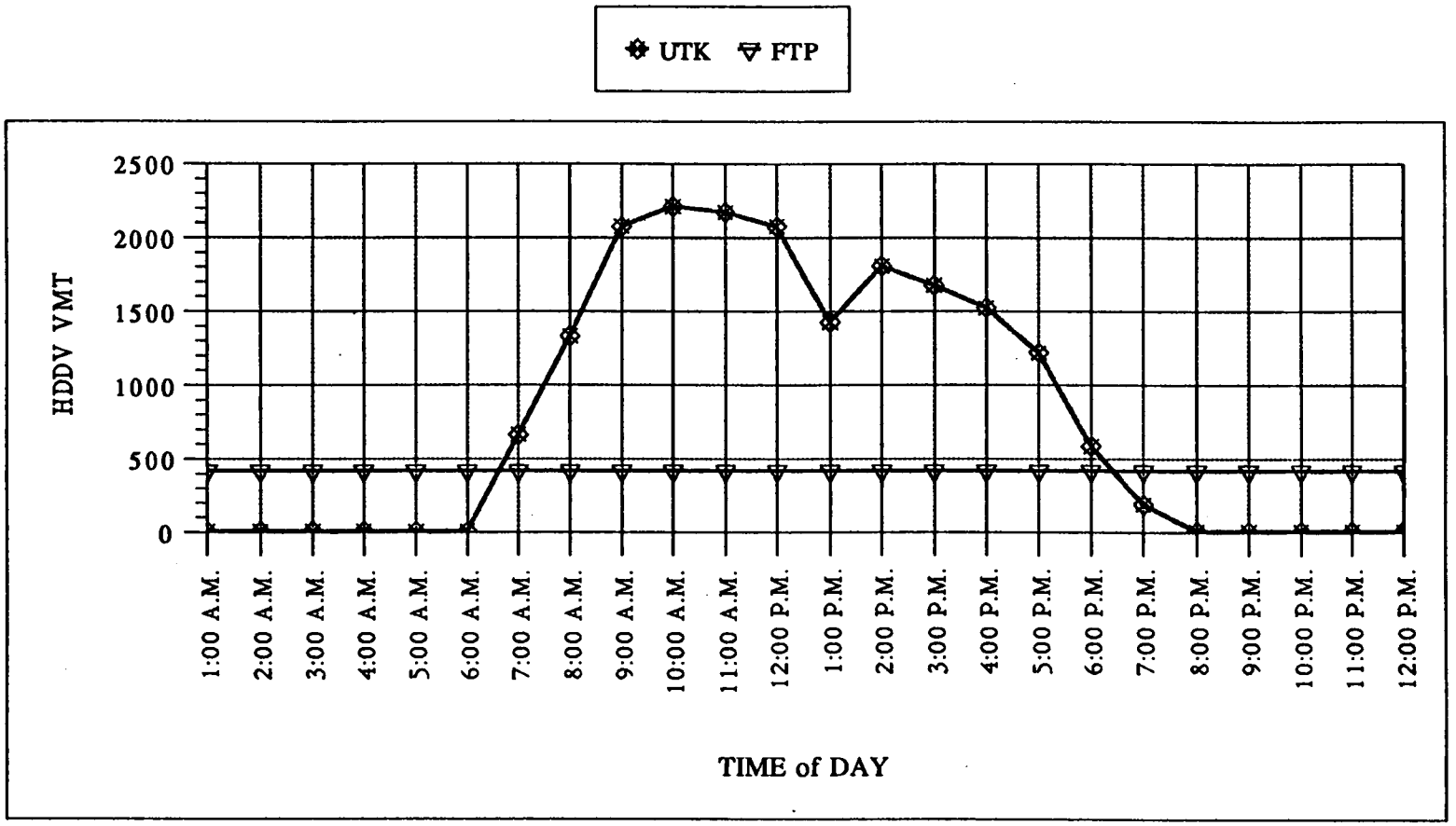


FIGURE 55
HOURLY DISTRIBUTION OF HDDV ON RURAL PRINCIPAL ARTERIALS IN RUTHERFORD COUNTY

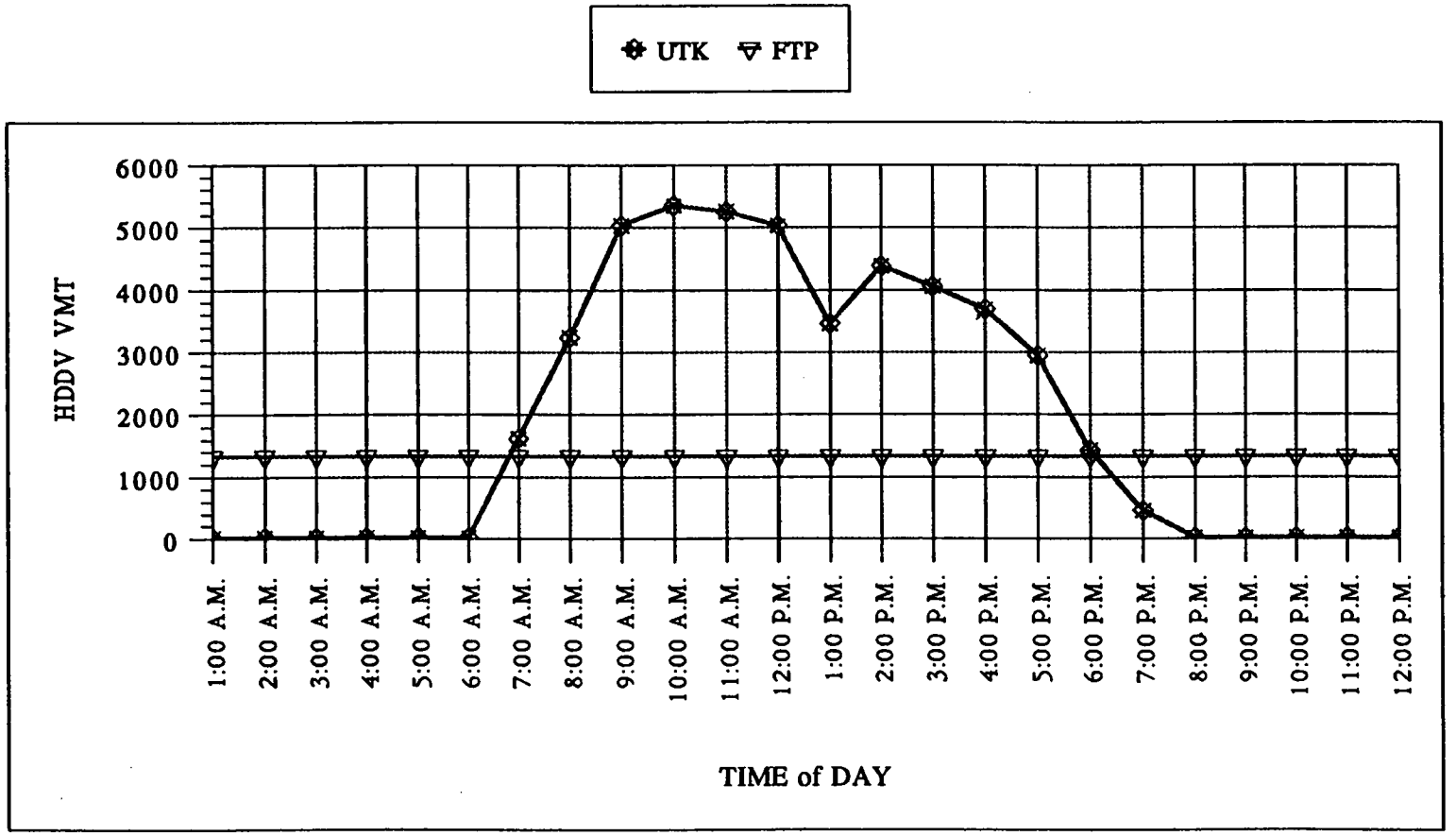


FIGURE 56
HOURLY DISTRIBUTION OF HDDV ON URBAN FRINGE PRINCIPAL ARTERIALS IN RUTHERFORD COUNTY

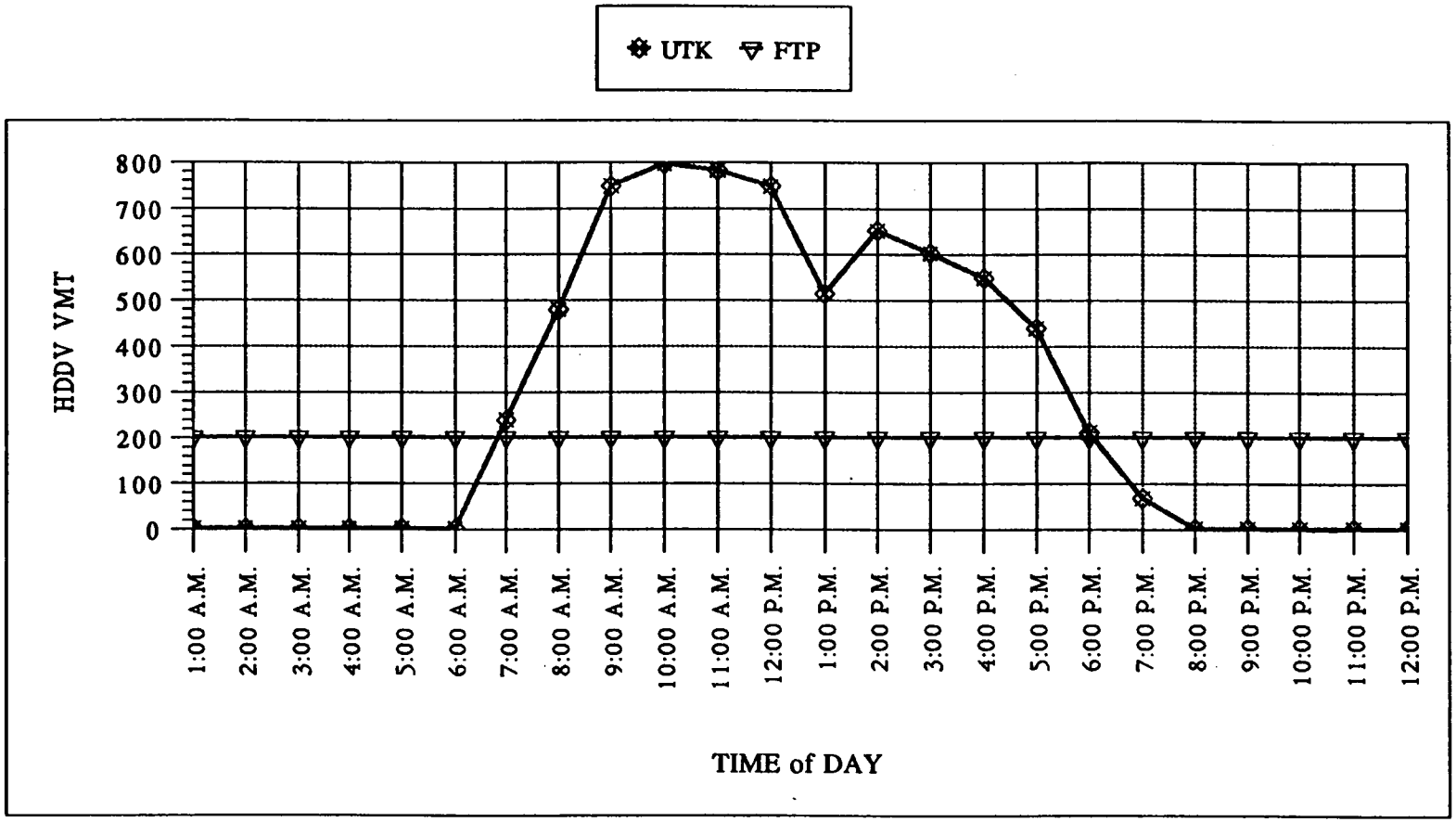


FIGURE 57
HOURLY DISTRIBUTION OF HDDV ON RURAL MINOR ARTERIALS IN RUTHERFORD COUNTY

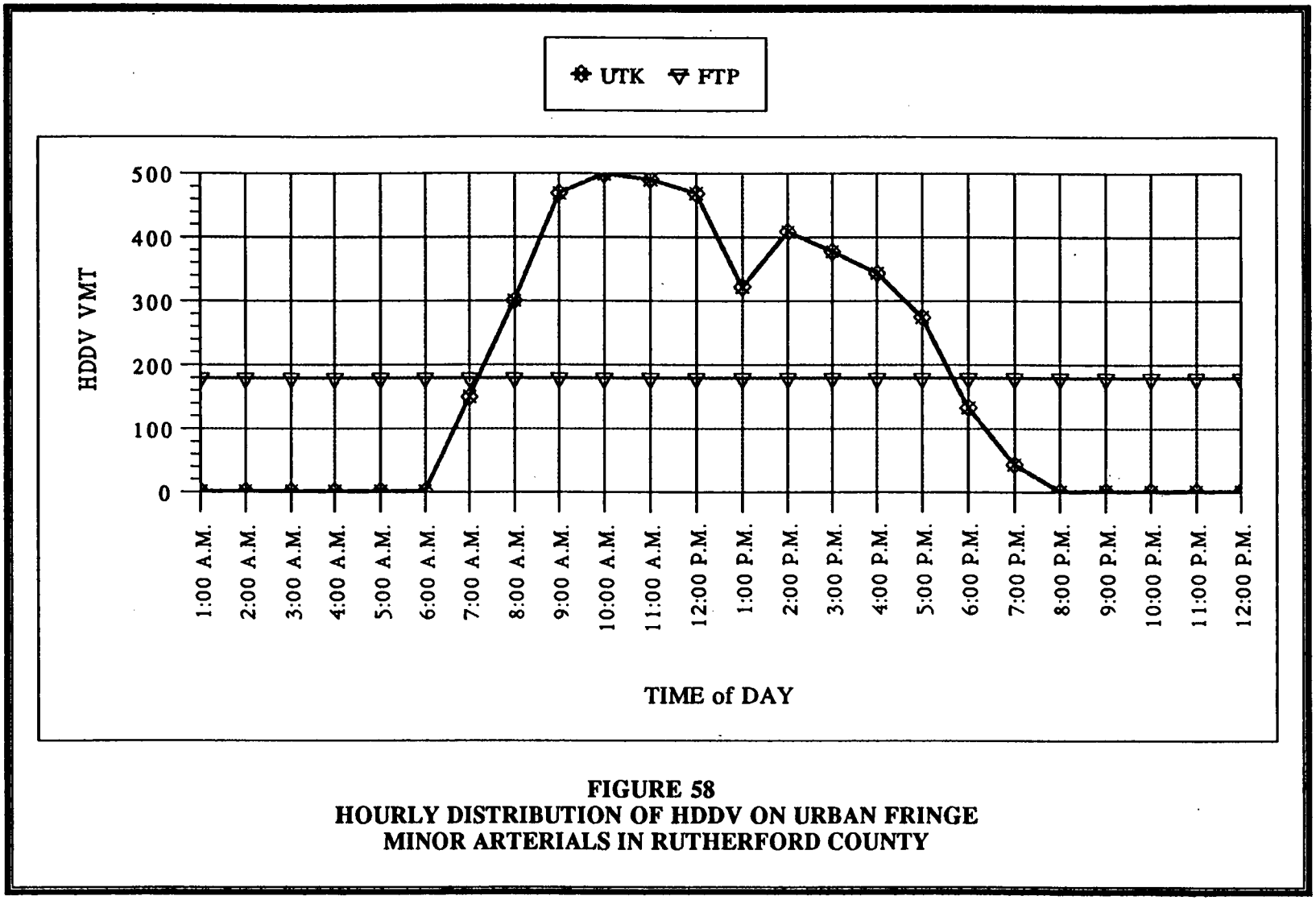


FIGURE 58
HOURLY DISTRIBUTION OF HDDV ON URBAN FRINGE MINOR ARTERIALS IN RUTHERFORD COUNTY

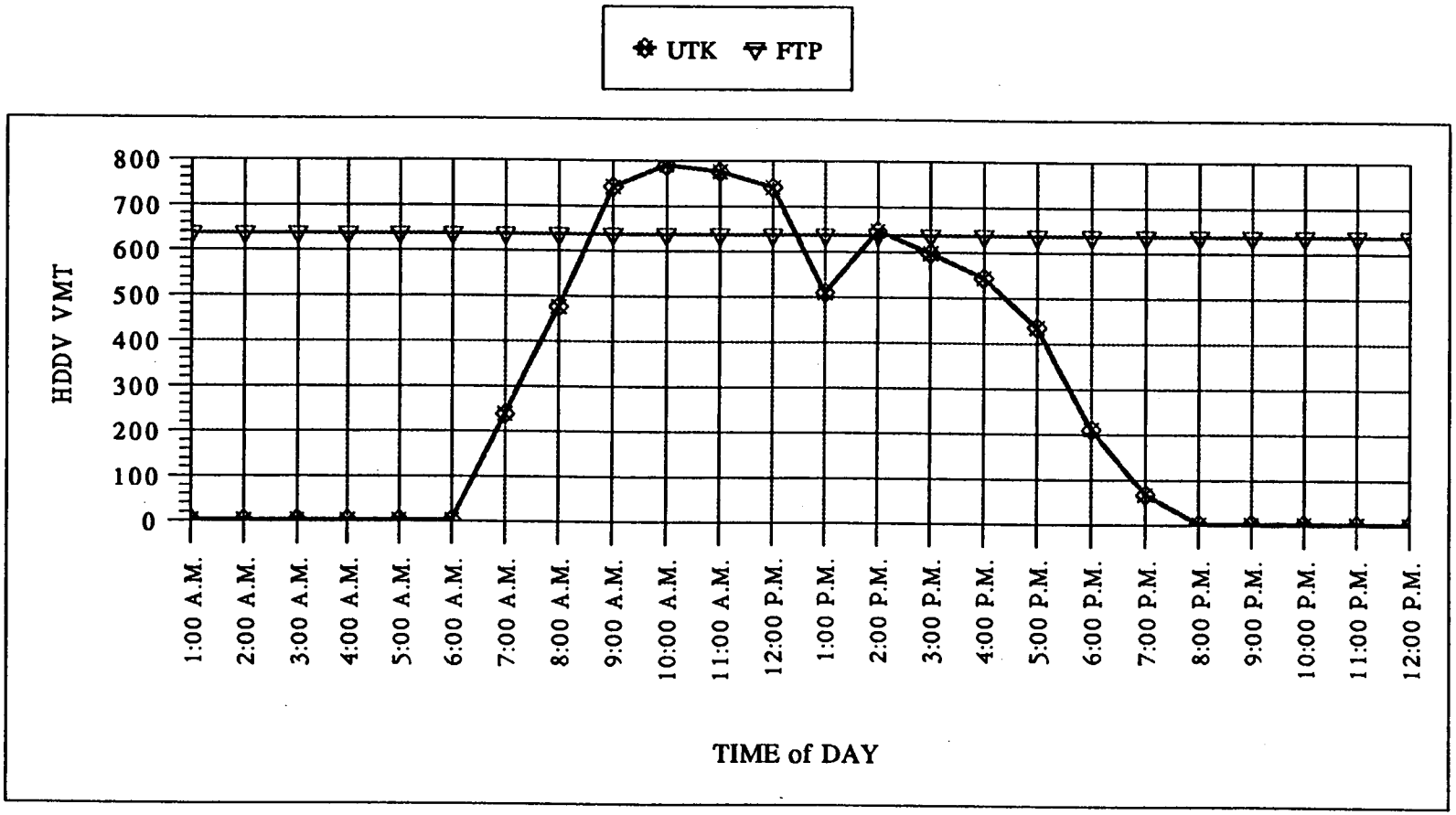


FIGURE 59
HOURLY DISTRIBUTION OF HDDV ON RURAL COLLECTORS IN RUTHERFORD COUNTY

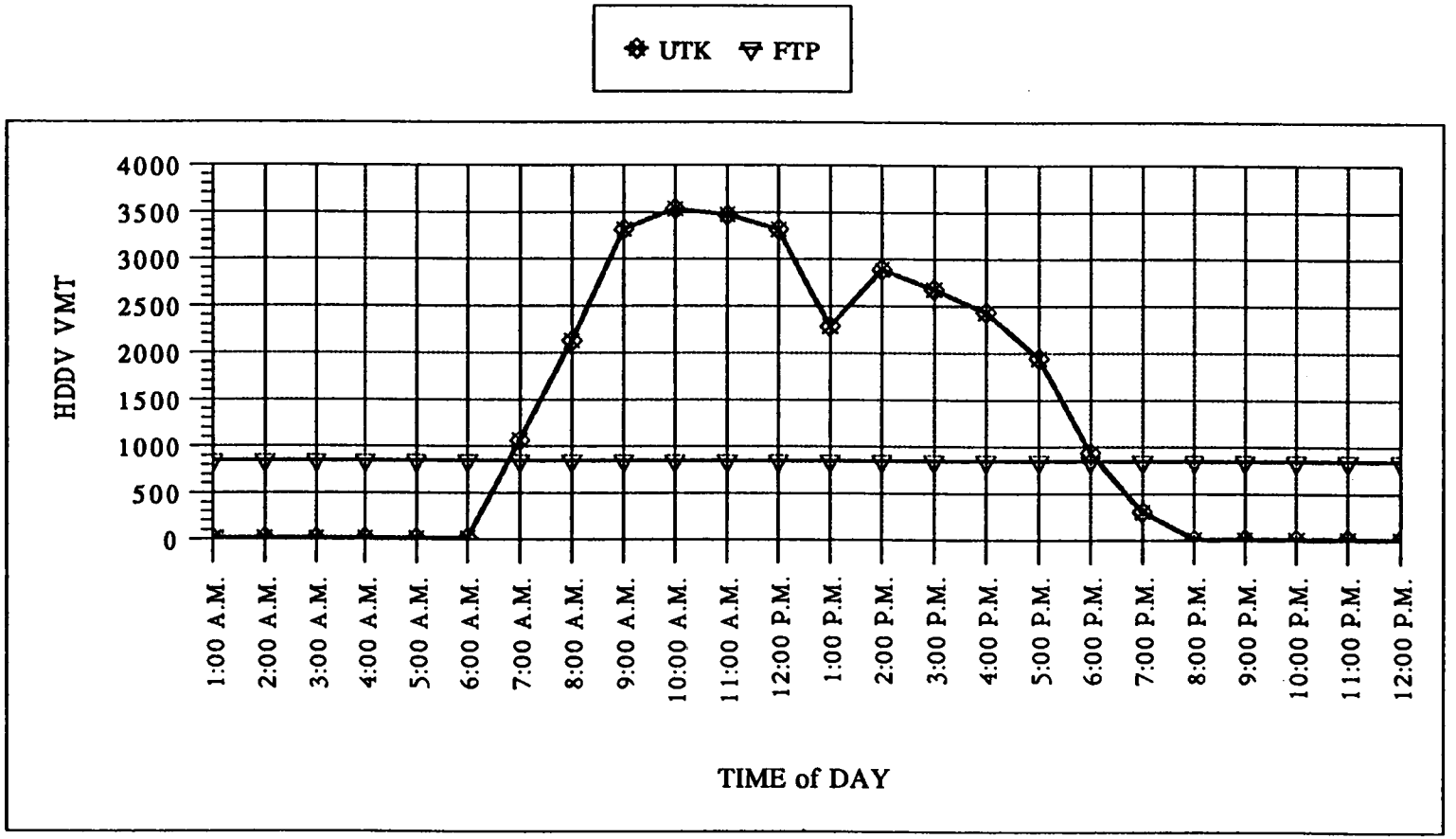


FIGURE 60
HOURLY DISTRIBUTION OF HDDV ON URBAN FRINGE COLLECTORS IN RUTHERFORD COUNTY

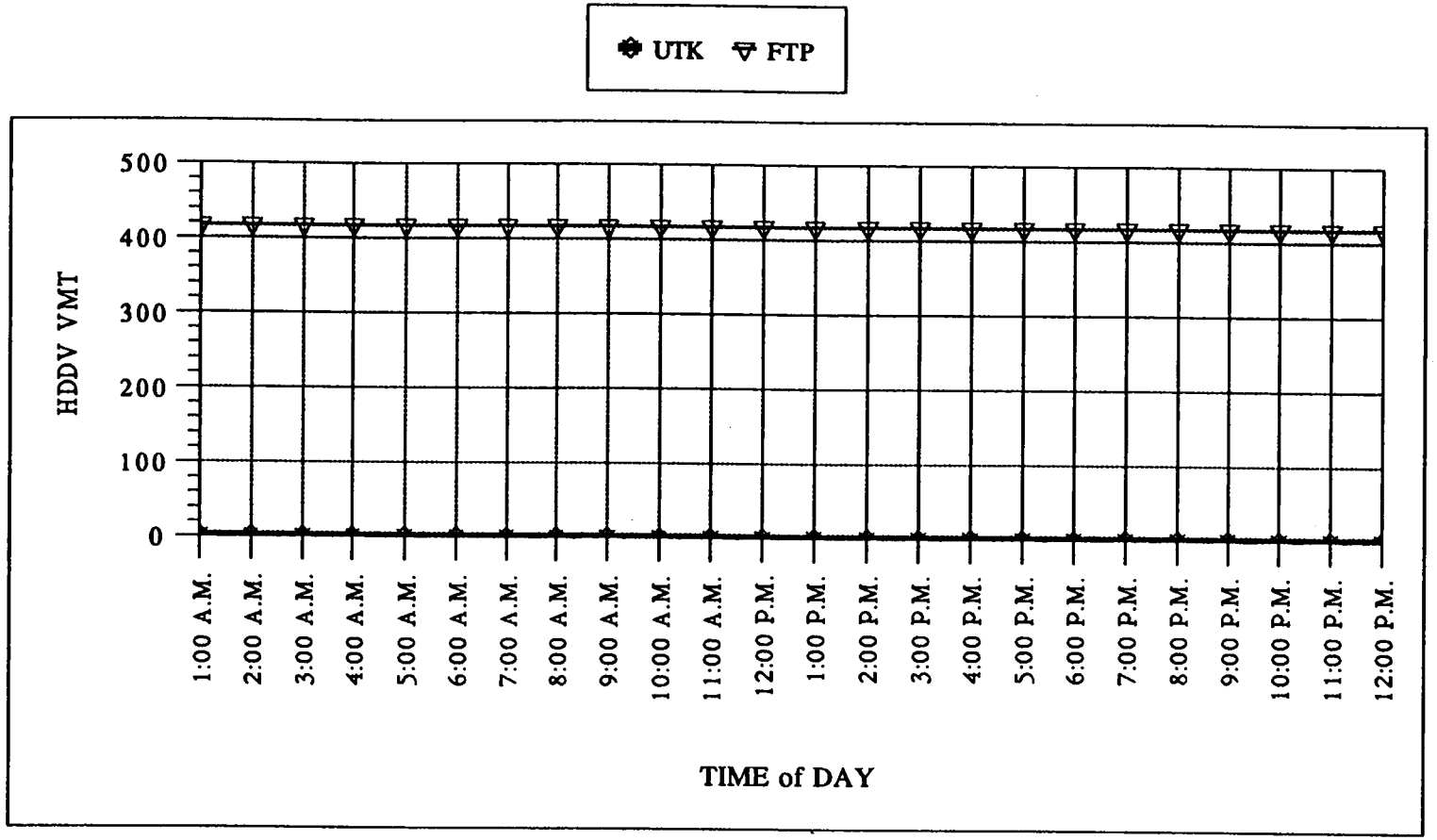


FIGURE 61
HOURLY DISTRIBUTION OF HDDV ON URBAN FRINGE LOCALS IN RUTHERFORD COUNTY

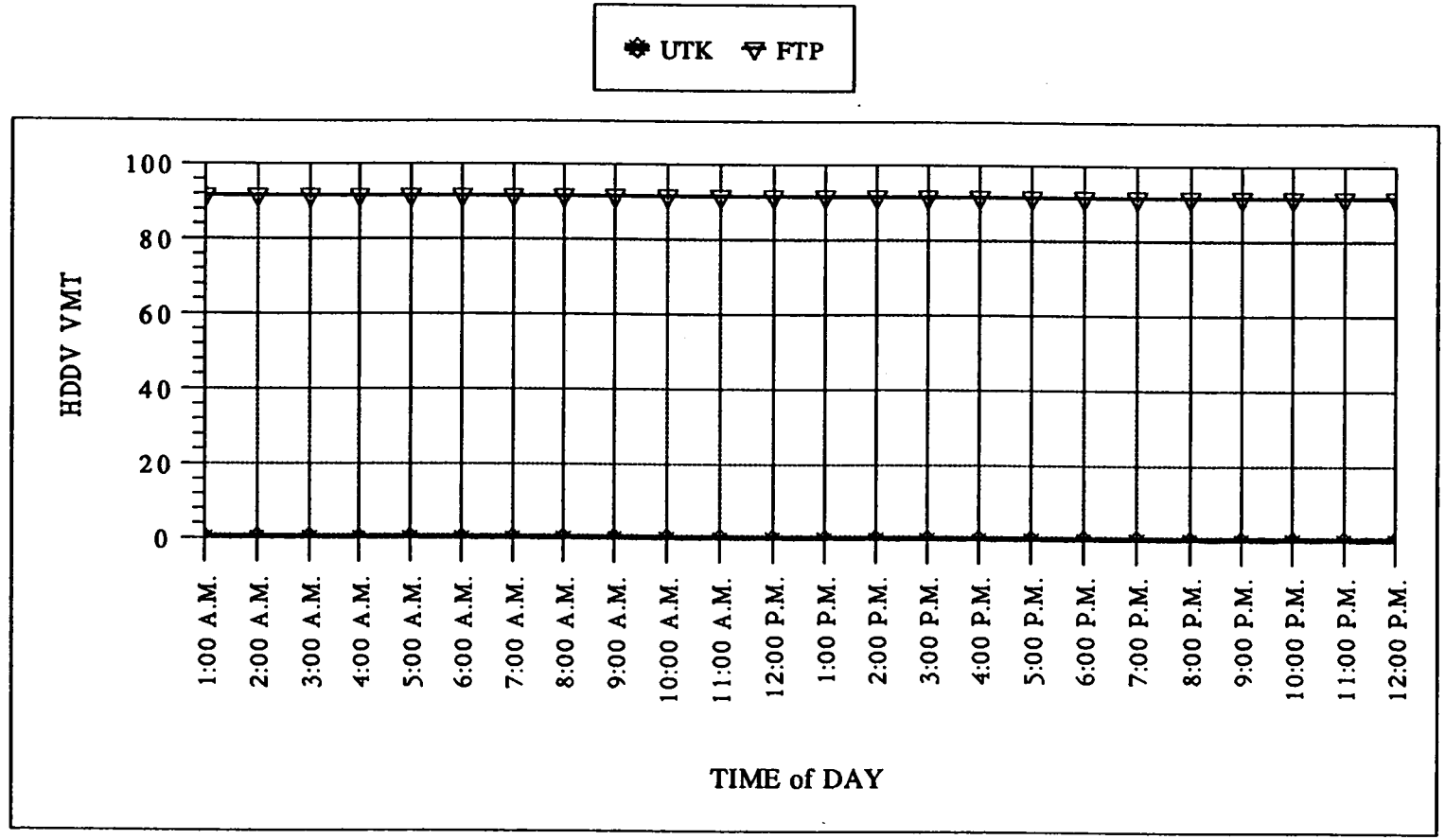


FIGURE 62
HOURLY DISTRIBUTION OF HDDV ON RURAL LOCALS IN RUTHERFORD COUNTY

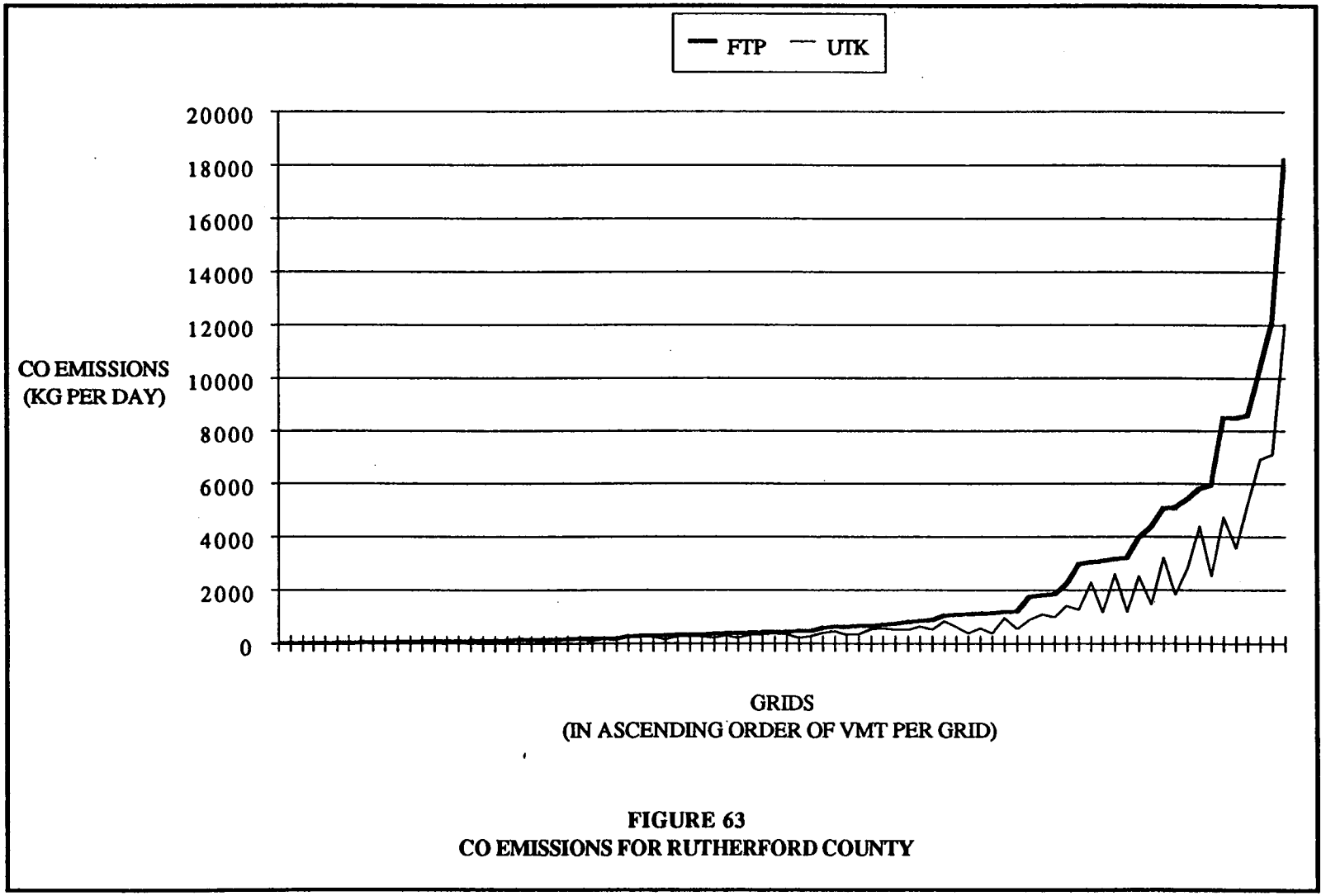


FIGURE 63
CO EMISSIONS FOR RUTHERFORD COUNTY

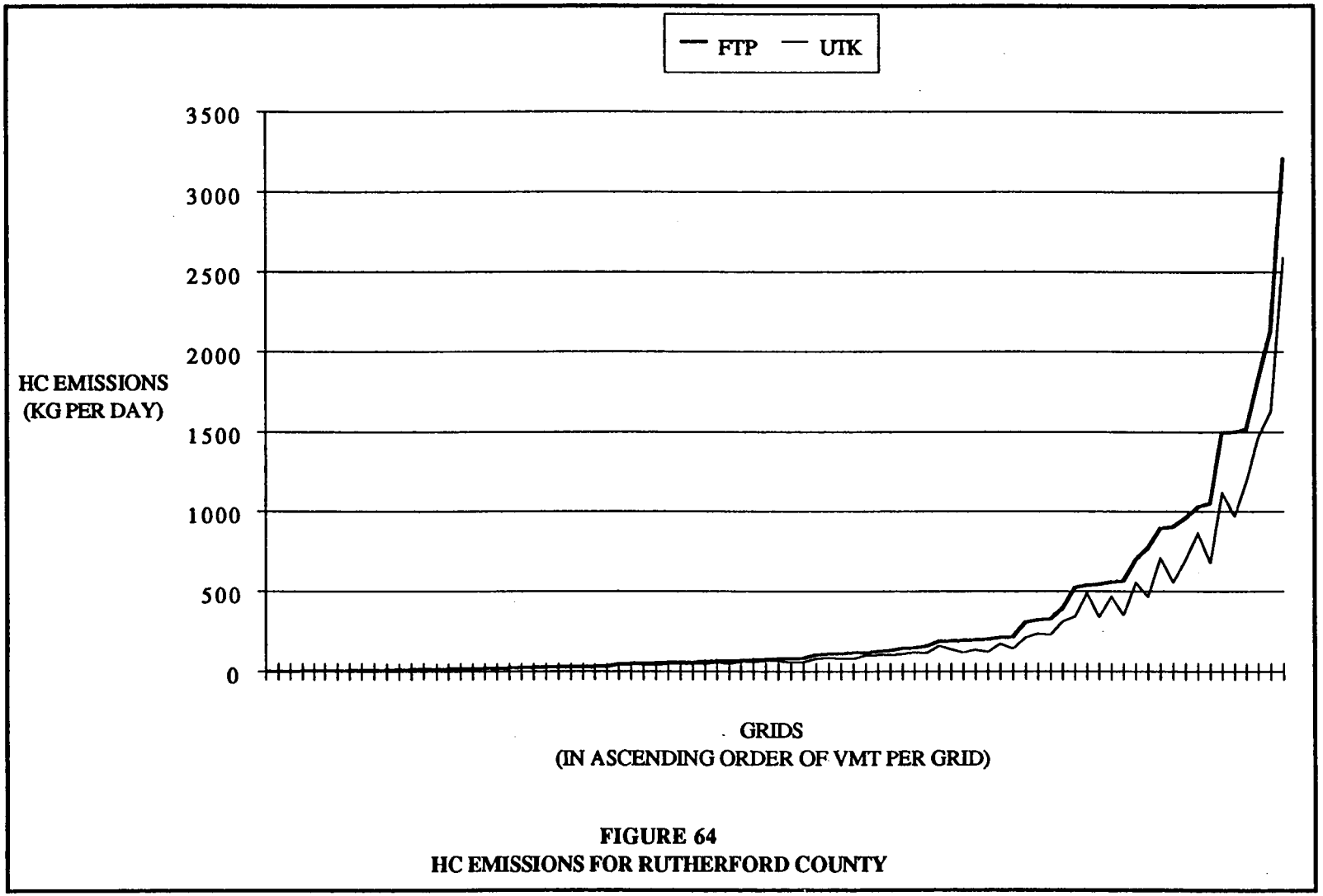


FIGURE 64
HC EMISSIONS FOR RUTHERFORD COUNTY

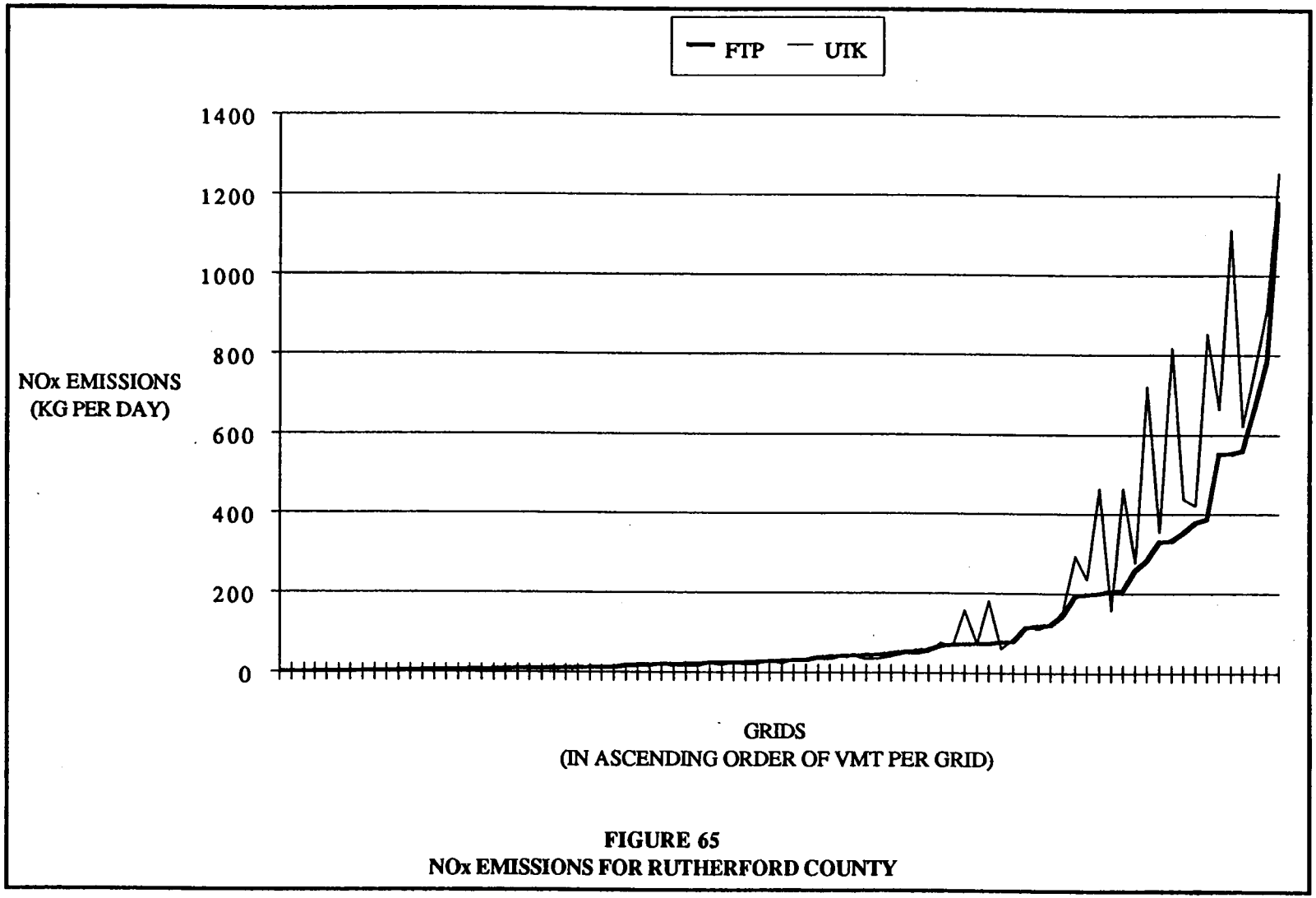


FIGURE 65
NOx EMISSIONS FOR RUTHERFORD COUNTY

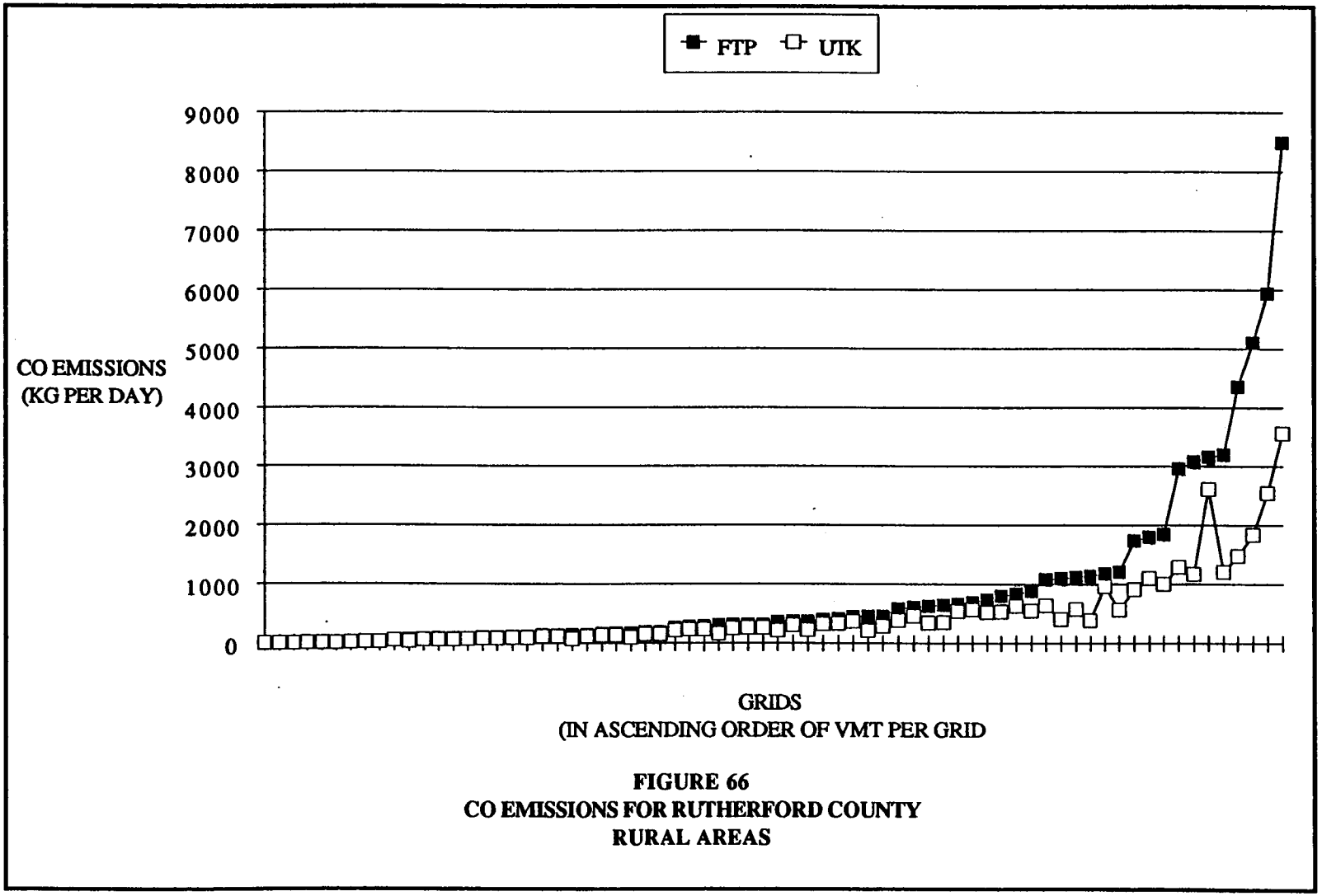


FIGURE 66
CO EMISSIONS FOR RUTHERFORD COUNTY
RURAL AREAS

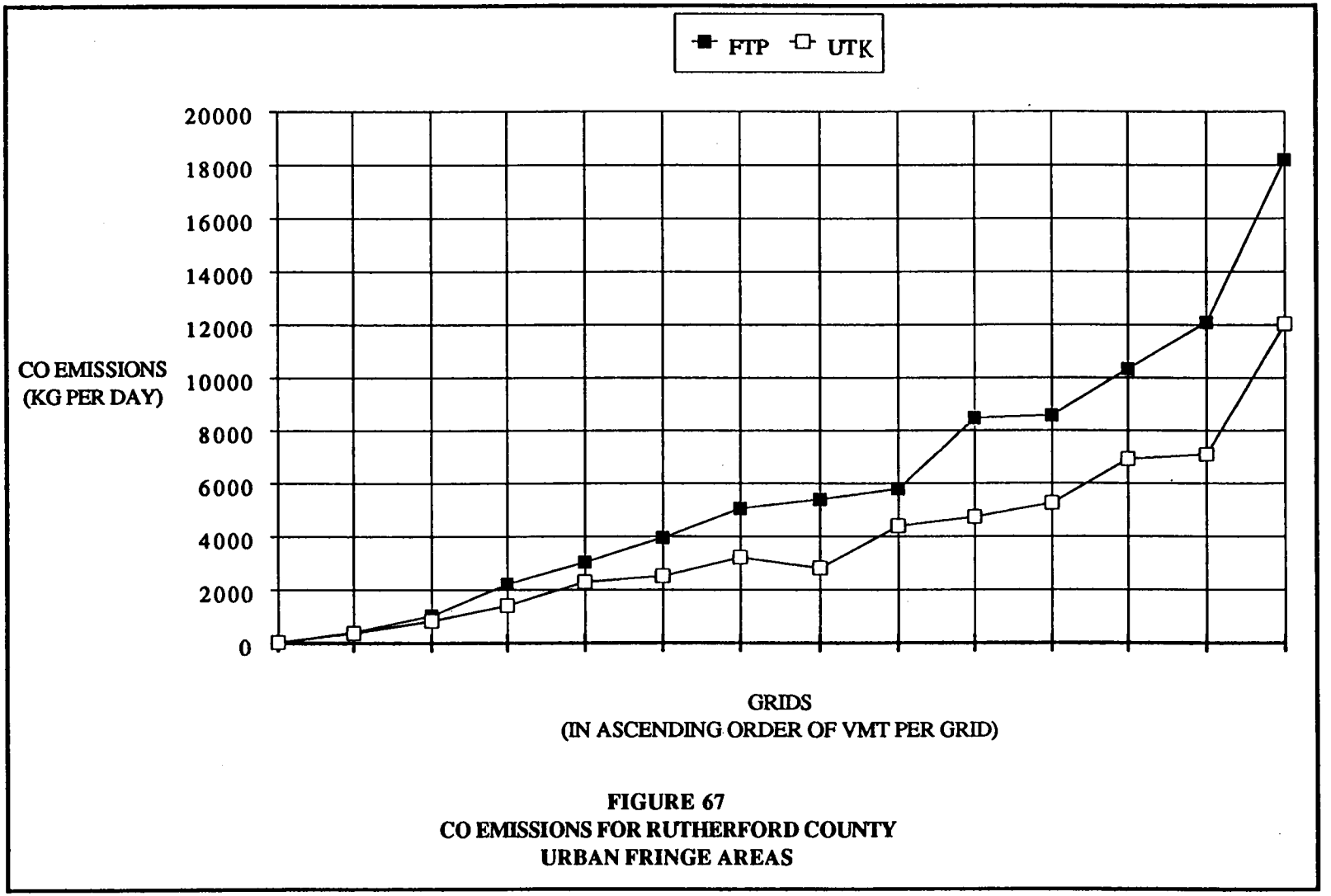


FIGURE 67
CO EMISSIONS FOR RUTHERFORD COUNTY
URBAN FRINGE AREAS

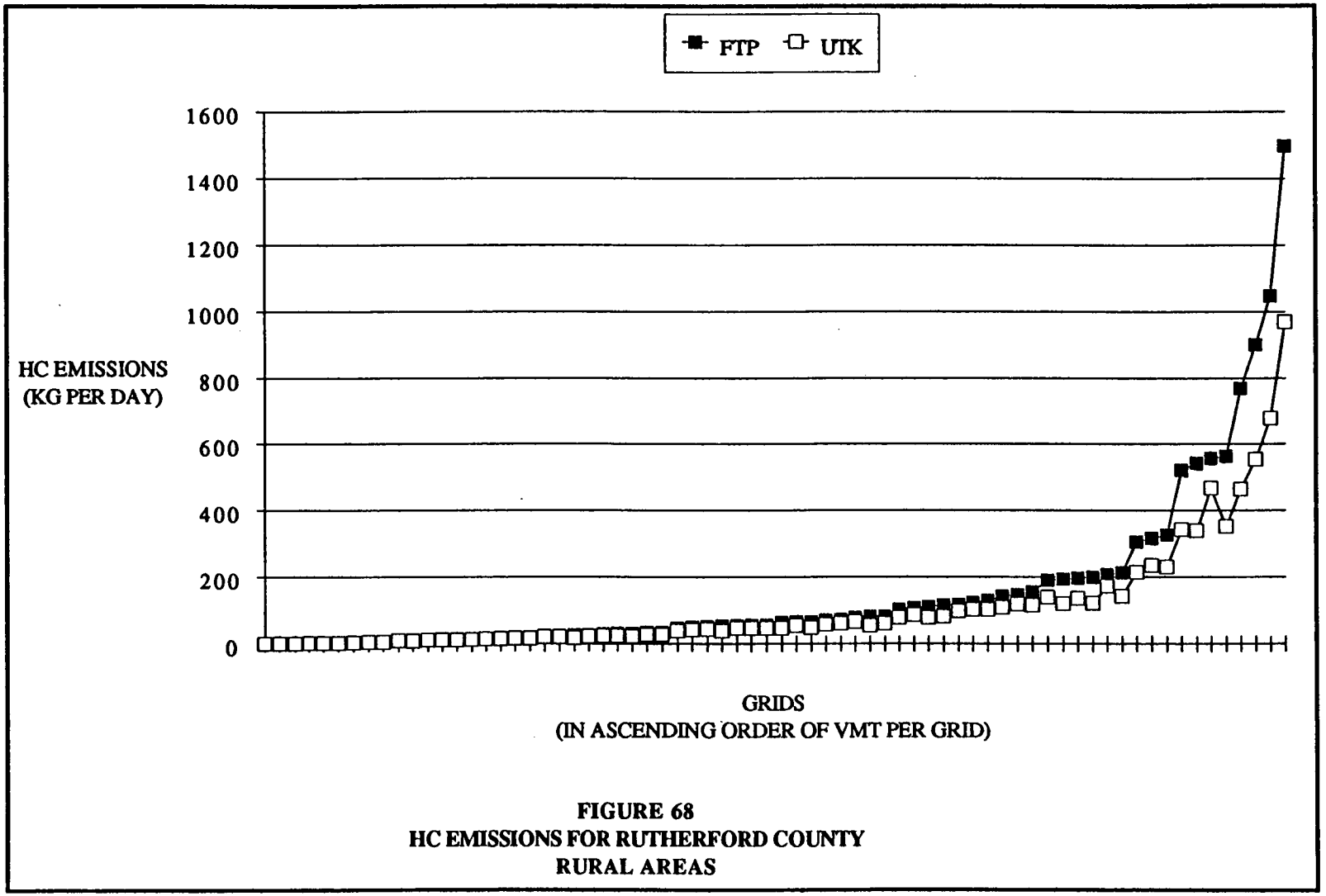


FIGURE 68
HC EMISSIONS FOR RUTHERFORD COUNTY
RURAL AREAS

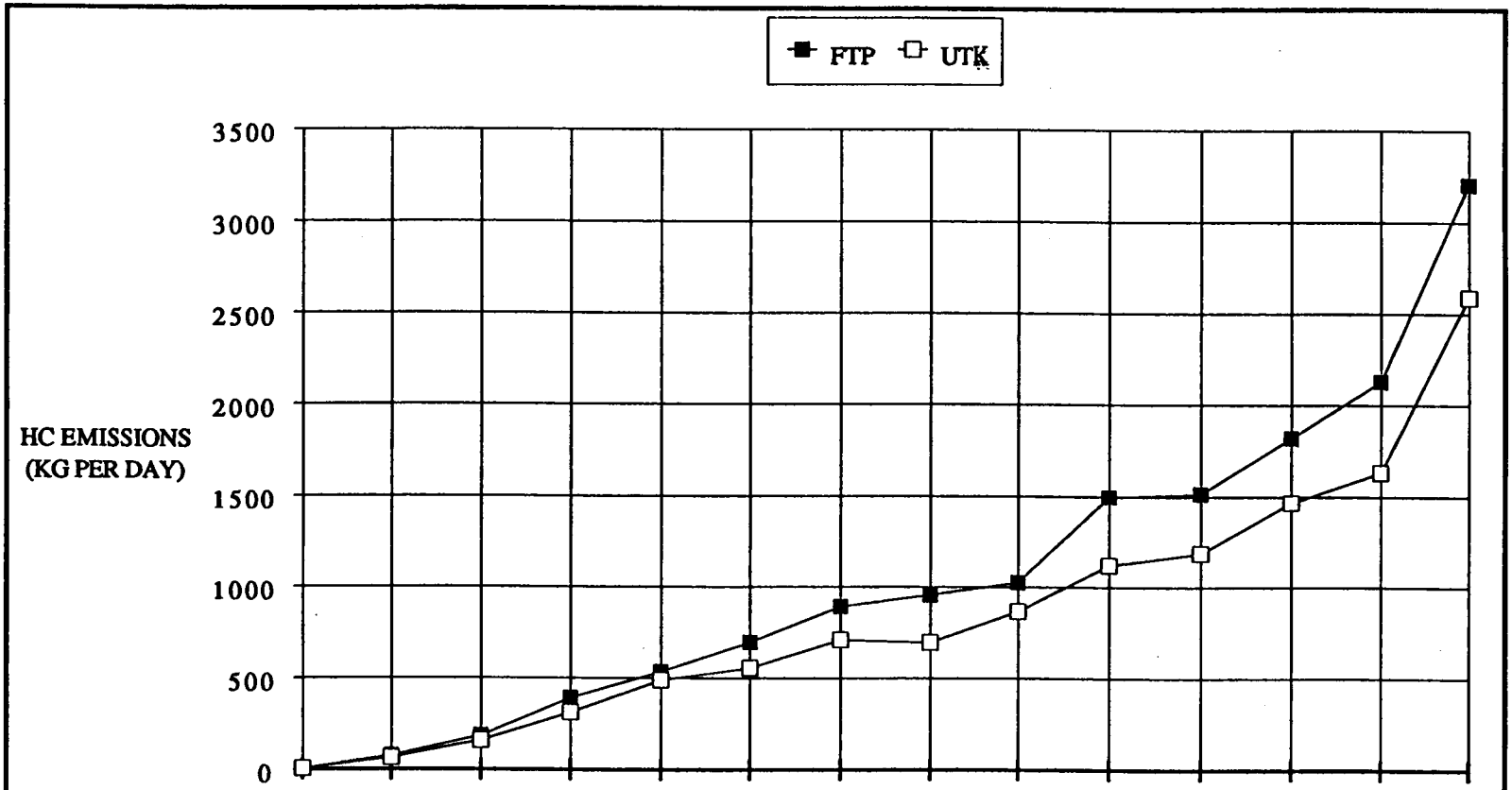


FIGURE 69
HC EMISSIONS FOR RUTHERFORD COUNTY
URBAN FRINGE AREAS

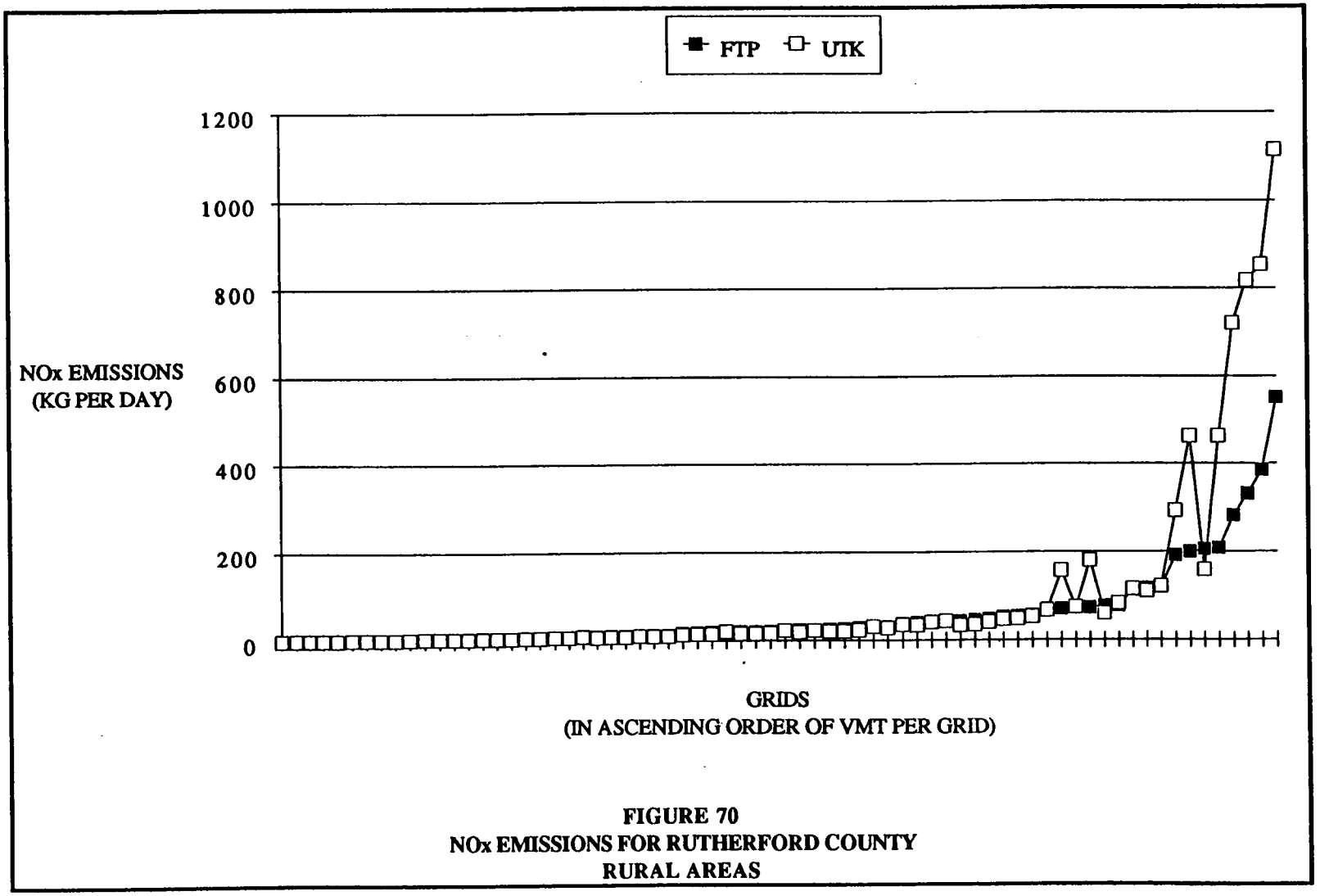


FIGURE 70
NOx EMISSIONS FOR RUTHERFORD COUNTY
RURAL AREAS

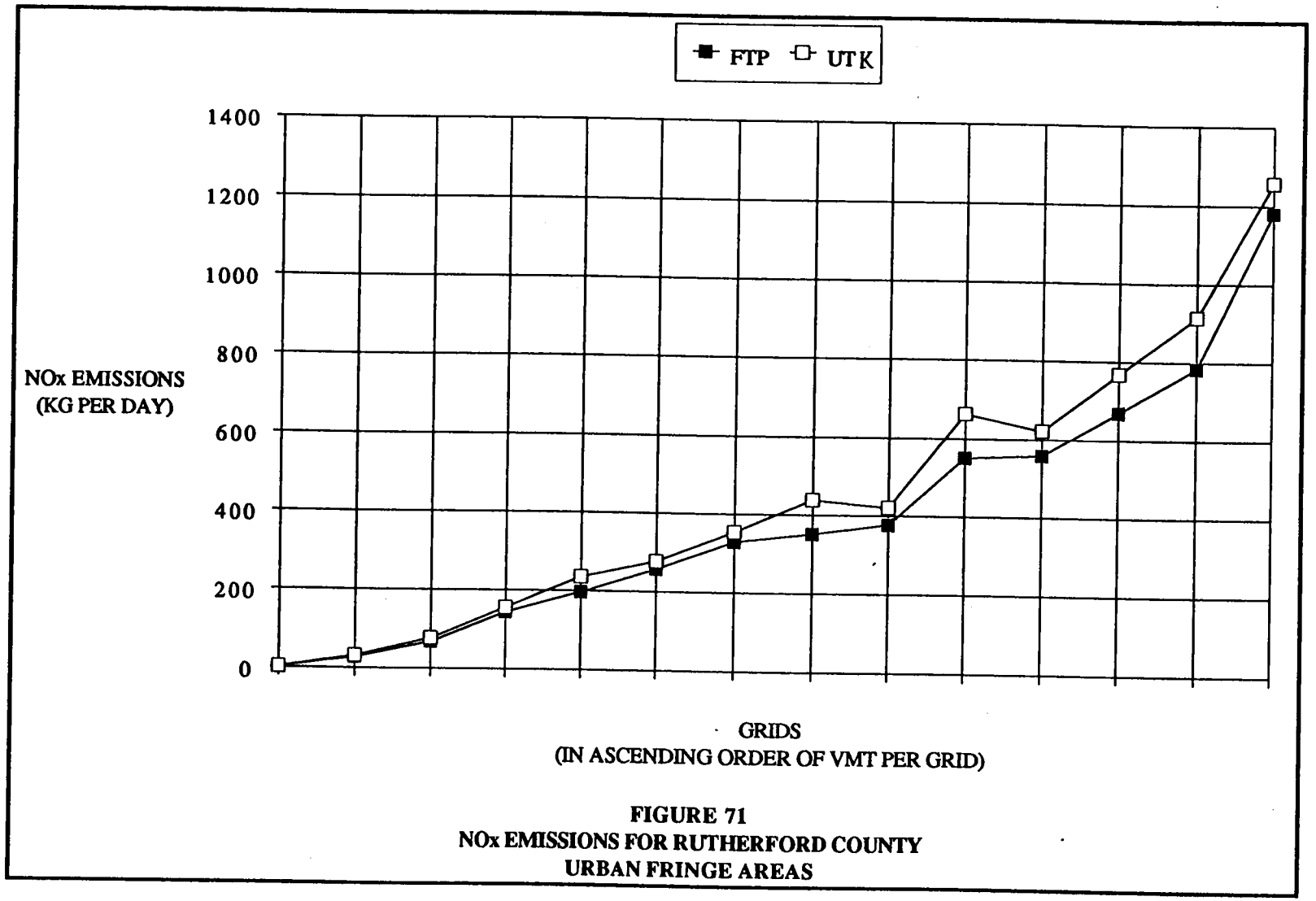


FIGURE 71
NOx EMISSIONS FOR RUTHERFORD COUNTY
URBAN FRINGE AREAS

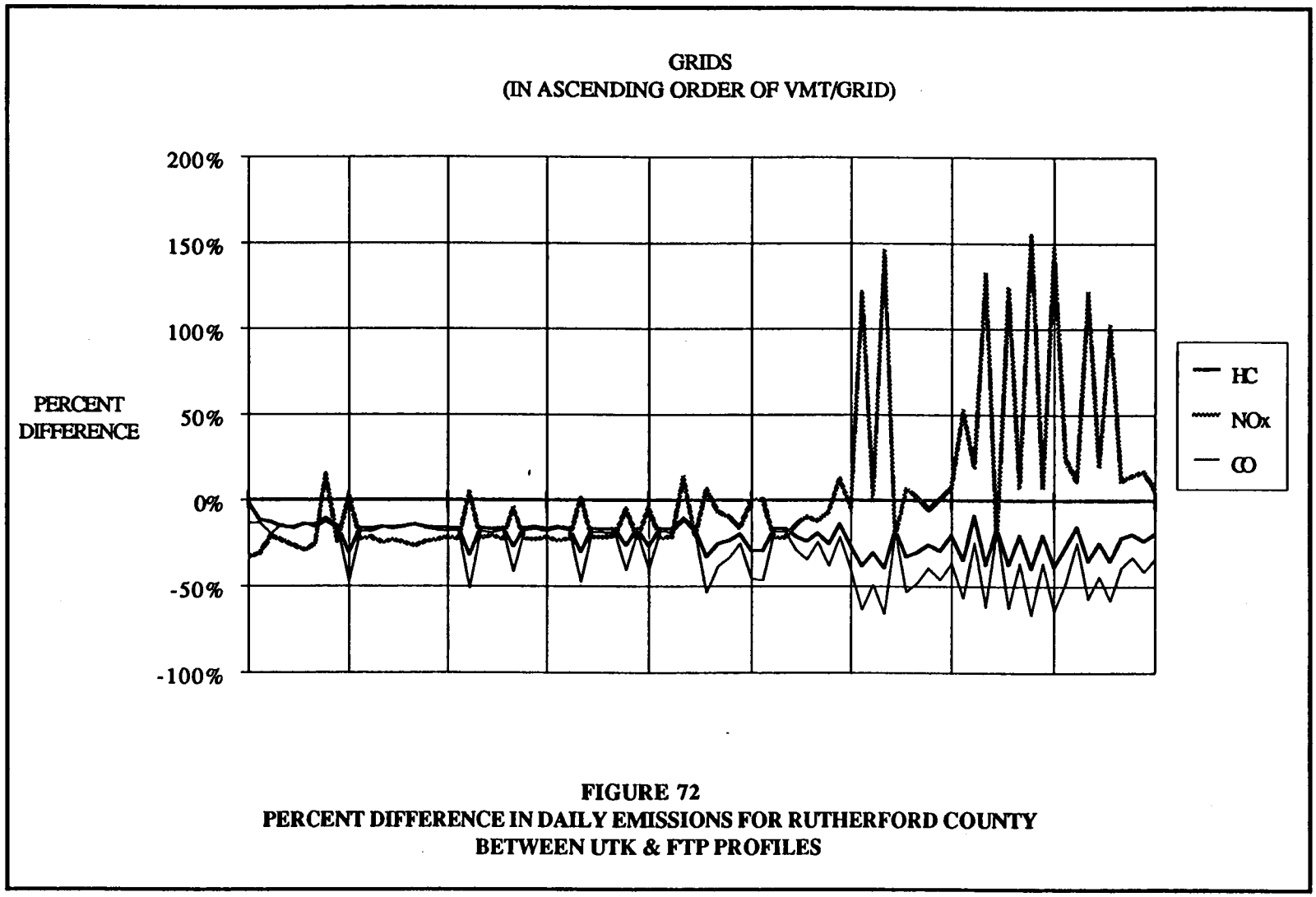


FIGURE 72
PERCENT DIFFERENCE IN DAILY EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES

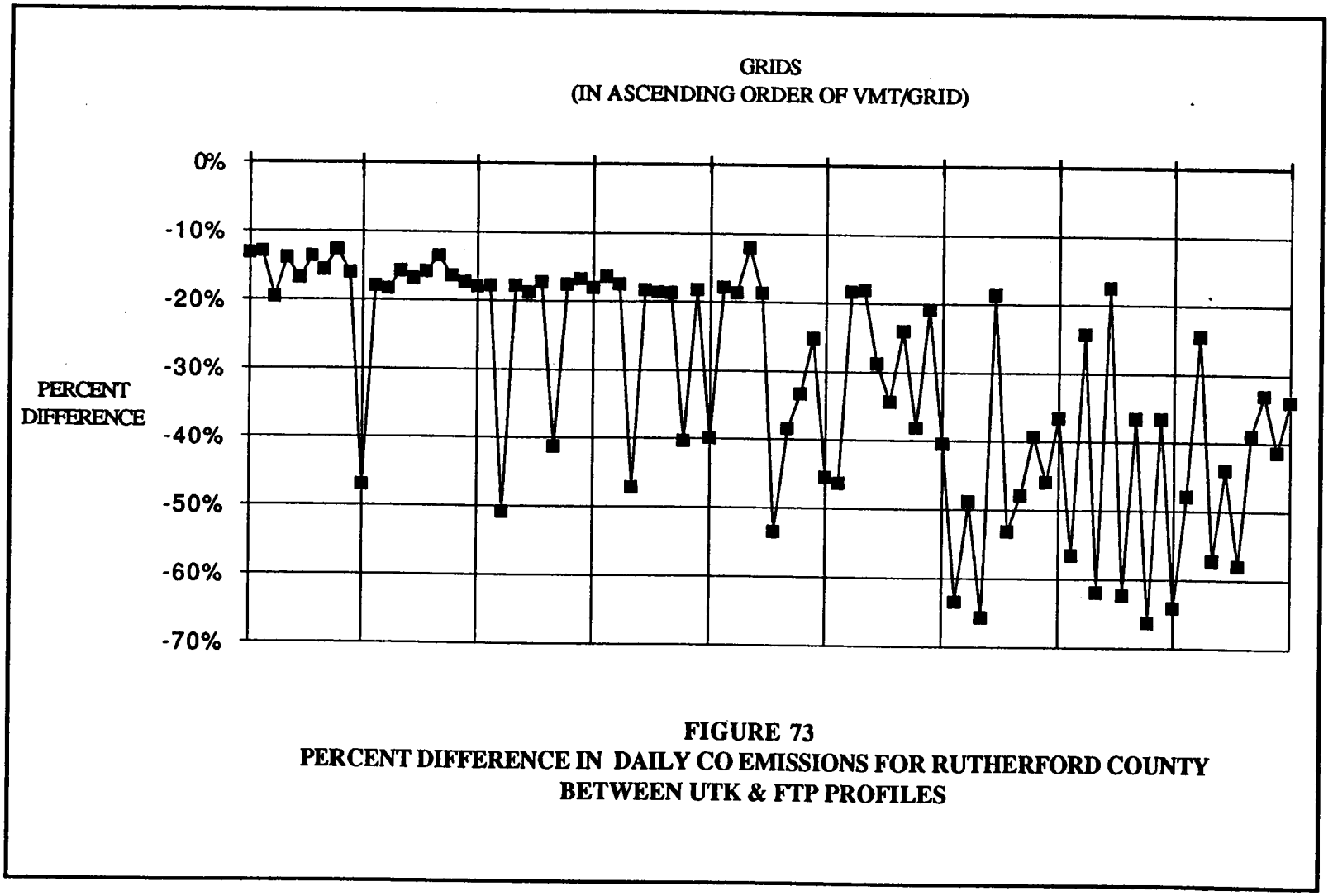


FIGURE 73
PERCENT DIFFERENCE IN DAILY CO EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES

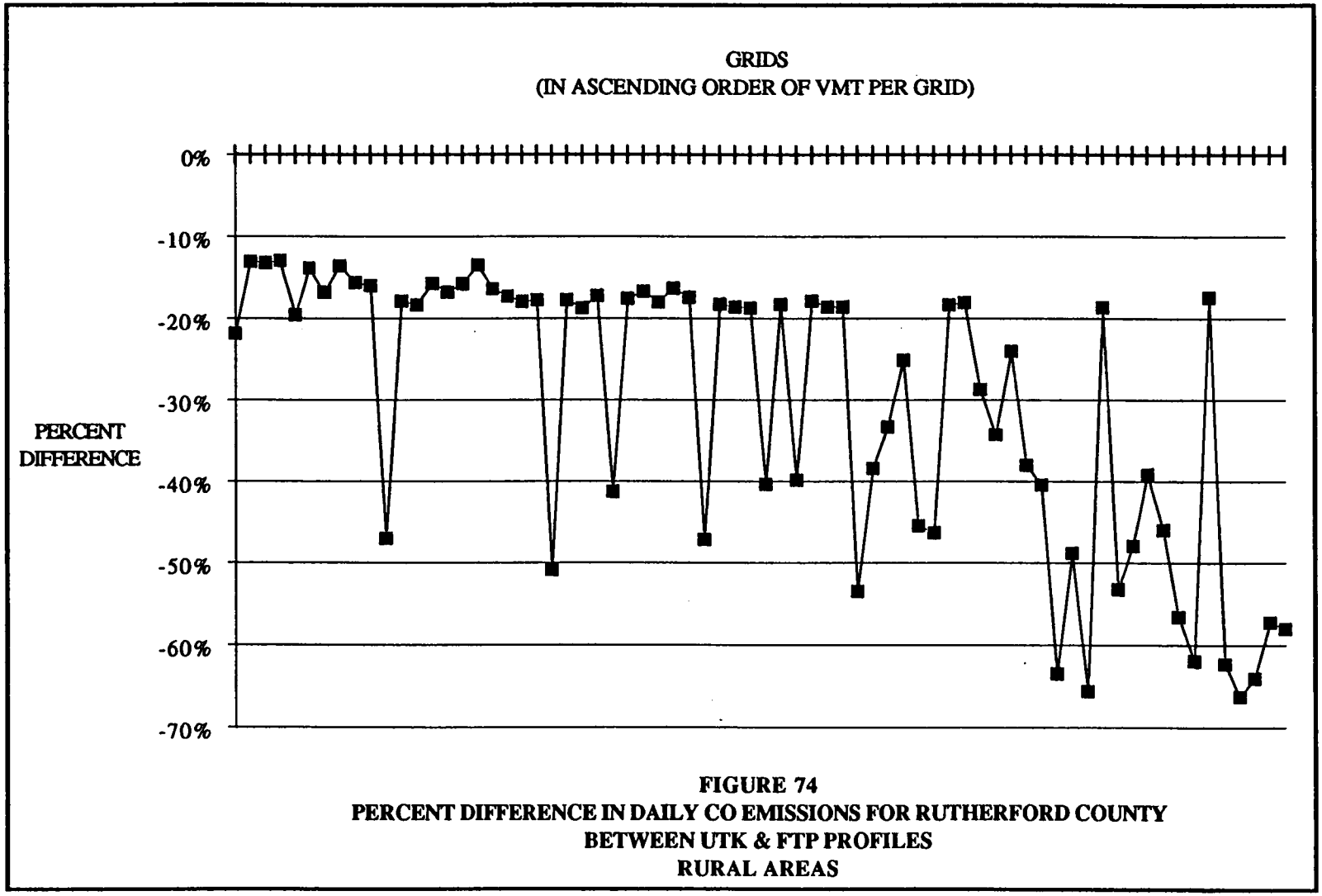


FIGURE 74
PERCENT DIFFERENCE IN DAILY CO EMISSIONS FOR RUTHERFORD COUNTY
BETWEEN UTK & FTP PROFILES
RURAL AREAS

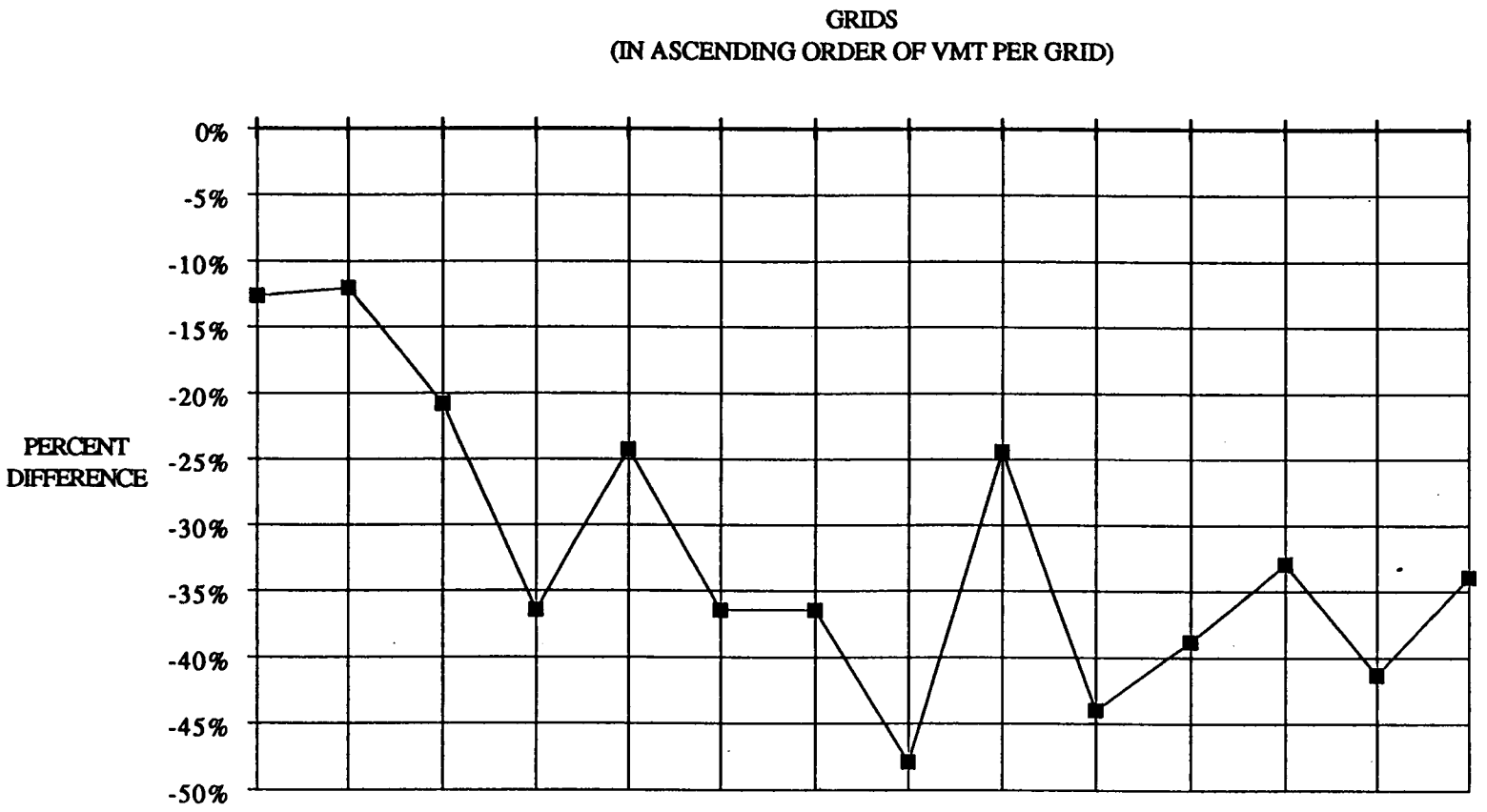


FIGURE 75
PERCENT DIFFERENCE IN DAILY CO EMISSIONS FOR RUTHERFORD COUNTY
BETWEEN UTK & FTP PROFILES
URBAN FRINGE AREAS

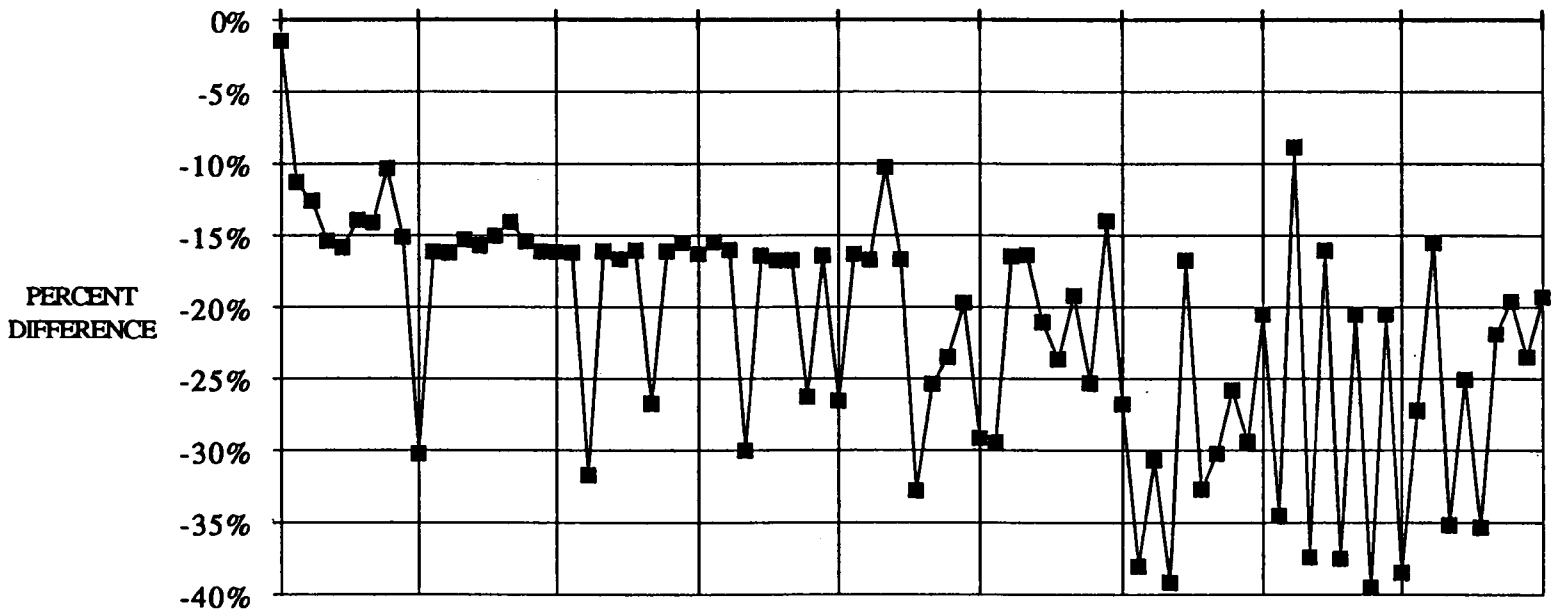


FIGURE 76
PERCENT DIFFERENCE IN DAILY HC EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES

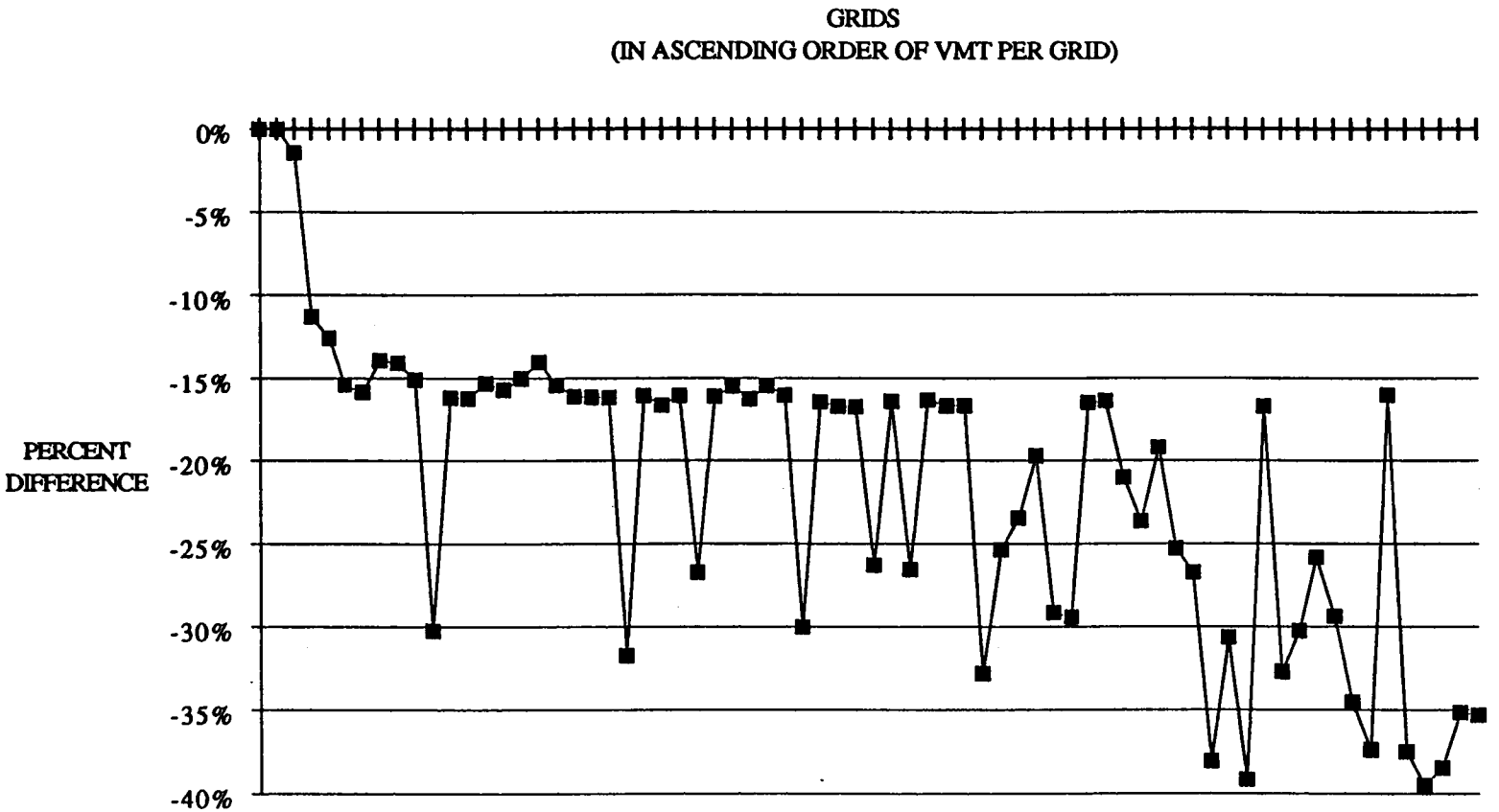


FIGURE 77
PERCENT DIFFERENCE IN HC EMISSIONS FOR RUTHERFORD COUNTY
BETWEEN UTK & FTP PROFILES
RURAL AREAS

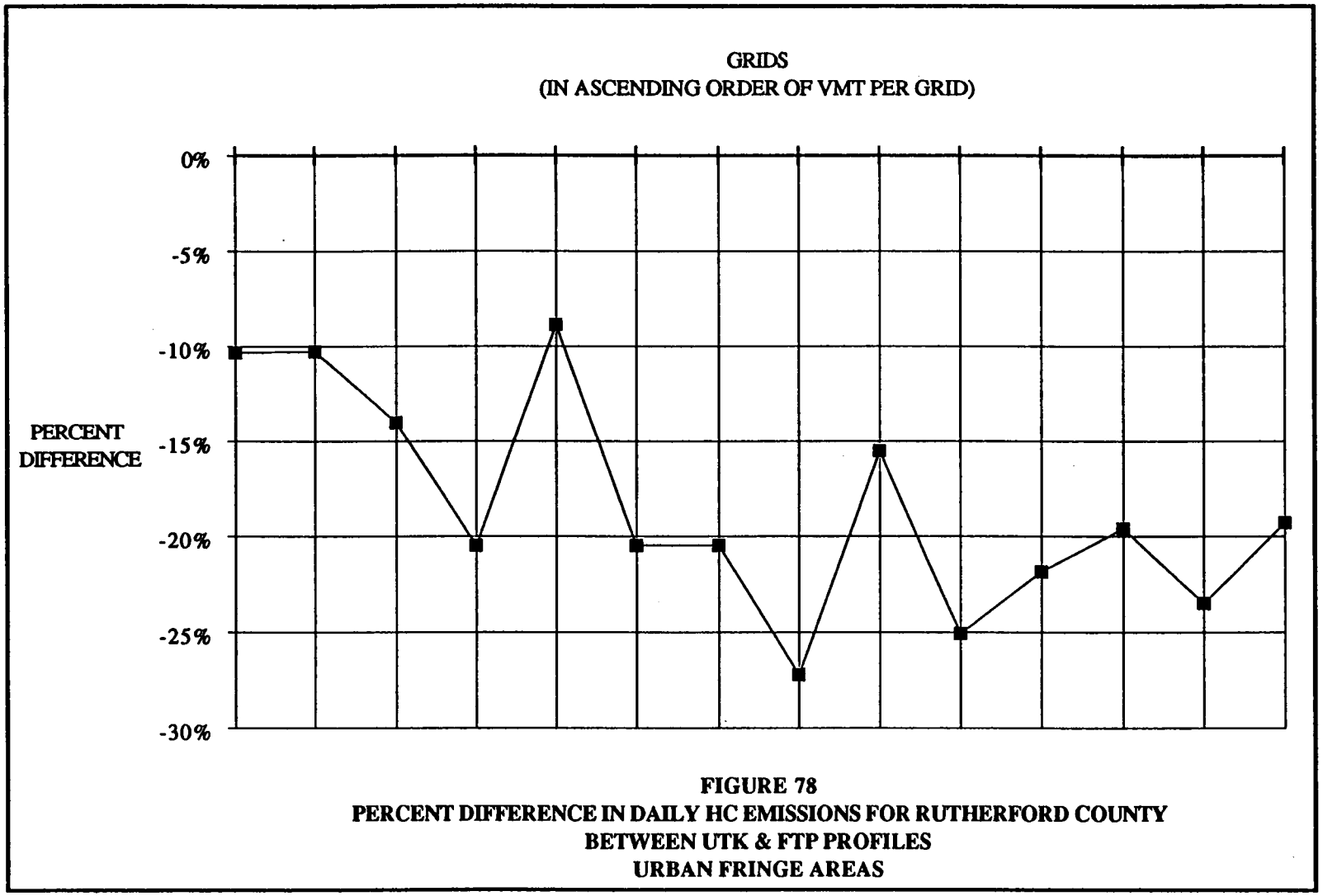


FIGURE 78
PERCENT DIFFERENCE IN DAILY HC EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES URBAN FRINGE AREAS

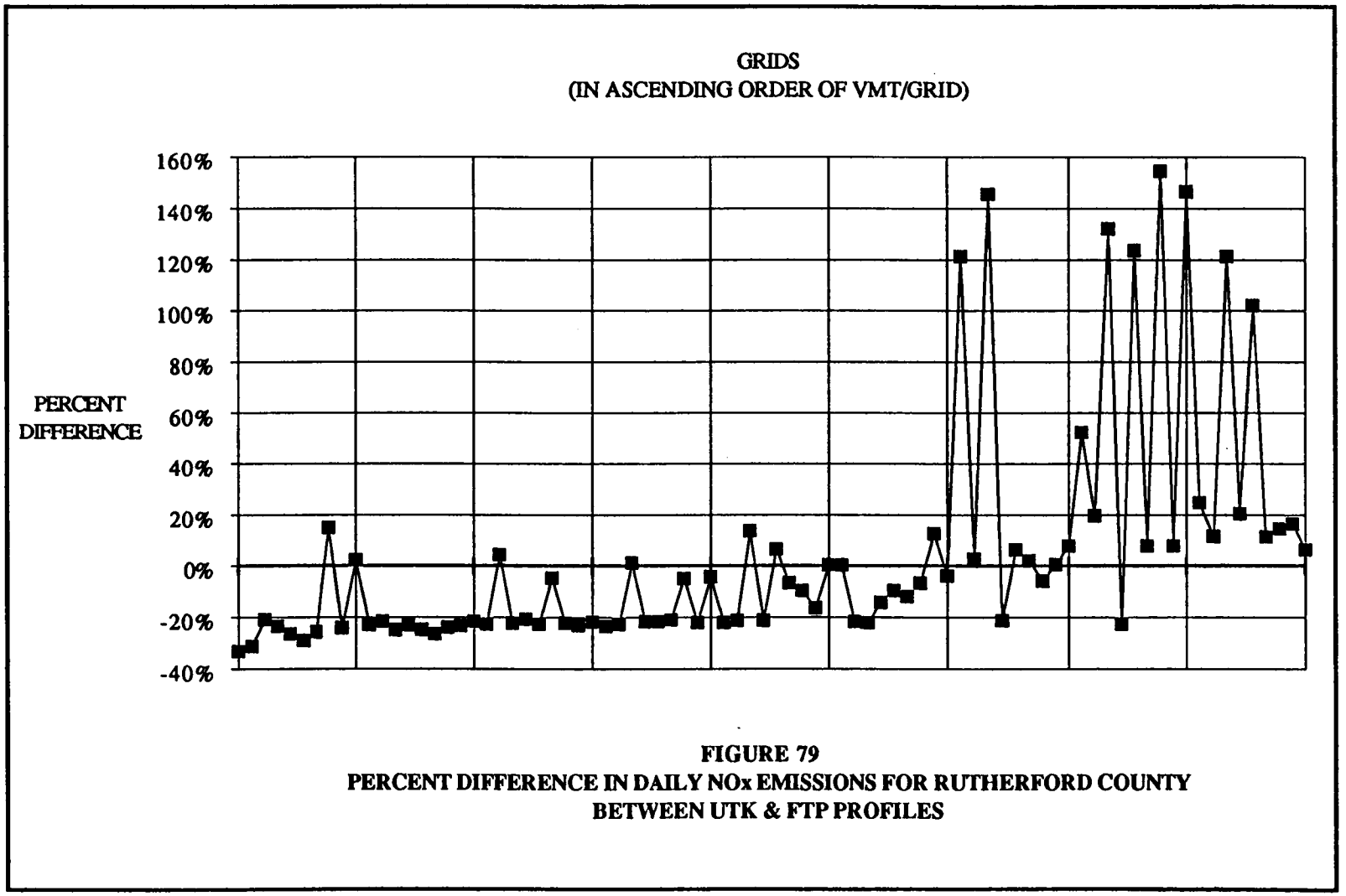


FIGURE 79
PERCENT DIFFERENCE IN DAILY NOx EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES

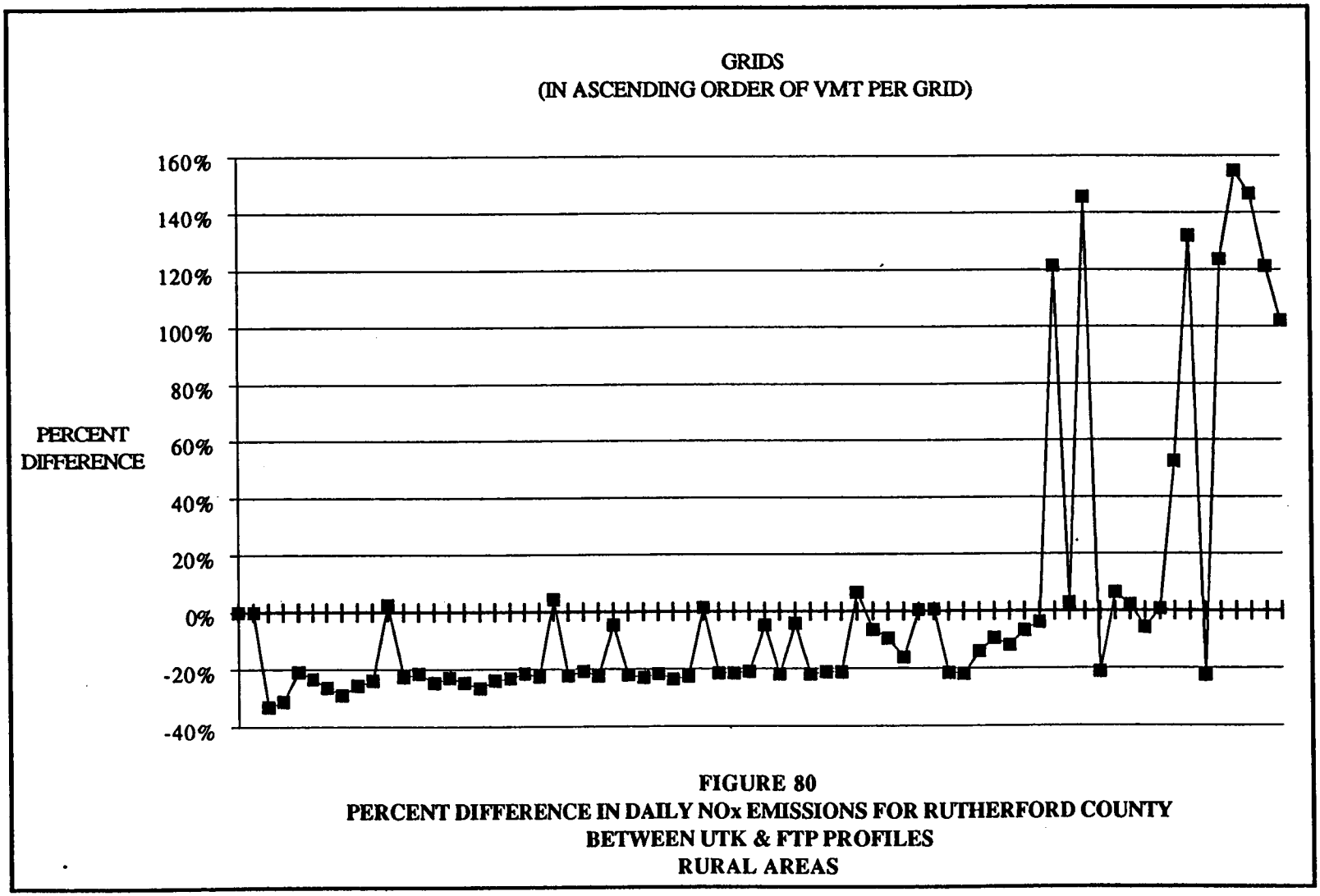


FIGURE 80
PERCENT DIFFERENCE IN DAILY NOx EMISSIONS FOR RUTHERFORD COUNTY BETWEEN UTK & FTP PROFILES RURAL AREAS

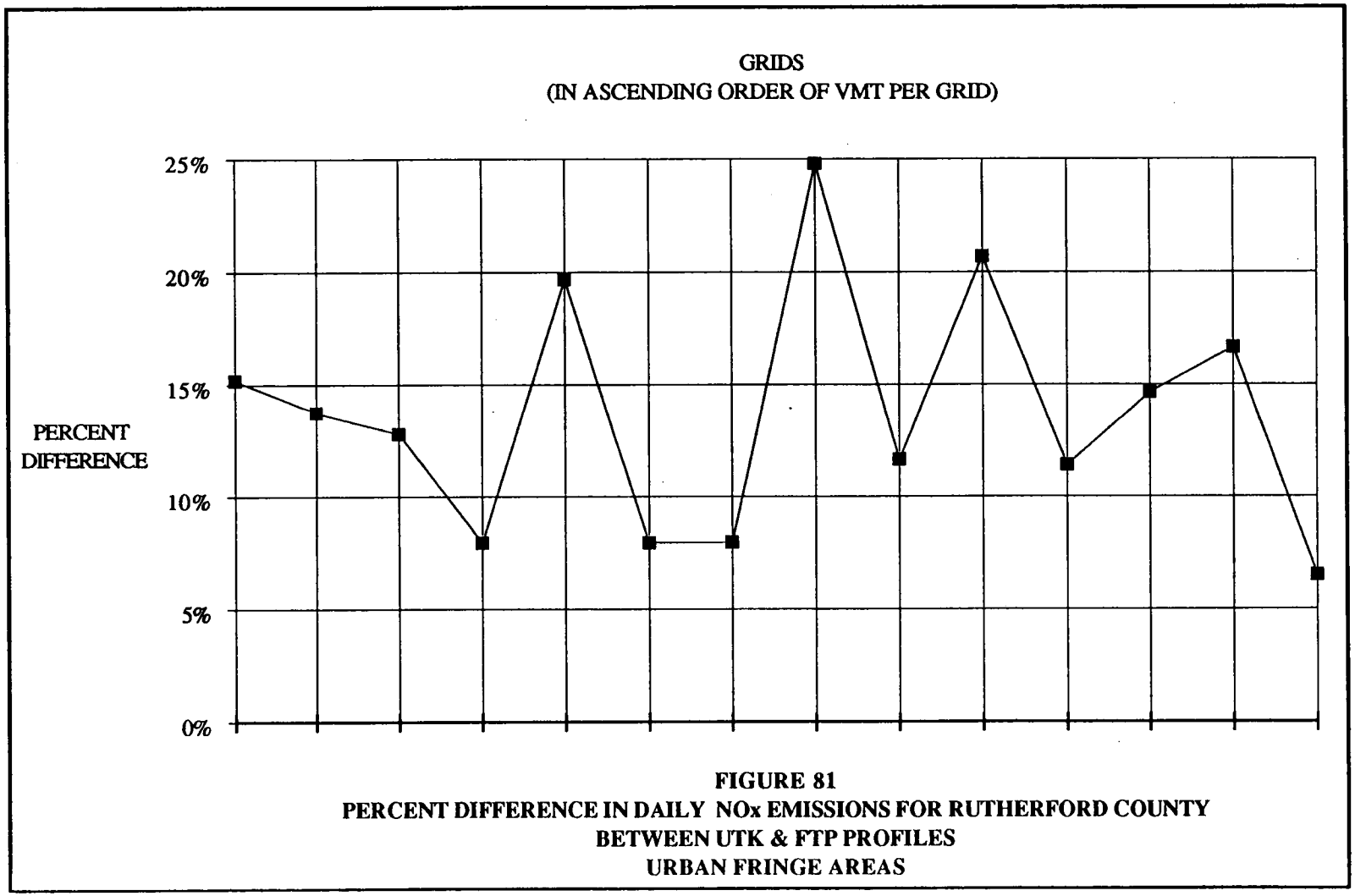


FIGURE 81
PERCENT DIFFERENCE IN DAILY NOx EMISSIONS FOR RUTHERFORD COUNTY
BETWEEN UTK & FTP PROFILES
URBAN FRINGE AREAS

APPENDIX 3

GLOSSARY OF ABBREVIATIONS

(AC)	air conditioner
(ADT)	Average Daily Traffic
(ASTM)	American Society for Testing and Materials
(CAAA's)	Clean Air Act Amendments of 1990
(CBD)	Central Business District
(CFR)	Code of Federal Regulations
(CO)	Carbon Monoxide
(CUTS)	Characteristics of Urban Transportation Systems: A Handbook for Transportation Planning
(DOT)	U.S. Department of Transportation
(EPA)	United States Environmental Protection Agency
(F)	Fahrenheit
(FHWA)	U.S. Federal Highway Administration
(FTP)	Federal Test Procedure
(GVW)	Gross Vehicle Weight
(HC)	Hydrocarbons
(HDDV)	heavy duty diesel vehicles
(HDGV)	heavy duty gasoline vehicles
(HPMS)	Highway Performance Monitoring System
(kg)	kilogram
(km)	kilometer
(LDDT)	light duty diesel trucks
(LDDV)	light duty diesel vehicles
(LDGT1)	light duty gasoline trucks1
(LDGT2)	light duty gasoline trucks2
(LDGV)	light duty gasoline vehicles
(MC)	motorcycles
(mph)	miles per hour
(MPO's)	Metropolitan Planning Organizations
(MVMA)	Motor Vehicle Manufactures Association
(NOx)	Nitrogen Oxides
(NTPS)	Nationwide Personal Transportation Study
(O_3)	photochemical oxidants (0ZONE)
(PCCC)	catalyst cold-start
(PCCN)	non catalyst cold-start
(PCHC)	catalyst hot-start

(RVP)	Reid Vapor Pressure
(SIP)	State Implementation Plan
(SMSAs)	Standard Metropolitan Statistical Areas
(T)	percent trucks on a daily basis
(TCMs)	Transportation Control Measures
(TDOT)	Tennessee Department of Transportation
(Ti)	percent trucks by hour
(UAM)	Urban Airshed Model
(UTK)	University of Tennessee, Knoxville
(UTPS)	Urban Transportation Planning System
(v/c)	volume to capacity ratio
(VMT)	vehicles miles of travel
(VOCs)	volatile organic compounds

VITA

Jerry Don Everett was born in Daytona Beach, Florida on February 8, 1964. He accepted Jesus Christ as his Lord and Saviour and was Baptized on April 9, 1978. He received a Bachelor of Science Degree in Civil Engineering from the University of Tennessee, Knoxville in December of 1988. In August 1991 he will receive a Master of Science Degree in Civil Engineering. from the same university. He will be married to Mary Joyce Odom on August 31, 1991. In September of 1991 he will begin work with the Federal Highway Administration.