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DEVELOPMENT OF A METHODOLOGY FOR ESTIMATING VEHICLE EMISSIONS

Jennifer Armstrong, B.Eng. & Soc.
McMaster University
Hamilton, Ontario, 1998

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Master of Engineering

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Ottawa, Ontario

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The undersigned hereby recommended to the Faculty of Graduate Studies and Research
acceptance of the thesis:

Development of a Methodology for Estimating Vehicle Emissions

Submitted by:
Jennifer Armstrong, B.Eng. & Soc.

in partial fulfillment of the requirements for the degree of Master of Engineering

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August 2000

ABSTRACT

Vehicle emission models enable transportation planners to evaluate the environmental implications of alternative transportation policies and assist decision makers in selecting the most cost effective strategies to improve urban air quality. Travel activity is an important determinant of vehicle emissions. Traditionally, travel demand models were developed separately from vehicle emission models. Today, the need exists for better model integration.

In this research study, a set of tools was developed to predict vehicle emissions in Canada's National Capital Region using output from the regional travel demand model implemented in EMME/2. Travel characteristics are computed within the EMME/2 environment and summarized in an output file. This file is then read into the Emission Calculator, a Visual Basic program developed to estimate criteria pollutants using the U.S. Environmental Protection Agency's MOBILE5 model. The Emission Calculator is also capable of estimating greenhouse gas emissions using fuel consumption equations and greenhouse gas emission factors supplied by the user. Emissions can be summarized according to the link classification scheme, or formatted into a file suitable for importing into EMME/2 for visual display of emission results.

As part of the research effort, input data specific to Ottawa-Carleton was collected, including estimates of intra-zonal travel, temperature, operating mode fractions, fleet characteristics, and commercial vehicle traffic. Sensitivity tests were conducted to determine the sensitivity of emission estimates to changes in input data. Results of the study suggest that vehicle emissions in Ottawa-Carleton will grow by approximately 50% between 1995 and 2021 unless policy changes are implemented or technological solutions can be found.

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INTRODUCTION

1.1 TRANSPORTATION AND THE ENVIRONMENT

Transportation is central to our modern way of life; the well being of our nation depends on our ability to move people and goods efficiently, quickly, and economically. Private automobiles enhance our mobility, allowing people to participate in a wide range of activities essential to human existence. Our desire for mobility, independence, and status has created a society that is dependent on personal vehicles, a dependency that has shaped our urban landscape, and influences our quality of life, health, and relationship to the natural environment.

Transportation systems are an integral part of our communities, our economy, our heritage and our future. The benefits of such systems are significant, yet the negative consequences of automobile dependency cannot be ignored. Indeed, the impact of transportation on the environment has gained increasing attention as air pollution in urban areas continues to affect human health. Transportation is a major source of air pollution; efforts are currently underway to reduce vehicle emissions and improve the quality of urban life. However, the success of such efforts depends on the ability of transportation planners and policy-makers to understand the relationship between vehicle emissions and travel activity. While technological solutions will certainly play a role in reducing vehicle emissions, technology alone is unlikely to solve the problem. Air pollution exists now; the technology and political willpower to eliminate air pollution does not.

Checkel (1996) describes the extent of the problem:

Although vehicle emission rates have been dramatically reduced over the past two decades, the urban air quality problems have not disappeared, particularly in large cities with sensitive climatic conditions like Los Angeles. Other large urban areas (including many Eastern and Midwestern American cities as well as Vancouver and Toronto) have also suffered notable deterioration in air quality, despite tightened vehicle emission standards. This occurs because of the increasing size of urban areas. Large

cities generate more traffic ... so the total amount of pollutants increases... (2)

The cost of air pollution is significant. The Ontario Medical Association estimates that smog costs Ontario more than \$1 billion a year in lost productivity, health care costs, and premature deaths (Duffy 2000; DSS Management 2000). Each year in Ontario, air pollution is responsible for 13,000 emergency room visits, 9,800 hospital admissions, and 47 million sick days for Ontario employees. In Ottawa, over 100 people die each year from poor air quality. Medical costs from air pollution reach \$23 million annually, while lost production costs the city nearly \$29 million.

Environment Canada (2000c) estimates that air pollution contributes to the premature death of over 5000 Canadians each year. A recent study of the effects of urban ambient air pollution on daily mortality rates in Canadian cities found an increase in the death rate when smog is most severe (cited in ACPH 1999).

The Federal, Provincial, and Territorial Advisory Committee on Population Health (1999) notes that environmental pollution is a “significant and fairly consistent worry for the majority of Canadians” (69). Indeed, each year between 1987 and 1996, over two thirds of Canadians have reported that they are very concerned about air quality, while one quarter believe that their health is affected “a great deal” by pollution (ACPH 1999, 69).

Air pollution also impacts the environment. In a comprehensive investigation of the social costs of motor vehicle use in the United States, Delucchi (1998) estimates that air pollution cost Americans between \$35 billion and \$500 billion in 1990-1991. Of this cost, between \$3.3 and \$5.7 billion was associated with damage to agricultural crops. Damage to forests was estimated at between \$0.2 and \$2 billion.

Air quality in Canada has improved significantly since the 1970's due to environmental regulations aimed at reducing air pollution (Environment Canada 2000a). However, the trend over the past decade is more difficult to interpret. While Environment Canada's *National Environmental Indicator Series* shows a decrease in average carbon monoxide and nitrogen dioxide concentrations between 1990 and 1996, the rate of decrease has

slowed considerably compared to previous years (Environment Canada 2000d). At the same time, ground-level ozone concentrations have increased, and airborne particulate concentrations have remained virtually unchanged. The number of ground-level ozone violations has fluctuated between 1990 and 1996; it is difficult to predict how air quality will change in the future based on recent trends.

In Ontario, volatile organic compound (VOC) emissions decreased between 1990 and 1997 (Ontario MOE 1999). However, carbon monoxide and nitrogen oxide emissions have remained relatively stable since 1993. Over this same interval, nitrogen dioxide and airborne particulate concentrations have changed only marginally. Mean annual ozone levels have increased, yet the number of air quality advisories shows no discernable trend. In 1997, Ontario's air quality rating was reported as 'good' or 'very good' 95.5% of the time (Ontario MOE 1999). Although improvements have been made, air quality remains a concern in urban areas across Canada. As Environment Canada (1997b) writes: "Despite the reduction of national levels of common pollutants, poor air quality remains a problem in large urban areas where ... [pollutant] concentrations occasionally reach unacceptable levels" (1-3e).

Numerous human activities contribute to air pollution. However, emissions from motor vehicles are a major source, accounting for over 30% of carbon monoxide emissions, 15% of VOC emissions, and 30% of nitrogen oxide emissions in 1995 (Environment Canada 1998a). According to Environment Canada (1997b), automobiles produce approximately half the pollutants that combine to form ground-level ozone, the primary ingredient in smog.

Automobiles are also a major source of man-made carbon dioxide (CO₂) emissions: emissions that contribute to the greenhouse effect and global warming. The 1998 *Foundation Paper on Climate Change* reports that approximately 11.3% of greenhouse gas emissions in Canada are produced by passenger cars. An additional 3.8% are produced by passenger trucks, while commercial trucks produce nearly 6.2% (Transportation Table 1998). Overall, the transportation sector accounts for 27% of all greenhouse gas emissions in Canada. These emissions have the potential to change local

precipitation patterns, alter ecosystems, and raise sea-levels, affecting crop yields, forests, and water supplies.

Transportation systems provide many benefits, yet the social, economic, and environmental impacts of such systems are far-reaching, and difficult to predict. Careful planning and design is critical to ensure that human and environmental needs are balanced against the need for increased mobility. Policies must be enacted to encourage the development of sustainable urban communities. Such communities can only be achieved if the impacts of transportation are explicitly considered and addressed.

1.2 PROBLEM DEFINITION

As air pollution harms our communities and greenhouse gas emissions threaten our global environment, the ability to model vehicle emissions has become more and more important. Such models allow planners and transportation engineers to quantify the change in vehicle emissions associated with a particular transportation or land use policy. Although policy decisions are rarely based on one criterion alone, information concerning the environmental impacts of alternative policies enables decision makers to make more informed decisions: decisions which not only consider economic costs and benefits, but environmental and social costs and benefits as well. Since vehicle use is expected to increase significantly during the coming decades, automobile pollution will only grow worse unless solutions can be found. This implies that the ability to predict future travel patterns is important in order to derive accurate emission estimates.

Emissions from motor vehicles are a major cause of urban air pollution. Thus, any effort to improve air quality must address vehicle design and operation, as well as travel demand, and driver behaviour. Models have been developed to compute vehicle emissions as a function of travel activity and vehicle characteristics. Such models include emission factor models which are able to forecast nitrogen oxide, hydrocarbon, and carbon monoxide emissions on a regional scale, as well as fuel consumption and greenhouse gas models.

Vehicle emission models are often used in conjunction with travel demand models, which are able to forecast future traffic volumes given changes in the socio-economic environment or transportation network. Although the output from travel demand models becomes the input to vehicle emission models, the models were developed separately, for widely different applications. As a result, model integration is largely nonexistent; it is difficult to evaluate the change in vehicle emissions under different policy scenarios.

Consequently, the need exists to develop a set of tools to integrate travel demand models with vehicle emission models, allowing modellers to investigate changes in vehicle emissions from measures that influence travel behaviour. Such tools will enable decision makers to select the most cost-effective means to improve air quality, and are thus essential for developing sustainable communities.

To date, the Region of Ottawa-Carleton has not considered the impact of vehicle emissions when evaluating transportation policies. However, there is a desire to build new tools, which will allow planners to study the environmental implications of policy decisions. The tools must be capable of interacting with the Region's travel demand model, which has been implemented using the software, EMME/2.

To address the needs of both the Region of Ottawa-Carleton and the larger modelling community, a research study was undertaken. The goals of this study are outlined below.

1.3 GOALS AND OBJECTIVES

The ability to model vehicle emissions is essential if policy makers are to take effective action to improve air quality and reduce greenhouse gases. Consequently, the overriding goal of any transportation-vehicle emission study is to enhance the accuracy of the modelling process, and increase the functionality of existing tools and methods. In Canada, much effort has been focused on forecasting vehicle emissions at the provincial and national level. Statistical techniques are then employed to produce emission estimates at a finer level of detail (EEA 1999). However, considerable work remains to be done at the urban level.

Given the lack of integration between travel demand models and vehicle emission models, the primary objective of this study was to develop a set of tools to estimate vehicle emissions from on-road mobile sources using output from the travel demand model, EMME/2. The tools were developed using data for Canada's National Capital Region. Applying such tools, modellers will be able to investigate future vehicle emissions under different transportation and land-use policies. Moreover, the relationship between vehicle emissions and travel activity can be readily understood.

In general, the study had three main objectives:

- Develop a set of tools to estimate criteria pollutants and greenhouse gases
- Gather input data and compute vehicle emissions for the National Capital Region
- Analyze the sensitivity of emission estimates to changes in input parameters

The emission estimation tools were designed to integrate the travel demand model, EMME/2, with the vehicle emission model, MOBILE5. In addition, the tools were enhanced with the capability to model greenhouse gas emissions. Unlike emissions affecting air quality, greenhouse gas emissions have generally been excluded from vehicle emission models. However, as governments strive to meet greenhouse gas reduction targets and avert global climate change, the ability to model greenhouse gas emissions has grown increasingly important.

An additional objective of the research was to investigate methods to improve the transportation modelling process. In particular, geographic information systems were used to compute the trip length of intra-zonal trips in the National Capital Region, illustrating a potential application of GIS technology in transportation planning. An attempt was also made to account for the impact of commercial vehicles when assigning trips to the transportation network in EMME/2. Traditionally, the congestion from commercial vehicles has been ignored in the travel demand model for the National Capital Region. A further outcome of the research was the development of travel distance and duration values for each vehicle trip captured in the 1995 Origin-Destination Survey. This information can be used for a variety of applications, and is an improvement over the

previous distance and duration values in the survey database, which did not account for differences in travel characteristics throughout the day.

1.4 THESIS ORGANIZATION

This document describes the research effort that was undertaken to develop a set of tools to estimate vehicle emissions in the National Capital Region using output from the regional travel demand model, EMME/2. Chapter 2 provides background information on vehicle emissions modelling, and also highlights the deficiencies of current modelling practice. The research methodology for the study is presented in Chapter 3, along with a description of the study area, and the regional travel demand model used to predict travel activity. Chapter 4 describes the process of obtaining input data, including estimates of intra-zonal travel, temperature, operating mode fractions, fleet characteristics, and commercial vehicle traffic. The analysis periods selected for the study are also described, as well as the road classification scheme. The tools developed to compute vehicle emissions are presented in Chapter 5. A detailed summary table is provided, documenting the data requirements of the emission calculation tools.

Since the input data used to compute vehicle emissions often involves assumptions, numerous sensitivity tests were conducted to determine the impact on vehicle emissions of changes in input data. The results of the tests are presented in Chapter 6. Chapter 7 describes the vehicle emissions that were computed for the National Capital Region for a typical October day in 1995 and 2021. The results of a simple case study are also included, to demonstrate the ability of the emission calculation tools to analyze the environmental implications of alternative transportation policies. Finally, conclusions and recommendations are presented in Chapter 8. Additional information is included in the appendix of the report, including summary tables and computer source code.

The research study described in Chapters 2 to 8 is the result of over 12 months of work conducted in collaboration with the Region of Ottawa-Carleton and Carleton University. The research has encompassed several phases, including literature review, data collection, computer programming, modelling, and analysis, with the ultimate goal of contributing to

the extensive knowledge-base of vehicle emissions modelling available in the literature. The research seeks to improve upon existing methods and tools, but is subject to certain limitations which will only be overcome with further research and investigation, as members of the research community stretch the boundaries of understanding even further.

2 BACKGROUND

2.1 INTRODUCTION

While vehicle emissions modelling is mandated by law in the United States through such acts as the Clean Air Act and the Intermodal Surface Transportation Efficiency Act, Canada has no such legislative framework governing air quality analyses. However, as urban air pollution begins to exceed acceptable limits, modelling mobile source emissions will grow increasingly important, not only to predict future levels of pollutants, but also to evaluate alternative policies for mitigating transportation air quality impacts. To date, Canadian attempts to model vehicle emissions have been largely dependant on American technology, in particular, the MOBILE series of models produced by the U.S. Environmental Protection Agency (EPA). Since the United States has a much longer history of modelling vehicle emissions, in part because of more severe levels of urban air pollution, much can be learned from the American experience.

This chapter is intended to provide a background to vehicle emissions and vehicle emissions modelling. The most important mobile source pollutants are described, including their health impacts and method of formation. In addition, the basic procedure for modelling vehicle emissions is discussed, as well as deficiencies with current modelling practice.

For more information, Environment Canada (1997b), Chevron (1996), U.S. EPA (2000b) and Horowitz (1982) provide an excellent introduction to transportation related air pollution, vehicle emissions modelling, and emission control measures such as alternative fuels, inspection and maintenance programmes, and travel demand management.

2.2 VEHICLE EMISSIONS OVERVIEW

Vehicle emissions result primarily from the combustion of fossil fuels. Under ideal conditions, fuel and air combine to form carbon dioxide, water, and nitrogen. However,

under typical vehicle operating conditions, fuel combustion is incomplete, leading to the combustion by-products illustrated in Equation 2-1.

With the exception of water vapour, these combustion by-products are considered pollutants: pollutants which impact human health, harm the environment, and degrade our society's quality of life*. Although these pollutants are formed during combustion and are emitted from the tailpipe as exhaust emissions, they result from widely different mechanisms. Nitrogen oxides are formed during the high heat of combustion. At elevated temperatures, reactions occur between the nitrogen and oxygen present in air. As a result, excess oxygen in the combustion chamber increases nitrogen oxide emissions.

In contrast, carbon monoxide is formed due to incomplete combustion of organic fuels. An intermediate product of combustion, CO is rapidly oxidized to CO₂ under ideal conditions. However, if insufficient oxygen is present in the combustion chamber, it is impossible to convert all the fuel carbon to carbon dioxide, leading to high levels of CO in the vehicle exhaust. Carbon monoxide emissions are particularly high during deceleration and idling. Under conditions of high power demand, enrichment of the fuel-air mixture is required: a process which reduces the amount of oxygen available for combustion, increasing CO emissions. Indeed, the rich fuel-air mixture required after engine start-up contributes to incomplete combustion, causing CO emissions to be highest during this phase of vehicle operation.

Not surprisingly, hydrocarbon emissions are also affected by the fuel-air mixture: the more fuel vapour in the combustion chamber, the more unburned hydrocarbons that are able to escape through the vehicle exhaust system. Although most fuel is burned in the engine, between one and five percent escapes unburned, depending on the engine design, operating temperature, air-fuel ratio, fuel system deposits, and engine condition.

* Nitrogen oxides, hydrocarbons, and carbon monoxide are commonly referred to as "criteria" pollutants since they are regulated by the U.S. Federal Government under the Clean Air Act

While most people only associate automobile pollution with exhaust, or "tailpipe" emissions, evaporative emissions can also be significant. Indeed, there are two primary mechanisms which contribute to vehicle emissions: combustion, which is associated with the vehicle exhaust system, and evaporation, which is associated with the fuel storage and delivery system.

Evaporative emissions consist entirely of hydrocarbons which escape as vapour from a number of locations in the vehicle. Of all the hydrocarbons emitted from a vehicle, the U.S. Environmental Protection Agency estimates that over half are produced through evaporation (Chevron 1996). Highly dependent on temperature, these emissions tend to have a different composition than hydrocarbons which escape from the combustion chamber as vehicle exhaust. In general, evaporative hydrocarbon emissions contain no combustion products. Moreover, since they are formed from gasoline vapour, their composition tends to be weighted towards fuel components with lower boiling points. Evaporative emissions can be classified as either hot soak, diurnal, running loss, resting loss, refueling loss, or crankcase. These emission categories are defined in Table 2-1, which is based on a workshop presented by the U.S. Department of Transportation for transportation air quality analysis (U.S. DOT 1994).

When modelling vehicle emissions, it is important to consider both evaporative and exhaust emissions. Figure 2-1 summarizes the types of emissions associated with motor vehicle use. In addition to the emissions illustrated in Figure 1-1, motor vehicles also produce toxic emissions such as benzene, formaldehyde, acetaldehyde, 1,3 butadiene, and particulate matter (PM_{10} , $PM_{2.5}$). Many of these emissions are known or suspected carcinogens. While some are produced during the combustion process, others are present in gasoline, and are released as fuel evaporates or escapes from the engine unburned. Air toxics can also be formed through secondary chemical reactions in the atmosphere. Although hazardous air pollutants are not addressed in this report, these compounds have been the focus of recent regulation and their importance in human health issues should not be overlooked.

Vehicle emissions are influenced by a number factors. Indeed, both traffic conditions and driver behaviour have a significant impact on CO, NO_x, and VOC emissions. As vehicles accelerate, decelerate, or idle at an intersection, emissions increase. The mode of vehicle operation is also important, since exhaust emissions tend to be highest immediately following engine start-up. For light-duty vehicles, three modes of operation are defined, each with different emission characteristics. After a vehicle is started, it operates in either a cold transient or hot transient mode until stabilized conditions have been achieved. Whether the starting mode is classified as hot or cold depends on the length of time the engine has been turned off and the type of emission control equipment present. Typically, vehicle emissions are highest during cold transient operation, and lowest during hot stabilized operation.

According to data from the California Air Resources Board, the transient start mode accounts for nearly 34% of the hydrocarbon emissions produced by a standard 1990 light-duty automobile during a 20 mile round trip in the California Bay Area (cited in Outwater and Loudon 1994; Loudon and Quint 1993). During the transient modes, elevated HC and CO emissions occur due to the rich fuel-air mixture which is required to optimize engine performance while the engine is cold. Moreover, catalytic control systems function less efficiently when operating under cold conditions, causing emissions of all three primary pollutants (CO, HC, and NO_x) to be higher until a hot stabilized mode of operation is reached. While levels of CO and HC are significantly higher during the transient modes, NO_x emissions increase only moderately since NO_x emissions are largely unaffected by the fuel-air mix.

In their investigation of emission model sensitivity, Miller et al. (1995) found that, at an ambient temperature of 32 °F, CO emissions were three times higher during cold start operation than when the engine had warmed to a stabilized condition. Emissions of volatile organic compounds* (VOC's) were over five times higher. At a warmer ambient temperature (75-95 °F), cold start emissions were less severe; however, emissions of both VOC's and CO were higher than during hot stabilized operation by a factor of two. In

* Volatile organic compounds are hydrocarbon emissions, excluding methane and ethane

contrast, NO_x emissions were found to be less sensitive to operating mode, with emissions only slightly higher during cold start operation.

While the operating mode is important, so too is the type of vehicle. Gasoline-powered vehicles emit high amounts of CO, VOC's and NO_x. On the other hand, diesel-powered vehicles emit high amounts of particulate matter and NO_x, but only small amounts of CO and VOC's. Emissions are also impacted by the characteristics of the gasoline. Adjusting the amount of sulfur, oxygenates, olefins, aromatics, and benzene in gasoline will change the overall composition and quantity of emissions. Indeed, reformulated gasolines have been developed in an attempt to control emissions. In the summer, fuels with a lower vapour pressure are sold in an attempt to reduce evaporative VOC emissions. In the winter, oxygenates are added to gasoline to increase the amount of oxygen in the combustion chamber, reducing CO emissions.

Alternative fuels such as propane, natural gas, methanol and ethanol also have the potential to reduce emissions, but only if vehicle technology is properly adapted to the new fuel (Environment Canada 1997b). To date, such fuels are not in widespread use, and current vehicle emission models are unable to distinguish between fuel types (Checkel 1996). Work is currently underway to develop “zero-emission” vehicles which are powered by electricity or hydrogen. As the market penetration of these vehicles increases, their effect on vehicle emissions must be incorporated into existing models to obtain accurate emission forecasts.

Other factors which influence vehicle emissions include:

- operating speed
- temperature
- trip duration
- vehicle maintenance

These factors are included in vehicle emission models, and are discussed in detail in Section 2.6.3.

Table 2-1 Categories of Evaporative Emissions

Category	Description
Hot Soak	Emissions from the carburetor or fuel injector that occur when the engine is turned off
Diurnal	Results from "breathing" of the gasoline tank due to temperature fluctuations over the 24-hours in a day
Running Loss	Losses that occur while the vehicle is being operated as more fuel is emitted into the emissions control canister than can be purged from it
Resting Loss	Emissions that result from vapour permeating the evaporative emission control system or from liquid fuel leaks
Refueling Loss	There are two components, vapour space displacement and spillage, both of which occur while a vehicle is being refueled
Crankcase	Not true evaporative emissions, but are defined as those that result from defective positive crankcase ventilation valves

(adapted from U.S. DOT 1994, Module 2)

(adapted from Environment Canada 1997b, 1-2e)

Figure 2-1 Formation of Vehicle Emissions

2.3 POLLUTANTS OF INTEREST

Each of the pollutants associated with motor vehicle activity has important consequences for human health and the environment. It is not the intent of this report to describe in detail the precise chemical formation of these pollutants or their health and environmental impacts. However, a basic understanding of these pollutants is essential, not only to appreciate the implications of model results, but also to illustrate why efforts to reduce emissions are so important.

The primary pollutants associated with vehicle operation are described in Table 2-2. Nitrogen oxides produced during combustion react in the atmosphere to form acid rain and ground level ozone. Carbon monoxide reduces the ability of blood to carry oxygen. Carbon dioxide is a naturally occurring compound which poses no direct danger to human health; however, it is one of the primary greenhouse gases, and as such, it is believed to be a major contributor to global climate change.

Ground-level ozone is also an important pollutant associated with vehicle operation, particularly in urban areas. As one of the main ingredients of smog, ozone can have a severe impact on human health and vegetation. However, ozone is not emitted from vehicles directly. Instead, ozone is formed through a series of chemical reactions in the earth's atmosphere as hydrocarbons and nitrogen oxides combine in the presence of sunlight. As such, it is impossible to estimate ozone formation using traditional vehicle emission models. Instead, these models are used to predict hydrocarbon and nitrogen oxide emissions, the precursors to ozone. To obtain ozone concentrations for a particular area, photochemical dispersion models must be used. Since ozone formation requires sunlight, the highest concentrations of ozone occur during the summer, typically during the afternoon.

According to Environment Canada (1997b), the average Canadian automobile produces over five tonnes of emissions annually: emissions that include carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC). Over 57 million tonnes of CO₂ were produced by Canadian automobiles in 1994, representing 10% of the

national total. In Ontario, the transportation sector produced nearly 30% of all greenhouse gas emissions in 1996. Of this, light-duty vehicles contributed nearly 54% (Neitzert et al. 1999). Estimates from 1995 indicate that approximately 20% of the volatile organic compounds (VOC's) released in Canada can be attributed to transportation (Environment Canada 1998a). This figure increases to 40% for CO and 50% for NO_x. Light duty vehicles such as passenger cars and trucks account for approximately 15% of VOC and NO_x emissions, and almost 30% of CO emissions. Clearly, emissions from motor vehicles contribute significantly to Canadian air quality. Thus, any efforts to improve air quality must necessarily address motor vehicle design, operation, and maintenance, as well as vehicle activity and driver behaviour.

2.4 VEHICLE EMISSIONS AND AIR QUALITY

Since the early 1970's, Canadians have monitored air quality in urban areas. The National Air Pollution Surveillance (NAPS) network was established for this purpose, and encompasses over 130 air quality monitoring stations across Canada. National Ambient Air Quality Objectives for common air pollutants have been incorporated into the Canadian Environmental Protection Act. However, it should be emphasized that vehicle emissions and air quality are two distinct concepts. Air quality relates to the concentration of various pollutants in the atmosphere, and is affected by such factors as air movement and temperature, as well as the amount of pollutants released at a particular location. These pollutants can include vehicle emissions, which vary both temporally and spatially as a result of patterns in vehicle activity.

While emissions are clearly related to air quality, it is air quality that impacts human health. Although the level of vehicle emissions along a roadway may be constant, air quality can vary significantly depending on the level of development and the ability of pollutants to disperse. The ultimate goal of any transportation - air quality modelling exercise is to predict pollution concentrations which can then be related to impacts on human and environmental health. However, air quality models can only be as accurate as the emission estimates used as input. Consequently, much effort has been directed at

improving mobile source emission estimates, not only in the environmental field, but also in the transportation field. Since regional travel patterns are such an important determinant of vehicle emissions, transportation engineers are often called upon to provide estimates of vehicle activity data, such as average speed, operating mode, and vehicle-kilometers travelled. These data are then used in vehicle emission models, such as the MOBILE model described in Section 2.5.

Table 2-2 Motor Vehicle Emissions: Health and Environmental Impacts

Automobile Pollutant	Description	Method of Formation	Health Impacts	Environmental Impacts
Nitrogen Oxides (NO _x)	<ul style="list-style-type: none"> Nitric oxide (NO) is the major NO_x component and oxidizes into nitrogen dioxide (NO₂) in the presence of hydrocarbons and sunlight In the atmosphere, NO₂ reacts with hydrocarbons to form ozone or with water to form nitrate (NO₃), a significant source of acid rain 	<ul style="list-style-type: none"> Various compounds of nitrogen and oxygen are formed during high temperature combustion Released into the atmosphere through the vehicle exhaust system 	<ul style="list-style-type: none"> Odour Increased sensitivity of asthmatics and those suffering from bronchitis NO₂ is a lung irritant which can produce pulmonary edema at high concentrations Increased susceptibility to respiratory infections in young children and the elderly 	<ul style="list-style-type: none"> NO₂ reacts with water to form nitrate (NO₃), a source of acid rain Acid rain accounts for an annual loss of \$197 billion in commercial forest wood products and a further \$1.3 billion due to recreation and wildlife habitat destruction NO₂ contributes to the corrosion of metal and degradation of textiles, rubber and polyurethane NO₂ is associated with suppressed vegetation growth NO₂ contributes to ground-level ozone formation NO₂ contributes to stratospheric ozone depletion
Carbon Monoxide (CO)	<ul style="list-style-type: none"> CO is a colourless, odourless and tasteless gas Personal vehicles are one of the main sources of CO Cars operating at colder temperatures (during winter or engine warm-up) produce significant quantities of this poisonous gas 	<ul style="list-style-type: none"> Produced as a result of incomplete fuel combustion Released into the atmosphere through the vehicle exhaust system 	<ul style="list-style-type: none"> CO reduces the ability of the blood to carry oxygen Smokers, persons with heart disease, and those with anemia are especially sensitive Greater susceptibility to respiratory infections in children and the elderly 	<ul style="list-style-type: none"> CO released into the atmosphere depletes the atmosphere's supply of hydroxyl radical (OH) which is the main natural cleansing agent of the atmosphere. As a result, CO emissions contribute to increases in methane, partially halogenated CFCs and the formation of ozone under certain NO_x conditions

Table 2-2 Continued -- Motor Vehicle Emissions: Health and Environmental Impacts

Automobile Pollutant	Description	Method of Formation	Health Impacts	Environmental Impacts
Hydro-Carbons (HC)	<ul style="list-style-type: none"> A numerous and chemically diverse group of non-methane hydrocarbons and volatile organic compounds (VOC's) Specific compounds include benzene, polycyclic organic matter, acetaldehyde, formaldehyde, and 1,3-butadiene VOC's are important in the formation of ozone VOC's have at least one carbon atom and evaporate easily 	<ul style="list-style-type: none"> Released as fuel evaporates in the fuel storage and delivery system Evaporative HC emissions can be classified as hot soak, diurnal, running loss, resting loss, or refueling loss emissions Amount of evaporation is highly dependant on temperature HC's are also released as unburned fuel escapes through the exhaust system 	<ul style="list-style-type: none"> Many individual VOC's (e.g. benzene) are suspected of having human health effects ranging from carcinogenicity to neurotoxicity Some hydrocarbons from diesel emissions are carcinogenic 	<ul style="list-style-type: none"> VOC's contribute to the formation of ground-level ozone
Carbon Dioxide (CO ₂)	<ul style="list-style-type: none"> CO₂ is a gas that comes from the decay of materials, respiration of plants and animals and the natural and human-induced combustion of materials and fuels Since the industrial revolution, the natural cycle of release and absorption of CO₂ in the atmosphere has become unbalanced due to an increase in human-produced CO₂ 	<ul style="list-style-type: none"> A direct product of fuel combustion Released into the atmosphere through the vehicle exhaust system 	<ul style="list-style-type: none"> As a greenhouse gas responsible for global warming, CO₂ may have several indirect impacts on human health, including deaths due to: heat waves, dramatic weather events, and increased transmission of vector-borne and infectious diseases 	<ul style="list-style-type: none"> CO₂ is the most significant greenhouse gas contributing to global warming Global warming is expected to: <ul style="list-style-type: none"> raise sea levels, causing coastal flooding change local climate conditions and precipitation patterns. Such changes may potentially harm forests, crop yields, and water supplies, as well as natural ecosystems

Table 2-2 Continued -- Motor Vehicle Emissions: Health and Environmental Impacts

Automobile Pollutant	Description	Method of Formation	Health Impacts	Environmental Impacts
Ozone (O ₃)	<ul style="list-style-type: none"> Ozone is not a direct by-product of combustion but is formed when NO_x and VOC emissions combine in the presence of sunlight Vehicle emission models do not predict ozone formation, only the precursors of ozone, NO_x and VOC's 	<ul style="list-style-type: none"> Formed in the atmosphere (not emitted from vehicles directly) 	<ul style="list-style-type: none"> Decrease in lung function Eye irritation Decreased immune function Possible long-term role in the development of chronic lung disease 	<ul style="list-style-type: none"> Reduced agricultural productivity in crops such as soybeans, tomatoes, potatoes, and corn Reduced growth rate in trees including red spruce, yellow pine, and sugar maple Ground-level ozone is a global warming agent
Suspended Particulates	<ul style="list-style-type: none"> Suspended particulates are small particles of solid or liquid matter found in most fuel emissions Are found in significantly higher quantities in diesel emissions 	<ul style="list-style-type: none"> Escape through the exhaust system with gaseous emissions Also formed from dust and tire wear 	<ul style="list-style-type: none"> Small particles can penetrate lungs and cause respiratory infections Toxic particles can be taken into the blood stream Effects vary with the type of particulates 	<ul style="list-style-type: none"> Decreased visibility Aesthetic damage to buildings
Nitrous Oxide (N ₂ O)	<ul style="list-style-type: none"> Nitrous oxide is a greenhouse gas that is produced both naturally, as well as from agricultural, industrial, and waste-management activities Motor vehicles are a major source of nitrous oxide 	<ul style="list-style-type: none"> Formed during combustion of fossil fuels 	<ul style="list-style-type: none"> As a global warming agent, N₂O may have several indirect impacts on human health, including deaths due to: heat waves, dramatic weather events, and increased transmission of vector-borne and infectious diseases 	<ul style="list-style-type: none"> Contributes to global warming Although N₂O emissions are much lower than CO₂ emissions, N₂O is approximately 310 times more powerful than CO₂ at trapping heat in the atmosphere

(Adapted from Environment Canada 1997b, 2-6c; Additional information from Chevron 1996, U.S. EPA 2000a and U.S. DOT 1994)

2.5 OVERVIEW OF MODELLING TOOLS

Vehicle emission models have been developed for a wide range of applications. Anderson et al. (1996) describe the spectrum of models currently available. These range from macro-scopic “average speed” models such as MOBILE5 to micro-scale models which simulate the instantaneous behaviour of individual vehicles on a second-by-second basis. Although emissions are highly dependent on vehicle accelerations, decelerations, and idle periods, average speed models are based on driving cycles which attempt to approximate typical driving conditions. In such models, emission rates are assigned on the basis of average travel speed. Slower speeds are associated with frequent accelerations, decelerations, and stops, while higher speeds correspond to highway cruising at constant speed. Certainly, average speed models cannot provide the same level of accuracy as models which track vehicle motion. However, average speed models can be readily implemented using existing transportation planning models without extensive model redevelopment and data collection. Indeed, average speed emission models are often used in conjunction with travel demand models to forecast regional emission levels.

To estimate emissions at a finer level of detail, traffic operation models are required. While transportation planning models predict future traffic volumes based on anticipated socio-demographic and economic trends, traffic operation models “are aimed at providing solutions to detailed traffic operations and system performance issues at the facility level” by simulating vehicle behaviour on the transportation network (Delcan 1998, 17)*. Such models typically incorporate fuel consumption and vehicle emission algorithms which account for the travel behaviour of individual vehicles or vehicle groups. Outputs also include detailed estimates of vehicle delay and travel time. Traffic operation models vary widely in level of detail and functionality; however, in all cases, the data requirements of such models preclude all but small-scale modelling exercises.

* Appendix A provides a detailed description of traditional travel demand models. For additional information on the differences between travel demand models and traffic operation models, the reader is referred to Delcan (1998).

While it is important to understand the range of models available to predict vehicle emissions, the remainder of this report focuses on the macro-scopic average speed models used to forecast regional emission levels.

2.6 EMISSION FACTOR MODELS

2.6.1 Description

At the regional level, vehicle emissions are typically modelled using emission factor models. These models produce a composite emission factor which is multiplied by the level of vehicle activity in an area to give an overall estimate of vehicle emissions.

Given the range of vehicle models manufactured over the past two decades, it is impossible to analyze each vehicle model individually. Instead, emission factor models produce composite emission factors which approximate the emission characteristics of the entire vehicle fleet (U.S. DOT 1994). Perhaps the most well-known emission factor model is the MOBILE model developed by the U.S. Environmental Protection Agency. Every state except California is required to use this model in preparing emission inventories. In Canada, the most recent version of the MOBILE model (MOBILE5) was adapted to reflect Canadian conditions, such as differences in emission control technology and vehicle age. However, the underlying structure of the model was unchanged. Consequently, the MOBILE model has become the North American standard for predicting emissions on a regional scale.

In emission factor models, composite emission factors are developed for each pollutant of interest. In the MOBILE model, these pollutants include NO_x, HC, and CO. Since different classes of vehicles have different emission characteristics, an emission factor is computed for each type of vehicle present in the fleet. These factors are then weighted together to form composite emission factors which are output from the model. Multiplying this output by the amount of vehicle activity in the region provides an estimate of vehicle emissions for each pollutant analyzed.

The MOBILE model recognizes eight vehicle classes, including:

- Light Duty Gasoline Vehicles (LDGV)
- Light Duty Gasoline Trucks 1 (LDGT1)
- Light Duty Gasoline Trucks 2 (LDGT2)
- Light Duty Diesel Vehicles (LDDV)
- Light Duty Diesel Trucks (LDDT)
- Heavy Duty Gasoline Vehicles (HDGV)
- Heavy Duty Diesel Vehicles (HDDV)
- Motorcycles (MC)

An emission factor is computed for each of these vehicle classes, based on Equation 2-2.

Equation 2-2 Emission Factor (g/km) = Base Emission Rate (g/km) * Adjustment Factors

The base emission rate is obtained from laboratory tests. When a new vehicle is produced, it must comply with existing emission standards. However, as the vehicle ages, its emission control systems become less effective, causing emissions to increase. These emissions are measured in the laboratory using standardized procedures. Based on such measurements, deterioration rates can be developed which describe the increase in vehicle emissions associated with increasing mileage. Because deterioration rates for light-duty vehicles change above 50,000 miles (80,000 km), such vehicles are characterized by two deterioration rates.

The MOBILE model requires as input the vehicle age distribution for a given analysis year. Using mileage accumulation rates to determine the accumulated mileage, and deterioration rates to determine the corresponding level of vehicle emissions, a base emission rate can be obtained for each age of vehicle represented in the fleet. These rates are then adjusted for non-laboratory conditions, and weighted together to produce a base emission rate for each vehicle class.

It should be emphasized that vehicles in the same age category will not have identical emission characteristics, even if they are in the same vehicle class. Different vehicle models have different operating characteristics, just as different drivers exhibit different driving behaviour. However, emission rates are developed for an “average” vehicle

driven by an “average” driver over a test cycle representative of “average” travel conditions. The test procedure typically followed for deriving emission rates is described in Section 2.6.2.

To more accurately reflect conditions in the study area, adjustment factors are used to modify emission rates obtained in the laboratory. In MOBILE5, adjustment factors are computed for:

- average speed
- temperature
- trip length distribution
- percentage of travel in each operating mode (cold start, hot start, hot stabilized)
- inspection and maintenance programs
- anti-tampering programs
- use of reformulated gasoline

Once an adjusted emission rate is computed for each vehicle class, a composite emission rate is developed as described earlier. This rate can then be used to predict emissions according to Equation 2-3.

Equation 2-3 Vehicle Emissions (g) = Emission Factor (g/km) * Vehicle Activity (km)

Typically, vehicle activity is estimated as the number of vehicle-kilometers travelled (VKT). For consistency, this value should correspond to the average speed, temperature, and operating mode percentages used to develop emission factors. For example, if emissions are to be computed for an individual link during the peak period, the average speed used in the model should correspond to the volume of traffic using the link during periods of high demand. This same volume of traffic should be used to compute the number of vehicle-kilometers travelled on the link. Moreover, temperature inputs must correspond to the appropriate time period. On the other hand, if emissions are to be computed for a particular class of roadway in the suburbs, estimates of average speed, operating mode, and vehicle-kilometers travelled should be developed by aggregating the appropriate links.

For more information on the basic structure of the MOBILE model, the reader is urged to consult the MOBILE5 User's Guide (U.S. EPA 1994). The U.S. Department of Transportation's workshop notes on transportation air quality analysis (U.S. DOT 1994) also provide an excellent summary of emission factor models such as MOBILE5. For a history of the MOBILE model, the reader is referred to U.S. EPA (1999). Additional information can also be found in Sierra Research (1994), including an in-depth description of the emission calculation process in MOBILE5.

2.6.2 The Federal Test Procedure

MOBILE model emission rates are based on empirical relationships developed by testing vehicles on a chassis dynamometer according to a standardized methodology known as the Federal Test Procedure (FTP). Vehicles are operated over a standardized driving cycle which attempts to duplicate typical urban driving conditions. The cycle is referred to as the Urban Dynamometer Driving Schedule, and is based on the speed-time profile of actual vehicle trips taken in the Los Angeles area in the late 1960's. For this reason, the cycle is also known as the LA4 cycle. Characteristics of the LA4 cycle are shown in Table 2-3 as well as Figure 2-2.

Table 2-3 LA4 Driving Cycle Characteristics

Trip Length	7.5 miles
Number of Segments with Non-Zero Speed	18
Average Speed	19.6 mph

Since each mode of vehicle operation has different emission characteristics, the Federal Test Procedure is divided into three sections. The cold start portion of the test consists of the first 3.59 miles or 505 seconds of the LA4 cycle. This is followed by the hot stabilized portion of the test, which consists of the final 3.91 miles or 867 seconds of the LA4 cycle. At this point, the vehicle's engine is turned off for a period of ten minutes. The hot start portion of the test is then conducted by repeating the first 3.59 miles or 505 seconds of the LA4 cycle. During each portion of the test, emissions are collected in a special bag.

As a result, the term "bag" is often used to describe the emissions associated with the three operating modes.

Since the Federal Test Procedure measures vehicle emissions in all three operating modes, the emissions corresponding to each mode must be combined to form a base emission rate for use in the MOBILE model. The U.S. EPA assumes that 43% of all vehicle starts are cold starts, while 57% are hot starts. Based on this assumption, the base emission rate for each vehicle tested can be estimated as follows:

$$\text{Equation 2-4} \quad \text{BER} = \frac{3.59 * (0.43 * \text{cold start} + 0.57 * \text{hot start})}{7.5} + \frac{3.91 * \text{stabilized}}{7.5}$$

$$= 0.206 * \text{cold start} + 0.521 * \text{stabilized} + 0.273 * \text{hot start}$$

BER = base emission rate

cold start = exhaust emissions produced during cold start portion of FTP

hot start = exhaust emissions produced during hot start portion of FTP

stabilized = exhaust emissions produced during stabilized portion of FTP

This is the base emission rate reported in Equation 2-2. If the proportion of travel in the three operating modes is different than that assumed by the U.S. EPA, then adjustment factors must be computed.

(U.S. DOT 1994, Module 2)

Figure 2-2 Federal Test Procedure

2.6.3 Model Inputs

Many of the inputs required to compute vehicle emissions using the MOBILE model were alluded to in Section 2.6.1. The following section describes these inputs in more detail, with special emphasis given to transportation-related inputs, the focus of this report.

2.6.3.1 Fleet Characteristics

Vehicle age influences air quality in two ways:

1. New cars are designed to higher vehicle emission standards and incorporate state-of-the-art emission control systems
2. As vehicles age, their emission control systems become less efficient

Indeed, Miller et al. (1995) report that new vehicles typically emit 96% less CO and VOC emissions, and 75% less NO_x emissions than vehicles manufactured in 1968. However, after ten years of vehicle operation, VOC emissions are approximately four times higher than emission levels when the vehicle was new. Over the same time, CO emissions increase tenfold, while NO_x emissions double.

In the MOBILE model, deterioration rates are specified for each vehicle class. These rates indicate how vehicle emissions change as mileage increases. Each vehicle class has a unique mileage accumulation rate and age distribution. Thus, the proportion of vehicles belonging to a particular model year is known, as is the accumulated mileage. Knowing this mileage and the emission deterioration rate, an appropriate emission factor can be determined for each model year represented in the fleet. These rates are then weighted together by considering the percentage of vehicles comprising each model year.

For example, if the analysis year is 1995, we might expect 5% of the vehicles on the road to be 10 years old. In other words, 5% of the vehicles are from model year 1985. Given that ten year old vehicles have typically accumulated more than 100,000 miles over their lifetime, emission rates for each pollutant can be determined. This process is repeated for every model year represented in the vehicle fleet. The results are then weighted together to form an overall base emission rate for the pollutant and vehicle class in question.

The default age distribution and mileage accumulation rates in the MOBILE model are obtained from national trends. However, these data can be modified to reflect local conditions. If vehicles are retired from the fleet faster than the national average, the vehicle fleet is likely to contain a higher proportion of new vehicles, causing emission rates to be lower.

Characteristics of the vehicle fleet are also important when computing the composite emission factor. As explained in Section 2.6.1, a composite emission factor is computed for NO_x, CO, and HC emissions. This factor is derived by combining the emission rate for each vehicle class after adjustments have been made for non-standard conditions. Again, default values can be used to represent the proportion of travel in each vehicle

class. However, the U.S. EPA recommends the use of local values wherever possible since the vehicle mix is likely to vary significantly depending on location.

2.6.3.2 Temperature

Ambient temperature has a significant impact on both exhaust and evaporative vehicle emissions. In general, exhaust emissions are lowest at the ambient temperature specified for the Federal Test Procedure (75°F). As temperatures either increase or decrease from this value, emissions increase (U.S. EPA 1992). As Figure 2-3 illustrates, cold-start CO and HC emissions increase dramatically during winter driving conditions, while NO_x emissions increase slightly. Not surprisingly, high summer temperatures cause HC emissions to increase during all three operating modes compared to emissions at more moderate temperatures. In contrast, NO_x and CO emissions are only marginally affected by high ambient temperatures.

In the MOBILE model, emission rates are based on tests conducted according to the Federal Test Procedure. For exhaust emissions, an ambient temperature of 75°F is specified, while hot soak emissions are measured at 82°F. As a result, temperature correction factors are required to adjust emission rates for non-FTP conditions. In the MOBILE model, minimum and maximum daily temperatures must be specified by the user. These temperatures are used to calculate an average ambient temperature weighted to account for the distribution of travel throughout the day, as well as the variation in emission rates resulting from daily temperature changes. Consequently, emission factors based on this ambient temperature are representative of an entire day, and should be multiplied by the daily number of vehicle-kilometers travelled.

However, if daily emissions are not desired, the user of the MOBILE model has the option of specifying the ambient temperature. While this temperature is used to compute correction factors for exhaust emissions, hot soak emissions, resting loss emissions, and running loss emissions, diurnal emissions are still modelled using the “full day” approach, based on the minimum and maximum daily temperature.

Typically, transportation engineers are not responsible for obtaining the temperature data used in air quality modelling. However, it is essential that temperature inputs correspond to travel inputs. If emissions are to be calculated for the AM peak period, PM peak period, and off-peak period, input data should reflect the variations in temperature and travel characteristics which occur over the course of the day.

(adapted from Miller et al. 1995)

Figure 2-3 MOBILE5 Temperature Sensitivity Tests

2.6.3.3 Operating Mode Mix

The proportion of travel in each of the three operating modes can have a significant impact on vehicle emissions. Emissions tend to be highest in the cold-start mode, since the vehicle's engine and emission control equipment are at ambient temperature, and thus function less efficiently. In the hot-start mode, emissions are somewhat lower, since the vehicle has not yet cooled to ambient temperature. Not surprisingly, emissions are generally lowest in the hot-stabilized mode, when the vehicle has been operated for sufficient time to attain optimal operating conditions. The MOBILE model computes base

emission rates by assigning a weight to each mode of vehicle operation based on the percentage of travel assumed to occur in the hot start, cold start, and hot stabilized modes.

Because a vehicle's operating mode depends, in part, on the type of emission control system present, two categories of vehicles must be considered: those with catalytic converters, and those without. According to the U.S. EPA (1994), vehicles without catalytic converters will initially operate in the hot start mode if the engine has been turned off for less than four hours. However, if the engine has been turned off for more than four hours, the vehicle will begin operation in the cold start mode. On the other hand, catalytic emission control systems are quite sensitive to drops in temperature. Thus, vehicles with catalytic converters will only operate in the hot start mode if the engine has been turned off for less than an hour before it is restarted. Otherwise, the vehicle will operate in the cold start mode following engine start-up.

To properly adjust base emission rates, the MOBILE model must consider six vehicle technology/operating mode combinations. In MOBILE5, operating mode correction factors are applied only to emission rates for light-duty vehicles. The model assumes that the percentage of travel in the hot stabilized operating mode is the same for both catalyst and non-catalyst equipped vehicles. The model requires as input the percentage of travel by non-catalyst equipped vehicles in the cold start mode, catalyst equipped vehicles in the hot start mode, and catalyst equipped vehicles in the cold start mode. Values for the other three parameters are calculated internally. Table 2-4 illustrates the default values assumed by MOBILE5. However, the user is free to specify alternative operating mode fractions if such data are available.

Table 2-4 MOBILE5 Default Operating Mode Fractions

Technology Type	Operating Mode	Default Value
Non-Catalyst Equipped	Cold Start	20.6%
Non-Catalyst Equipped	Hot Start	27.3%
Non-Catalyst Equipped	Hot Stabilized	52.1%
Non-Catalyst Equipped	Total	100%
Catalyst Equipped	Cold Start	20.6%
Catalyst Equipped	Hot Start	27.3%
Catalyst Equipped	Hot Stabilized	52.1%
Catalyst Equipped	Total	100%

It should be noted that the proportion of travel in each of the three operating modes is the same for both vehicle types. This is a reasonable assumption, since there is no reason to believe that drivers behave differently depending on the type of emission control system present in their vehicle. While the total amount of travel by vehicles with and without catalytic converters may differ depending on the vehicle mix, the relative proportion of travel in each operating mode is unaffected by the vehicle technology.

2.6.3.4 Average Travel Speed

The base emissions rates in MOBILE5 were developed using the LA4 driving cycle as specified in the Federal Test Procedure. This driving cycle has an average speed of 31.5 km/hr (19.6 mph). However, both exhaust and evaporative emissions vary significantly with average speed. As a result, the user is required to specify a value of average speed based on regional travel patterns. Correction factors are then applied to account for differences in travel conditions from those of the Federal Test Procedure. In MOBILE5, correction factors were developed using a series of driving cycles, each with a different average speed.

It should be emphasized that the speeds used in the MOBILE model are average travel speeds, not spot speeds measured at a particular mid-block location. Average travel speed can be defined as the total distance travelled by all vehicles in the traffic stream divided

by the total travel time. This speed includes the effects of congestion and intersection delay. The U.S. Department of Transportation (1994) offers this important warning:

It is important to realize that the emission factor produced by the model for a given speed (i.e. 19.6 mph) is not the rate of emissions a vehicle would experience while traveling at that speed. It is an approximation of the average rate of emissions over a trip with an average speed of 19.6 mph (Module 2).

Average travel speed is one of the most important travel inputs in the MOBILE model. In general, travel speed will vary depending on the type of facility, location, and time of day. Thus, it is important that estimates of average speed be sufficiently accurate. This issue is discussed further in Section 2.9.2.

The non-linear relationship between speed and emissions has been well established. According to sensitivity tests conducted by Miller et al. (1995), emissions measured in grams/minute are lowest when the engine is idling, and increase steadily with speed. However, while CO emissions show only a gradual increase, NO_x emissions increase more rapidly. In both cases, the highest emission rates occur at the highest speeds, when engine loads are most intense. Likewise, HC emissions increase gradually with speed, reaching a maximum value at the maximum speed.

However, if emissions are measured in grams/kilometer, a different trend emerges. At speeds near 0 km/hr, emission rates approach infinity since the distance traveled is extremely small. Consequently, at speeds below 10 mph (16 km/h), emissions increase rapidly as speeds decrease. Emissions are lowest in the 40-55 mph (64-88 km/hr) range, at which point emissions begin to increase*. While this increase is gradual for CO and HC emissions, NO_x emissions increase rapidly above 55 mph (88 km/hr), eventually surpassing emission rates observed at the low end of the speed spectrum. In contrast, CO and HC levels at 65 mph (105 km/hr) remain well below emission levels at 2.5 mph (4 km/hr).

* Note that the MOBILE5 User's Guide (U.S. EPA 1994) indicates that the HC and CO emissions are lowest at 48 mph (77 km/hr), and remain constant between 48 and 55 mph (77 and 88 km/hr).

The relationship between average travel speed and vehicle emissions is shown in Figure 2-4 and Figure 2-5 for emissions measured in grams/mile and grams/minute, respectively. Although these figures are based on a 1996 vehicle fleet in a low altitude city without an inspection and maintenance program, Ireson et al. (1992) and Anderson et al. (1996) report similar findings for different input conditions. Indeed, in their analysis of Hamilton, Ontario, Anderson et al. (1996) found that the highest emission densities occurred on the most congested links. NO_x emissions were also found to be high along major roads with high travel speeds. These findings clearly reflect the non-linear relationship between travel speed and emissions, which results in high emission rates at both the low and high ends of the speed spectrum.

However, the use of speed in the above relationships can be misleading. The average speed used in MOBILE5 is based on vehicle trips. These trips are assumed to incorporate a mix of accelerations, decelerations, and travel at constant speed. As a result, estimates of average speed take into account delays at intersections, as well as intervals with high cruising speeds. A low average speed often indicates stop-and-go travel conditions, with a high level of congestion or intersection delay. In contrast, a high average speed generally indicates smooth driving conditions, with minimal idle time. Consequently, travel speed can be viewed as a proxy measure of driving conditions, and the relationships shown in Figure 2-4 and Figure 2-5 should be interpreted accordingly.

(adapted from Miller et al. 1995, 1151)

Figure 2-4 Relationship Between Travel Speed and Vehicle Emissions (grams/mile)

(adapted from Miller et al. 1995, 1151)

Figure 2-5 Relationship Between Travel Speed and Vehicle Emissions (grams/min)

2.6.3.5 Trip Length Distribution

The trip length distribution has an important impact on running loss emissions. These evaporative emissions escape from the fuel system and engine as the vehicle is being operated. The quantity of running loss emissions depends on the trip duration, as well as the vehicle speed, ambient temperature, and fuel volatility. As the fuel lines, fuel tank, and engine become heated, running loss emissions increase. The default trip length distribution assumed by MOBILE5 is presented in Figure 2-6.

Figure 2-6 Trip Length Distribution Assumed in MOBILE5

It should be emphasized that the values in Figure 2-6 refer to the percentage of vehicle-miles travelled during trips of a particular duration. For example, it is assumed that 6.74% of the total vehicle-miles travelled occurs during trips of 10 minutes or less. To account for regional variations in travel patterns, the user is able to specify an alternative trip length distribution for calculating running loss emissions.

2.6.3.6 Fuel Characteristics

In the development of base emission rates, the Federal Test Procedure requires the use of a standardized fuel known as Indolene. However, this fuel is not readily available to the average driver. Since fuel volatility affects emissions, the Reid Vapour Pressure of fuel sold in the study area must be specified. This value is used to correct the base emission rates in the MOBILE model to account for differences between the FTP test fuel and the actual fuel used by drivers.

In addition, the MOBILE model allows users to specify the use of oxygenated fuels and reformulated gasoline. These fuels tend to reduce CO and HC emissions, although their impact on NO_x emissions is typically quite small.

2.6.3.7 Emission Control Programs

The base emission rates used in the MOBILE model do not reflect the impact of emission control programs. However, areas with an Inspection and Maintenance program or Anti-Tampering program can model the benefits of these programs by specifying the type of program in the MOBILE5 input file. The overall impact of these programs depends on vehicle technology factors, as well as the design of the emission control program.

2.6.4 Vehicle Activity Patterns Internal to MOBILE5

MOBILE5 allows the user to specify a number of travel parameters which influence emission estimates. Such parameters include the trip length distribution, average speed, and operating mode fractions. However, it is also worth noting that many of the calculations within MOBILE5 require vehicle activity data which is internal to the model. This data is typically based on daily travel patterns recorded in trip diaries, and includes:

- Average number of trips per day, as a function of the vehicle age
- Average amount of travel per day, as a function of the vehicle age
- Hourly distribution of travel over a typical day
- Fraction of vehicles driven each day
- Length of time between successive vehicle trips

Table 2-5 illustrates some of the applications of this data in the emission calculation process. As this table shows, the accuracy of vehicle emission forecasts depends not only on the travel data supplied by the user, but also the travel data which is internal to the model itself.

Table 2-5 Application of Internal Vehicle Activity Data in MOBILE5

MOBILE5 Application	Internal Travel Data Required	Comments
Calculation of temperature correction factors	<ul style="list-style-type: none"> Hourly distribution of travel 	If an ambient temperature has not been specified by the user, MOBILE5 computes temperature correction factors based on the daily temperature profile, as well as the distribution of travel over the course of the day
Conversion of hot soak emissions from grams/trip to grams/mile	<ul style="list-style-type: none"> Average number of trips per vehicle per day Fraction of vehicles used each day Average amount of travel per vehicle per day 	Hot soak emissions measured in grams/trip are multiplied by the average number of trips per day and the typical vehicle usage rate to give emissions in grams/day. This value is then divided by the average amount of travel per day to give the emissions in grams/mile
Calculation of diurnal emissions measured in grams/day	<ul style="list-style-type: none"> Length of time between successive vehicle trips 	This information is used to determine the fraction of vehicles that have been idle for a single day, multiple days, or a partial day
Conversion of diurnal emissions from grams/day to grams/mile	<ul style="list-style-type: none"> Average amount of travel per day 	Diurnal emissions measured in grams/day are divided by the average amount of travel per day to give the emissions in grams/mile
Conversion of resting loss emissions from grams/hour to grams/mile	<ul style="list-style-type: none"> Average amount of travel per day 	To compute resting loss emissions in grams/mile, hourly emissions throughout the day are summed and divided by the average amount of travel per day
Conversion of refuelling emissions from grams/gallon to grams/mile	<ul style="list-style-type: none"> Average fuel economy of the vehicle class and model year being considered 	Refuelling emissions measured in grams/gallon are converted to grams/mile by dividing by the average fuel economy

* For additional information, see Sierra Research (1994)

2.7 MODELLING GREENHOUSE GASES

Unlike vehicle emissions of carbon monoxide and volatile organic compounds, carbon dioxide (CO₂) has no direct influence on human health. As a result, there has been little incentive to model CO₂ emissions. Accordingly, vehicle emission models have traditionally ignored CO₂ in their estimation of vehicle pollutants. However, there is a

growing interest in modelling CO₂ due to its perceived role in global warming and the greenhouse effect. Indeed, greenhouse gas reduction targets were established as part of the 1997 Kyoto Protocol aimed at reducing greenhouse gas emissions worldwide. In Canada, much attention has been focused on identifying and implementing strategies to reduce greenhouse gas emissions in urban transportation (Hagler Bailly 1999; Delcan 1999). However, evaluating the effectiveness of such strategies is hindered by a lack of reliable estimation procedures (Khan 1999a).

In addition to CO₂, N₂O, and CH₄ are also greenhouse gases emitted from mobile sources. These gases are often expressed in terms of CO₂ equivalents based on their long-term global warming potential. To model greenhouse gas emissions, accurate estimates of fuel consumption are required. Factors affecting fuel consumption include:

- Road characteristics (geometric design, traffic control, level of congestion, gradient, pavement conditions)
- Driving pattern / vehicle speed change profile (accelerations, decelerations, cruising speed, idle time)
- Operating mode (cold start, hot start, hot stabilized)
- Type of vehicle (engine size, use of auxiliary equipment, maintenance)
- Temperature

During short trips, vehicles tend to consume fuel at a higher rate since a higher proportion of travel is in the cold start mode. This effect is magnified with decreasing temperature; as ambient temperatures decrease, fuel consumption rises. In general, vehicle maintenance, speed, operating mode, and temperature have the greatest impact on fuel consumption, although the driving cycle, trip length, grade, and engine size are also important. Fuel consumption models range from complex relationships describing the instantaneous fuel requirements of the vehicle engine to simple formulations based on average travel speed (Biggs and Akcelik 1986). Additional information on the factors affecting fuel consumption can be found in Delcan (1998) and OECD (1982).

Vehicle manufacturing companies are required to conduct fuel consumption tests according to standardized procedures. Both an urban and highway driving cycle are used. The urban cycle simulates vehicle operation under conditions of signalized traffic control;

the highway cycle simulates travel at highway cruising speeds. However, laboratory tests have been found to underestimate on-road fuel consumption for a number of reasons. Laboratory tests are unable to account for the effects of severe traffic congestion, weather, road conditions, engine wear, and driving habits. As a result, fuel consumption for new vehicles must be adjusted accordingly, with a 15% increase applied to the urban fuel consumption rating and a 10% increase applied to the highway rating. However, tests from Natural Resources Canada suggest that factors as high as 20-25% may be appropriate (Khan 1999b).

Vehicles require fuel to perform the following four tasks (Delcan 1998):

- overcome air and rolling resistance to maintain motion at a given cruise speed
- overcome inertia during acceleration and deceleration
- climb steep grades
- maintain the engine in operation

The relative contribution of each activity to overall fuel consumption depends on the traffic environment. During periods of congestion, much of the fuel consumed is used to maintain the engine in operation; air and rolling resistance are minimal. However, at highway cruising speeds, aerodynamic and rolling resistance begin to dominate. A vehicle's fuel efficiency is determined by its weight, air and rolling resistance, engine and transmission efficiency, and gearing ratios (Delcan 1998).

Fuel consumption is often related to average travel speed. This speed includes the effects of traffic signalization and congestion, and should be distinguished from the instantaneous speed measured on vehicle speedometers. In stop and go conditions, internal combustion engines operate inefficiently. Thus, fuel efficiency improves as the average speed increases until an optimal speed is reached. At this point, aerodynamic drag begins to affect fuel consumption. As speeds continue to increase beyond optimal, a gradual increase in fuel consumption is observed. The optimal speed depends to a large extent on the type of vehicle; the more sophisticated the aerodynamic design, the higher the optimal speed. While experts have yet to agree on an approximate range for the

optimal speed, it can be generally stated that the optimal speed lies above 55 km/hr (Delcan 1998).

Figure 2-7 illustrates the variation in fuel consumption with speed under urban driving conditions. In this figure, fuel consumption has been normalized against fuel consumption at 31 km/hr, the average speed of the urban test cycle. At speeds below 25 km/hr, fuel consumption rises rapidly due to increasing congestion. Above 55 km/hr, a slight increase in fuel consumption is observed due to aerodynamic drag. Figure 2-7 is intended for illustrative purposes only; it amply demonstrates the relationship between fuel consumption and average travel speed. Vehicle operation under highway driving conditions exhibits similar trends. Aerodynamic drag dominates at high speeds, inefficient engine operation dominates at low speeds.

(adapted from Delcan 1998)

Figure 2-7 Fuel Consumption Trends as a Function of Average Speed

It should be noted that there is no direct relationship between fuel economy and vehicle emissions, with the exception of greenhouse gases. Emissions of CO, VOC's and NO_x depend on the design of the vehicle's engine, as well as its state of repair. Most emissions produced by the engine are destroyed in the catalytic converter. Indeed, large passenger cars can burn twice as much fuel per kilometer as smaller vehicles, yet still meet the same emission standards (Chevron 1996).

Once an estimate of fuel consumption has been obtained, greenhouse gas emissions can be calculated using emission factors expressed in grams of CO₂ per litre of fuel. Emission factors vary depending on the type of fuel as well as the vehicle's engine and emission control technology. During combustion, the carbon content of fuel is converted to carbon dioxide, a gas which escapes unchecked through conventional emission control systems. In addition to CO₂, CH₄ and N₂O are also produced during vehicle operation. These gases are converted to equivalent amounts of CO₂ using factors which account for their long-

term effects on global warming. CH₄ has an equivalency factor of 21, while N₂O has a factor of 310. The general procedure for estimating greenhouse gas emissions is illustrated in Figure 2-8.

Figure 2-8 Procedure for Estimating Greenhouse Gas Emissions

While fuel consumption can be estimated on the basis of regional fuel sales, such estimation procedures have certain limitations which are difficult to resolve. Fuel purchased in one city may be consumed in another. Estimates can only be applied to the region as a whole; a finer level of disaggregation is impossible. Furthermore, the impact of alternative transportation policies on fuel sales in the future is difficult to predict. Future fuel consumption can be estimated by multiplying the amount of travel by the average fuel efficiency of the vehicle fleet. However, it is difficult to account for changes in the operating characteristics of the transportation network which influence fuel consumption. Clearly, the advantage of modelling fuel consumption as a function of driver behaviour and traffic conditions is significant.

Fuel consumption is also a function of vehicle design. New vehicle technologies are currently being developed with significantly different fuel efficiency characteristics. The relationship between average speed and fuel consumption depends on the type of engine technology. Vehicles equipped with electric, hybrid, or fuel cell engines are expected to improve fuel efficiency and reduce emissions (Khan 1999a; Delcan 1998). Ideally, the impact of such vehicles should be considered when modelling greenhouse gas emissions. However, the market penetration of emerging vehicle technologies over the coming decades is subject to debate. According to Checkel (1996), an active researcher in alternative fuels and vehicle technologies, the main fuel for urban traffic will continue to be gasoline over the next quarter century. Checkel bases this prediction on two assertions:

- conventional fuels will continue to be available
- vehicles using conventional fuels will continue to meet acceptable pollution guidelines and will be the most economical alternative (Checkel 1996, 18).

It should also be noted that the Environmental Protection Agency prohibits urban areas from assuming changes in vehicle registration and age distribution when evaluating strategies to reduce emissions (U.S. EPA 1994). Until the emission and fuel consumption characteristics of new vehicle technologies have been evaluated, the ability to model the impact of such technologies is limited.

2.8 FUEL CONSUMPTION MODELS

Fuel consumption models attempt to predict fuel consumption as a function of vehicle activity and road characteristics. Numerous models have been developed, incorporating such parameters as vehicle-kilometers of travel, average speed, and delay. Selection of the most appropriate model for a given situation depends on data availability and accuracy requirements. Instantaneous fuel consumption models are used to analyze specific intersections, road segments, or network components. Such models track the instantaneous speed and acceleration of individual vehicles, and generally relate fuel consumption to power requirements. In contrast, drive mode elemental models estimate the fuel consumption associated with different vehicle operating modes, such as travel at constant speed, stopping maneuvers, and idling. Although these models are popular due

to their “simplicity, generality, and conceptual clarity”, they fail to capture the unique behaviour of individual drivers under different traffic conditions (Delcan 1998, 40). Instead, “average” maneuvers are assumed, which can lead to significant errors when modelling short trips with frequent stops. Finally, average speed models relate fuel consumption to average speed, and are most appropriate for estimating fuel consumption on a regional scale. These models are also valuable for evaluating transportation policies which impact travel speed and levels of demand. For a more detailed summary of fuel consumption models, the reader is referred to Delcan (1998).

2.9 DEFICIENCIES WITH CURRENT PRACTICE

2.9.1 Fundamental Limitations And Expected Accuracy

The ability to model vehicle emissions is of critical importance if improvements in air quality are to be achieved. Indeed, a sustainable future can only be realized if steps are taken today to reduce environmental degradation; without models to investigate potential solutions, the ability for effective action is hindered. However, deficiencies with existing modelling procedures are well-documented. This section highlights some of the key issues which must be addressed to improve the quality of vehicle emission estimates.

To assess the problems faced by metropolitan areas in the preparation of emission inventories, Suhrbier et al. (1991) conducted interviews with representatives from environmental and transportation agencies in 15 urban areas across the United States. Despite deficiencies in modelling vehicle activity, the authors conclude that “a variety of institutional problems may present more significant obstacles in the preparation of mobile source inventories than any technical limitations” (42). Such institutional problems include funding limitations, institutional fragmentation, lack of available technical expertise, and a high level of staff turn-over. Consequently, any effort to improve the accuracy of vehicle emission estimates should not overlook the non-technical issues that may influence the modelling process.

Nevertheless, the technical limitations are significant. Miller et al. (1995) describe the magnitude of error that can be expected in travel data used to compute vehicle emissions. Based on the available information, an error in travel speed of ± 5 mph (8 km/hr) is believed to be the highest level of accuracy that can be achieved using the best available traffic data and most sophisticated modelling tools. Under these same conditions, an error of $\pm 5\%$ in the amount vehicle travel can also be expected. However, the errors are typically much greater, up to ± 15 mph (24 km/hr) for travel speed, and $\pm 10\%$ for travel activity. Indeed, it has been suggested that traffic volumes on individual links may be in error by as much as 15 to 50%, depending on the traffic volume assigned to the link (U.S. DOT 1994).

2.9.1.1 Traffic Counts and Travel Demand Models

According to SAI et al. (1999), traffic counts and travel demand models provide the most widely available data for estimating travel activity in urban areas^{*}. To determine travel activity from traffic counts, data is extrapolated from a limited number of count locations. The number of count locations, the frequency of sampling, and the representativeness of the sites are sources of uncertainty. Often, traffic counts are only available for arterial roads and freeways in major urban centres, leading to errors in travel estimates. Limitations of the counting devices, malfunctioning equipment, and inconsistent data sets are also sources of error (SAI et al. 1998)

On the other hand, travel demand models are far from perfect. “Although it is generally recognized that regional models are essential in developing the data for air quality analysis, it is also recognized that there are certain limitations in the models that affect the accuracy of ... emission estimates” (Outwater and Loudon 1994, 116). Indeed, as Stopher and Fu (1996) claim: “a fundamental problem ... is that the commonly used regional travel-forecasting system was not designed to provide the information required for air

^{*} A summary of the methodologies currently applied by transportation planning organizations in the estimation of travel inputs for vehicle emission models is contained in Suhrbier et al. (1991). SAI et al. (1998; 1999) also summarize techniques to estimate vehicle activity and travel speed. Examples are provided for five urban areas in the United States.

quality models” (104). Instead, such models were used to evaluate transportation system performance, and are ill-suited for current applications in the field of vehicle emissions modelling. Suhrbier et al. (1997) write: “While the resulting sequence of linked models ‘works’ in that numbers are produced, serious reservations exist concerning the accuracy of ... the results, the robustness of the underlying data, and even whether the correct set of variables are captured in the [models]” (72).

Travel demand models were never designed to produce accurate estimates of travel speed and vehicle-kilometers of travel, particularly for different time periods throughout the day. Consequently, there are no checks within the travel-forecasting procedures to ensure the accuracy or reliability of the results (Stopher and Fu 1997). The variables influencing vehicle emissions are rarely the same as those traditionally emphasized in travel demand models; variables such as the number of trips, vehicle speed, and engine operating mode are growing in importance (Suhrbier et al. 1995).

The deficiencies of traditional travel demand models are far-ranging. Such models typically exclude residential streets and other low-capacity facilities. However, 10 to 15% of the travel in an urban area occurs on local roads (Suhrbier et al. 1991; U.S. DOT 1994; Miller et al. 1995). While techniques have been developed to estimate such travel, the results are approximate at best, leading to inaccurate estimates of vehicle emissions. Errors are also introduced if vehicle emissions are required for an urban area that is larger than the area encompassed by the transportation model. In this situation, travel occurring outside the model limits will be ignored when computing vehicle emissions. Since travel demand models are generally developed for large urban areas only, their applicability in provincial or national emission inventories is limited (EEA et al. 1999).

Integration between vehicle emission models and transportation planning models is essential if emissions are to be calculated on a link-by-link basis, taking into account the unique operating characteristics of each road in the transportation network. However, such integration has traditionally been difficult to achieve. Indeed, the objectives of transportation planning models rarely agree with the objectives of vehicle emission models, leading to inconsistencies which are difficult to resolve (Outwater and Loudon

1994). The “typical” day used to model travel activity seldom corresponds to the time period required to model CO or VOC emissions. While transportation models often have a single 20 year planning horizon, vehicle emission forecasts may be needed at more frequent intervals. Planning models are developed to provide accurate estimates of traffic volumes. Speed relationships are often calibrated to improve the accuracy of the traffic assignment process; the validity of the resulting travel speeds is of little importance. However, travel speed is an important determinant of vehicle emissions, as discussed in Section 2.9.2.

Stopher and Fu (1996) highlight the lack of integration between travel demand models and vehicle emission models: “Because the capability to estimate link-by-link emissions from a loaded network is not widely distributed in current transportation-planning software, ... [the ability to model emissions on a link-by-link basis] would generally require specific programming efforts using the output files from the assignment process” (113). Suhrbier et al. (1997) concur, noting that transportation, vehicle emissions, and air quality models were developed largely independent of each other, for different purposes than the ones for which they are currently being used. Originally developed to investigate the need for new or expanded transportation infrastructure, travel demand models are now being called upon to provide data on the temporal and spatial distribution of travel activity for use in emissions modelling. However, this data is not easily manipulated into a form suitable for emission models. As Khan (1999a) emphasizes, “post-processors” must be developed to integrate the output from travel demand models with vehicle emission models. Likewise, Loudon and Quint (1993) stress the need to take advantage of the new analytical capabilities of emission models by developing software that uses output from travel demand models to estimate vehicle emissions directly*.

2.9.1.2 Quantifying Uncertainty Through Sensitivity Tests

Miller et al. also allude to the lack coordination between procedures to estimate travel demand and mobile source emission models, a lack of coordination attributed to the

* An example of a program developed for this purpose is described in Loudon and Quint (1992)

independent development of modelling tools in the transportation and air quality fields. Since the accuracy of vehicle emission models depends on the accuracy of the input parameters, Miller et al. (1995) conducted a series of sensitivity tests to gain an understanding of the sensitivity of vehicle emission estimates to errors and uncertainties in travel related inputs. From the results of the study, the authors conclude that an accuracy of $\pm 15\%$ is the maximum that can be achieved using current state-of-the-art methods for estimating the travel-related parameters needed by the MOBILE5 model. Under normal conditions, an error of $\pm 30\%$ is likely. However, the authors note that errors in emission estimates can be as high as $\pm 50\%$ on certain links under “extreme” conditions, such as vehicle speeds below 20 mph (32 km/h) or greater than 55 mph (88 km/h), facility types where the operating mode fractions differ significantly from the default values, facilities with an abnormally high number of diesel trucks, and geographic areas with a relatively newer or older fleet than the national average.

Recognizing the complex interactions between travel demand models and vehicle emission models, Stopher and Fu (1996) also conducted a series of sensitivity tests to determine the impact of travel-related inputs on the estimation of mobile source emissions. The authors conclude that vehicle emission estimates should be determined for different periods of the day through diurnal factoring of 24-hour trip tables. To do so, link capacities must be adjusted appropriately, since the capacity of each network link “will have a substantial impact on the estimation of speeds and VMT, the primary ingredients of emissions estimation” (Stopher and Fu 1996). Stopher and Fu (1996) also found that seasonal and day-of-week adjustments to trip data can influence emission results, as well as post-processing of travel speeds and spatial disaggregation of network links.

2.9.1.3 Examples From Modelling Practice

Suhrbier et al. (1995) outline the range of responses within the transportation community to the increased demands of vehicle emission models. These responses include innovations within the existing modelling framework, as well as extending the modelling framework to include new analytical procedures. From relatively simple changes to travel

forecasting procedures, to extracting data from household travel surveys to specifying new travel demand choice models that have increased sensitivity to air quality variables, the response of the transportation profession has been substantial. Indeed, transportation modellers have enhanced current forecasting procedures by:

- Revising trip assignments to provide link volumes by operating mode
- Refining volume delay functions used in traffic assignments
- Developing assignment post-processors to provide more accurate speed estimates, and breakdown of link travel by vehicle type (Suhrbier et al. 1995)

Miller et al. (1992) describe an attempt to produce a high resolution emissions inventory for Tennessee by developing hourly traffic profiles for three different geographical locations (urban, urban fringe, and rural) and five different road classifications (freeway, major arterial, minor arterial, collector, local). Since traffic data was required for a large geographic area, data was obtained from a variety of sources, including traffic counts, speed studies, operating mode surveys, travel demand models, and trends published in the literature.

De Rouville (1992) also describes the work required to obtain traffic data for vehicle emission models disaggregated by time of day and functional class of road for both summer and winter conditions. While a travel demand model was used to obtain the majority of the data, deficiencies are apparent, particularly in the estimation of average travel speed. Adjustments were also required to account for the travel from intra-zonal trips, as well as the travel on local roads excluded from the model. However, de Rouville notes (1992) that improvements to the work are on-going, and that efforts have been undertaken to improve the average speed estimates by computing adjustment factors from local speed surveys.

In examples above, a complicated mix of in-house software was required to manipulate the relevant traffic data into a form suitable for estimating vehicle emissions. Although analytical procedures are being developed to address existing deficiencies, the tools and methodology often lack consistency, and are generally not available to other planning agencies; the need exists to incorporate new modelling capabilities into commercially

available transportation planning packages (Cambridge Systematics 1994). Indeed, Suhrbier et al. (1997) claim that, while improvements in both vehicle emissions models and travel demand models are currently on-going, the research is “not being driven by integrated transportation air quality analysis considerations”, nor is it sufficiently comprehensive in scope, or adequately coordinated (73).

2.9.1.4 Recommendations For Improvement

Outwater and Loudon (1994) describe a set of traffic forecasting guidelines which were developed for the California Department of Transportation to meet the legislative requirements of the Clean Air Act. The guidelines outline acceptable practices for travel demand forecasting in three distinct areas: input data and assumptions, travel demand modelling, and emissions inventories. The authors emphasize the need for more consistent methodologies and assumptions in the traffic modelling process to improve the accuracy of travel inputs used in air quality analyses.

Specifically, Outwater and Loudon (1994) recommend adapting travel demand models to include a more comprehensive coverage of vehicle trips, such as commercial vehicle trips, recreational trips, and transit trips. Intra-zonal trips which are traditionally ignored in the traffic assignment process must also be considered to improve the quality of vehicle emission estimates. SAI et al. (1999) concur, noting the need to include travel from both freight vehicles, as well as intra-zonal trips in emission inventory preparation.

It is also recommended that travel demand models be modified to forecast weekend and summer travel, when air quality standards are often violated, instead of limiting travel forecasts to a typical autumn weekday (Outwater and Loudon 1994). Models which are insensitive to travel demand management policies require changes as well, in order to determine the air quality impacts of strategies to reduce travel demand.

Accurate determination of trip volumes by time of day is considered essential to capture variations in vehicle emissions and pollutant concentrations resulting from daily temperature fluctuations and road operating characteristics. However, many models are

unable to forecast peak and off-peak travel demand. In other cases, link capacity values have been manipulated, so that a 24-hour traffic assignment will produce volume to capacity ratios that replicate peak hour conditions (Stopher and Fu 1996). Consequently, daily emission estimates are based on peak hour speeds, leading to inaccurate results.

To model peak and off-peak travel activity, the capacity of each network link is of critical importance, since the volume to capacity ratio determines not only the travel speed, but the number of vehicles assigned to the link. Estimation of link capacities based on lane configuration, traffic signalization, and parking characteristics is often infeasible due to the extensive amount of data required. Instead, capacities are often assigned according to the link's geographic location and functional classification. However, geographic information systems are currently being used in many cities to develop an extensive database of network link attributes. In the future, this database may provide a means of improving the lane capacity assigned to individual links, although integration between travel demand models and geographic information systems may be difficult to achieve (Stopher and Fu 1997).

Stopher and Fu (1997) outline a number of feasible improvements that can be made to conventional travel demand models in order to enhance the accuracy of input data for estimating vehicle emissions. These improvements encompass diurnal factoring, capacity estimation, hourly assignments, speed post-processing, feedback loops, and seasonal and day-of-week factoring. Likewise, Suhrbier et al. (1997) recommend improvements to network coding, trip generation, distribution of trips by time of day, treatment of heavy-duty vehicles, and speed estimation procedures. Improved data collection techniques are also recommended, including the modification of household travel surveys to incorporate questions on vehicle characteristics. Since the accuracy of vehicle emission estimates depends on the underlying transportation data, Suhrbier et al. (1997) provide a set of "high priority" data requirements for vehicle emissions modelling:

- Data on the number and location of trips taken by household members, how these trips may be chained or linked together, and how the trip patterns may vary as a function of available transportation and information options;
- Data on the length of time between individual vehicle trips;

- Information on a broader array of transportation alternatives, especially walking, cycling, and the mode of access to transit;
- Data on the length, routing, and timing of individual trips in addition to aggregate link vehicle miles of travel;
- More detailed information on travel by type of network link, including classification of travel by facility type and grade;
- More accurate estimates of the spatial and temporal distributions of travel;
- Increased data on the characteristics of the vehicles being used for particular trips;
- More accurate estimates of vehicle speed, as well as estimates of acceleration and modal driving patterns; and
- Improved information on freight due to the contributions of heavy-duty diesel trucks and locomotives to NO_x emissions (Suhrbier et al. 1997, 73-74).

2.9.1.5 Long-Range Improvements

While short-term improvements in the modelling process are needed to address existing deficiencies, long-term adjustments are also essential, as discussed by Suhrbier et al. (1997). Indeed, a fundamentally new set of analytical capabilities may be required, in addition to incremental improvements to existing tools. Activity-based transportation models and modal-based emission models, implemented within a GIS environment, may provide the analytical framework of the future*. As Suhrbier et al. (1995) note, the capabilities of new modelling systems may well include “the use of geographic information systems as a basic foundation for spatially storing and analyzing information, household rather than ... zone-based forecasting procedures, the consideration of telecommunications as a form of mobility, an improved interface between traffic micro-simulation and travel demand analysis, and new theoretical structures of household and travel behaviour that consider activity patterns rather than simply vehicle trips (1174).

In addition, the development of intelligent transportation infrastructure, including advanced electronic systems in vehicles and roadways, may provide the means for collecting continuous, real-time traffic data: data which is inherently more accurate than

* For further information on activity-based transportation models and modal-based emission models, the reader is referred to Suhrbier et al. (1997). Barth (1997), Barth et al. (1996), and CERT (2000) describe a modal-based emissions model, while Bachman et al. (1996) outline an approach taken to model vehicle emissions using geographic information systems.

results from existing data collection methodologies. (Suhrbier et al. 1997). New analytical tools will undoubtedly be required to exploit these emerging data collection techniques.

Williams et al. (1999) describe the TRANSIMS model, an integrated transportation-air quality model which is at the forefront of efforts to improve the modelling process. The TRANSIMS model is being developed at Los Alamos National Laboratory as part of the Travel Model Improvement Program sponsored by the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Energy. Within the model, travel activity is estimated on a household basis. Trips are assigned to the transportation network using a micro-simulation module to track the second by second behaviour of individual vehicles in the traffic stream. Vehicle emissions are estimated using a modal-based emissions model which accounts for a vehicle's speed and acceleration characteristics. The TRANSIMS model is but one of several research endeavours world-wide aimed at improving the accuracy of vehicle emission forecasts. Much work remains to be done.

For an in depth review of transportation modelling practice in the context of air quality analysis, the reader is referred to Deakin et al. (1993). Cambridge Systematics (1994) also provides an overview of short term travel model improvements that can be readily implemented to improve the accuracy of vehicle emission estimates. EEA et al. (1999) present a detailed assessment of models used in greenhouse gas estimation, including travel demand models and traffic operation models.

2.9.2 Average Travel Speed

When preparing emission inventories in the United States, it was frequently assumed that road capacity would grow proportionately with travel demand, causing congestion levels and travel speeds in the future to be similar to those experienced in the past. However, given current levels of highway funding and observed urban congestion trends, it is no longer realistic to assume that vehicle speeds will remain constant over time (Suhrbier et al. 1991). Indeed, congestion is predicted to increase in urban centres across North America.

Travel demand models offer one solution for analyzing the magnitude of traffic congestion in the future. Using such models, estimates of current and future travel speeds can be obtained, based on predicted levels of travel activity and proposed roadway modifications. By estimating emissions on a link-by-link basis, congestion information can be used that would otherwise be lost if a single system-wide average speed was applied. Such variation in average speed across road links has been shown to have a significant impact on vehicle emissions (Anderson et al. 1996). However, much criticism has been directed at the ability of travel demand models to produce accurate estimates of travel speed. Indeed, one of the most frequently cited deficiencies of current modelling practice concerns the validity of vehicle speed estimates derived from travel demand models (Suhriebier et al. 1997; Roden 1996; Dowling Associates 1997; Kurth 1996; U.S. DOT 1994; Stopher and Fu 1996). As Roden (1996) states:

Traditional travel demand forecasting models have not been calibrated to realistically estimate travel times or speeds. Most demand modeling efforts have focused on replicating traffic volumes and transit ridership. They have spent very little time or effort comparing the speeds or travel times generated by the model with observed data. (7)

In many cases, link capacities, free flow speeds, and speed relationships are adjusted to improve the accuracy of the forecasting process, with little regard to the accuracy of the resulting travel speeds (Dowling Associates 1997; Suhriebier et al. 1991; U.S. EPA 1992; U.S. DOT 1994). In this situation, “speed” is primarily a measure of travel impedance, and does not reflect actual travel times on the transportation network. Instead, the speed produced by the traffic assignment algorithm represents a value that optimizes the traffic assignment over the congested network (U.S. EPA 1992).

Traditionally, vehicle speeds are estimated using relationships that relate travel speed to the level of congestion observed on the link, as measured by the link volume to capacity ratio. The most commonly used relationship is the Bureau of Public Roads (BPR) speed-flow curve. However, this curve is based on data from the 1965 Highway Capacity Manual. Recent research suggests that the curve should be updated, and that the link volume to capacity ratios be supplemented with additional data on signal spacing, signal

timing, and signal progression to accurately predict travel speeds on signalized roads (Dowling Associates 1997). Indeed, the standard BPR curves have been shown to produce errors in travel speed of up to 40%, even though the equations have been proven to accurately replicate link volumes (Stopher and Fu 1996).

Methods to improve estimates of travel time and speed are recorded in the literature (Skabardonis and Dowling 1996; Kurth et al. 1996; Fambro and Rouphail 1996; Helali and Hutchinson 1994; Dowling and Skabardonis 1992; Roden 1996; Dowling Associates 1997). Such methods range from simple modification of existing speed relationships to complex queuing applications. Improvements can also be realized by enhancing estimates of free flow speed and link capacity which are used in the speed estimation process. In general, techniques to improve estimates of travel speed can be implemented within the travel demand model itself, or applied after the traffic assignment has been completed in the form of a speed post-processor. Such post-processors typically involve more elaborate methods of speed estimation that are difficult to incorporate into current traffic assignment procedures. By post-processing travel speeds, the calibrated model continues to produce reliable traffic volumes. However, estimates of travel speed are improved as additional variables affecting speed are taken into consideration: variables that are often precluded from existing modelling software.

Unfortunately, speed post-processors are not easy to implement. Often, the data requirements are extensive. The same holds true when applying techniques from the Highway Capacity Manual to estimate free flow speed and link capacity. Roden (1996) provides relevant advice:

Regardless of the techniques or tools that are applied in the modeling process, any enhancements to current procedures should be sensitive to the ultimate purpose of the modeling: supporting decision-makers. This leads to the bottom-line for any model enhancement: If the model becomes so cumbersome that it is reluctantly applied or it is so costly and time-consuming that it cannot be applied when needed, the overall model update effort will be considered a failure. (12)

2.9.3 Emission Models

While travel activity is an important determinant of vehicle emissions, accurate emission forecasts also depend on the ability of the emission model to simulate the relationship between vehicle emissions and the many factors that influence emission rates. However, the accuracy of vehicle emission estimates is often difficult to assess. While the output from air quality models can be compared with measured pollutant concentrations, it is impossible to measure “in-use” vehicle emissions on an urban-wide scale. Consequently, modellers can only ensure that vehicle emission estimates are reasonable, based on their current level of understanding, and identify input parameters that require further refinement (Ireson et al. 1992).

Ireson et al. (1992) identify two important issues which must be addressed to improve the quality of vehicle emission estimates:

1. Dependence on exogenous or unverified inputs
2. Dependence on “representative” or average values for key parameters

In particular, models such as MOBILE5 incorporate emission rates from standard driving cycles which may not be representative of local travel characteristics. Differences in driver behaviour and traffic operating characteristics are treated through a single input parameter, average speed. Consequently, Ireson et al. (1992) highlight the need to explicitly consider individual vehicle modes in the estimation of vehicle emissions, including acceleration, deceleration, idling, and travel at constant speed. Probability functions offer one means of improving the modelling process by replacing representative driving cycles with probability distributions describing driver behaviour.

However, average speed models such as MOBILE5 are under continual development. As Suhrbier et al. (1995) note, increasing attention is being paid to the driving cycle contained in the Federal Test Procedure to ensure that it is representative of typical driving conditions. Deviations from the standard driving cycle have been found to dramatically increase emissions, contributing to “significant inaccuracies” in current emission estimation tools (Williams 1999, 2). While procedures to account for “off-

cycle” travel are being developed, the underlying structure of the MOBILE5 model is unable to account for variations in travel behaviour on different road facilities. In MOBILE5, adjustment factors are applied to base emission rates to account for variations in travel speed. Unfortunately, a single travel speed may be representative of different driving conditions. On freeways, vehicles may travel at a constant speed of 50 km/hr during the peak period. In contrast, vehicles travelling at an average speed of 50 km/hr on collector roads typically experience delays at intersections, followed by rapid acceleration to speeds exceeding 50 km/hr. Consequently, the need exists to distinguish between the unique operating characteristics of different road facilities.

MOBILE5 is also limited in its ability to model the effects of fuel characteristics on vehicle emissions. While the fuel volatility in Ontario is 15.5 psi during the winter, and 14.4 psi during the months of October and May, MOBILE5 does not model fuel volatility effects over 11.7 psi (Philpott 1993). Moreover, it is difficult to model the impact of regulations aimed at controlling the sulfur content of fuel, since the MOBILE model assumes an average sulfur content for all fuels, and does not consider regional variations in the sulfur content. There is also evidence that the emission factors and deterioration rates in MOBILE5 are inaccurate, causing emission estimates to be inflated (Edwards 2000).

Emission estimates can also be influenced by the tendency of modellers to rely on statistically developed average characteristics that may not be representative of local conditions (Ireson et al. 1992). Indeed, many modellers use MOBILE5 default values instead of deriving regional-specific values. Although vehicle fleet characteristics vary by time of day and roadway classification, local data is often scarce. As a result, the impact of alternative vehicle and fuel technologies is difficult to evaluate (Suhriebier et al. 1995)

In another example, Venigalla et al. (1995b) emphasize the “serious reservations” of the research community in adopting operating mode fractions based on the Federal Test Procedure (36). Ideally, operating mode fractions should be developed for each functional class of road and geographic location. However, the FTP operating mode fractions are often applied to all road facilities in the study area due to a lack of readily available local

data. McIlvaine summarizes the problems associated with using default operating mode data:

The FTP operating mode mix is only representative of conditions similar to those under which it was developed. These conditions include an urban setting (like Los Angeles), an average trip length of approximately 7.5 miles, and average of 4.7 trips per day per vehicle. While the FTP was developed from a morning urban commute over a range of facility types, the FTP operating mode mix is not necessarily representative of the operating mode mix that occurs during a given hour, on a specific roadway facility type, and particularly not in non-urban areas (cited in Venigalla et al. 1995b, 36).

Household travel surveys provide one means of estimating the percentage of cold start vehicle trips. Many transportation modelling software packages have been revised, allowing planners to assign the start mode portion of trips to the transportation network in order to derive operating mode fractions based on local data (Suhrbier et al. 1995). Further improvements can be made by increasing the breadth of travel surveys to include questions on vehicle ownership and use. By tracking vehicle trips throughout the day, the vehicle start mode can be determined more accurately. Indeed, vehicle data from household travel surveys can be used for a variety of applications, including determination of the vehicle age distribution and mileage accumulation.

Given the complexities of vehicle emission models, it is critical that transportation planners have a clear understanding of both the capabilities and limitations of models such as MOBILE5. Suhrbier et al. (1995) provide an important warning: "There are significant uncertainties inherent in the MOBILE model and FTP. It is very important as transportation analysts that we understand the inner workings of these technical tools and that they are not simply accepted and used within the transportation profession without question (1167).

Indeed, DeCorla-Souza et al. (1994) highlight the need for consistency between travel inputs and the underlying structure of vehicle emission models. In current practice, travel activity is often summarized using data from individual road links. However, emission

rates in MOBILE5 are based on the Federal Test Procedure, which simulates typical driving conditions for a vehicle trip. Consequently, DeCorla-Souza et. al (1994) argue that development of link-based travel characteristics is inconsistent with the trip-based structure of the MOBILE model. Instead, a trip-based approach is proposed for estimating travel speed and vehicle activity. On the other hand, Anderson et al. (1996) point out the benefits of the link-based approach, in particular, the ability to use link-by-link emission estimates as input to air quality models. Link by link emission estimates also allow modellers to determine the location of emission “hot spots”, and devise appropriate solutions.

A further challenge identified by Khan (1999a) is the ability to handle new technology vehicles with radically different emission characteristics. Other deficiencies of the MOBILE model are being addressed through the development of MOBILE6. However, according to Ireson et al. (1992), the “single most pressing need” is model verification (158). On the transportation side, model validation must be expanded to include detailed verification of outputs used in vehicle emission models. On the emission side, efforts must be made to verify the accuracy of emission models through comparisons with in-use vehicle data. As Ireson (1992) notes, many of the modelling issues “fail to fall cleanly within the purview of either the transportation or air quality communities” (159). As a result, improved emission estimates will only be achieved through the “technical expertise and cooperation” of both professions (Ireson 1992, 159).

2.9.4 Improvements Possible with MOBILE6

Given the limitations of MOBILE5, work is currently underway to improve the accuracy of vehicle emission models. With a release date scheduled for Summer, 2000, development of MOBILE6 is nearing completion. MOBILE6 will incorporate numerous changes aimed at addressing the deficiencies of MOBILE5. It is not the intent of this report to provide a comprehensive study of the new MOBILE6 model. Rather, a brief overview is provided, highlighting a number of the changes that are planned. For more in-

depth information, the reader is urged to consult the MOBILE6 internet site maintained by the U.S. Environmental Protection Agency.

The development of MOBILE6 is anticipated to be the “most extensive revision of the highway vehicle emission factor model undertaken since MOBILE1” (Brzezinski and Newell 1998, 16). Not only are the basic emission rates and correction factors being updated to reflect more recent data, but the structure of the model is being changed. Underlying assumptions are being revised, in addition to the methods for calculating emission factors. Such revisions will entail modifications to the input data provided by the user, and will lead to changes in how the output data are presented. Table 2-6 provides a summary of the changes that are anticipated.

Table 2-6 Overview of Changes Anticipated for MOBILE6

Anticipated Change	Description
Update emission data	<ul style="list-style-type: none"> • In-use deterioration rates for light-duty cars and trucks are being revised • Basic emission rates are also being up-dated
Inclusion of driving behaviour not represented in the FTP driving cycle	<ul style="list-style-type: none"> • A new test procedure has been developed which simulates vehicle operation at higher speeds and acceleration rates than the FTP driving cycle • Consequently, the impact of driving behaviour not captured in the FTP cycle will be accounted for in the MOBILE6 model • Since new vehicles must now be certified using the modified test procedure, the resulting impact on vehicle emissions will be reflected in MOBILE6 • Modifications are also planned to better account for the impact of air conditioning on vehicle emissions
Diurnal evaporative emissions based on real-time diurnal testing	<ul style="list-style-type: none"> • In the past, diurnal emissions were estimated using a one-hour test procedure that simulated daily temperature fluctuations • In MOBILE6, diurnal emissions will be based on “real-time” diurnal tests, in which emissions are measured over a period of hours. Temperatures are increased gradually, rather than forcing heat build-up to occur over a one-hour interval using heat blankets on the vehicle fuel tank • Estimates of multi-day diurnal emissions are also being revised, based on diurnal tests spanning three or more days
Update fuel effects	<ul style="list-style-type: none"> • Based on recent test data, the impact of fuel oxygen content on CO emissions will be reduced in MOBILE6 • Due to variation in the sulfur content of fuels, changes are anticipated that will allow the user to specify an in-use sulfur level

Facility type and average speed correction factors	<ul style="list-style-type: none"> • In MOBILE5, base emission rates are derived from a standard driving cycle with an average speed of 19.6 mph. These rates are then corrected based on the average speed specified by the user • However, different roadway types can have significantly different operating characteristics, yet similar travel speeds. On a local road, an average speed of 45 km/hr represents essentially free-flow conditions; traffic operation is characterized by frequent accelerations and decelerations at traffic control devices. In contrast, an average speed of 45 km/hr on a freeway indicates severe congestion with stop and go driving conditions • In MOBILE6, separate emission factors will be provided for local roads, freeway ramps, arterial roads, and freeways. The factors will be based on vehicle tests over a series of driving cycles: cycles designed to represent the actual driving patterns experienced on different road classifications • For arterial roads and freeways, the user will be able to specify the average speed based on local data • Area-wide emission factors for each pollutant and vehicle type will be calculated as the weighted sum of the four facility-specific emission factors
Update hot soak evaporative emission factors	<ul style="list-style-type: none"> • Hot soak emissions are generated at the end of the vehicle trip due to increased temperatures in the fuel system and engine compartment • In MOBILE6, hot soak evaporative emission factors are being revised to incorporate test results in which the fuel volatility is less than 9.0 psi
Update heavy-duty engine conversion factors	<ul style="list-style-type: none"> • Emissions in heavy-duty vehicles are regulated in terms of grams per brake horsepower-hour. In the MOBILE model, these emissions are converted to grams/mile using conversion factors • Due to changes in fuel consumption rates, fuel density, tire resistance, and aerodynamic drag, the conversion factors must be periodically revised. These revised factors will be incorporated in MOBILE6
Update fleet characterization data	<ul style="list-style-type: none"> • The vehicle age distribution and mileage accumulation rates in MOBILE5 will be updated to reflect changes in the vehicle fleet
Updates to vehicle activity rates	<ul style="list-style-type: none"> • Many of the vehicle activity rates will be updated in MOBILE6 using data from instrumented vehicles. Examples include: <ul style="list-style-type: none"> – Distribution of soak times (used to estimate average start emissions, as well as average hot soak emissions) – Average trip duration (used to determine the rate of running loss emissions)
Separation of start and running emissions	<ul style="list-style-type: none"> • Historically, the proportion of travel in different operating modes was specified through the use of operating mode fractions • To respond to the need for a more detailed description of daily emissions, the MOBILE model is being revised so that separate “start” and “running” emission factors are produced • Running emission factors will be represented in grams/mile, and will be based on hot stabilized engine operation • Start-mode emission factors will be calculated as the added emissions resulting from vehicle start-up. The emission factors will be based on the distribution of engine soak times, which can be specified by the user • By separating start and running emissions, users are better able to allocate emissions spatially and temporally

Expansion of vehicle classes	<ul style="list-style-type: none"> To accommodate changes in emission regulations and address the needs of the modelling community, MOBILE6 will incorporate additional vehicle categories Existing categories for light-duty gas trucks, heavy-duty gas vehicles, and heavy-duty diesel vehicles will be broken down into various subcategories based on vehicle weight. Emission factors will also be available for gas and diesel buses
Inclusion of compressed natural gas vehicles	<ul style="list-style-type: none"> In MOBILE6, the user will have the option of modelling emissions from compressed natural gas vehicles. Although other alternative vehicle technologies are being developed, the vehicles are not in wide use, and insufficient data are available to compute emission factors.
Hourly calculation of emission factors	<ul style="list-style-type: none"> MOBILE6 will incorporate changes which permit daily average emission factors to be developed, as well as hourly emission factors covering a 24-hour period. The user will have the option of specifying minimum and maximum daily temperatures (from which a daily temperature profile will be developed) or supplying 24 hourly temperatures. Using the distribution of travel throughout the day, daily average emission estimates will be computed as a weighted sum of hourly emissions
Use of labelled input (elimination of control flags)	<ul style="list-style-type: none"> The use of control flags to describe input data will be eliminated in MOBILE6. Rather, a set of default assumptions will be used unless specified otherwise by the user. As a result, the input file will be simpler to create and understand MOBILE6 will also use "labelled" input to simplify the input file. Labelled input will allow MOBILE6 to identify certain instructions and operate accordingly, regardless of the order in which the instructions appear in the input file The format of input files will be further modified to allow the modeller to include comment lines. This additional documentation will make interpretation of the input files far easier than in the past Certain user inputs (such as vehicle age distributions and mileage accumulation rates) will be processed using external data files. As a result, complicated input data that are frequently required need only be developed and formatted once. To access the data, the name and location of the external file is simply referenced in the primary input file
Modified output files	<ul style="list-style-type: none"> In MOBILE5, the user is presented with four options for model output: short descriptive, long descriptive, short numeric, and long numeric In MOBILE6, the number of output formats will be reduced to two: one descriptive format with clear labelling of all information, and one numeric format, suitable for importing into spreadsheets The descriptive format will "echo" comment lines in the input file, and will be easier to understand than the previous output files produced by MOBILE5

(Adapted from Brzezinski and Newell 1998)

As Table 2-6 shows, the changes anticipated for MOBILE6 are extensive. For this reason, the tools developed in this research cannot be easily modified to work in conjunction with MOBILE6. To date, the input requirements for MOBILE6 have not been published. As a result, it is difficult to know, in detail, the changes that would be required in order to use

the emission calculation tools with the updated model. From a transportation perspective, the most important changes planned for MOBILE6 include:

- Development of facility-specific emission factors
- Separation of start and running emissions
- Calculation of hourly emissions

Not only are the input requirements changing, but also the format of the input and output files. Since the emission calculation tools described in Chapter 5 are based on MOBILE5, substantial modification will be required to benefit from the improvements in MOBILE6. More importantly, however, the emission factors themselves will change; the vehicle emissions calculated in this report are unlikely to be the same as those computed using MOBILE6. As the MOBILE model continues to evolve, changes are also required in the methods used to forecast travel activity. Indeed, the accuracy of vehicle emission estimates depends not only on the tools, but the quality of the input data.

3 RESEARCH DESCRIPTION

3.1 RESEARCH METHODOLOGY

As discussed in Section 1.3, the purpose of this research project was threefold:

- Develop a set of tools for estimating vehicle emissions using output from travel demand models
- Gather input data and compute vehicle emissions for the National Capital Region
- Analyze the sensitivity of emission estimates to changes in input parameters

To accomplish these goals, the research was broken down into a number of smaller tasks as illustrated in Figure 3-1. Essentially, the work consisted of gathering input data and creating analytical tools which were subsequently used to model vehicle emissions in the National Capital Region. Since vehicle emission models require substantial input data, initial research tasks focused on collecting data on commercial vehicle trips, intra-zonal travel, local temperatures, operating mode fractions, and vehicle fleet characteristics. Fortunately, much of the data could be collected in parallel; interdependence between input data requirements was largely nonexistent. However, a road classification scheme was selected early in the research due to its critical role in summarizing travel characteristics by road type and location. Likewise, analysis periods for modelling travel activity were chosen early in the research, facilitating later work within the EMME/2 environment.

The EMME/2 macros and Emission Calculator were developed after the majority of the input data were collected. In this way, the format of the input data was known prior to structuring the computer programs. The EMME/2 macros generate an output file summarizing travel activity. This file is then read into the Emission Calculator, a Visual Basic program which functions outside the EMME/2 environment. The Emission Calculator computes CO, NO_x, and VOC emissions using the vehicle emission model, MOBILE5. Greenhouse gas emissions can also be computed once fuel consumption

equations and greenhouse gas emission factors have been specified by the user. Because of the relationship between the analytical tools, the EMME/2 macros were developed in close conjunction with the Emission Calculator, thus ensuring that the travel data summarized in EMME/2 could be readily incorporated into the emission calculations.

After compiling the input data and developing the necessary tools, vehicle emissions in the National Capital Region were computed for a typical October day using trip tables derived from the 1995 Origin-Destination Survey database. In addition, the travel demand model implemented in EMME/2 was used to generate emission estimates for the PM peak hour in 1995 and 2021. Since the model predicts travel during the PM peak hour only, factors derived from the 1995 OD Survey were used to estimate daily emissions by adjusting PM peak hour emissions appropriately. Numerous sensitivity tests were conducted to determine the change in vehicle emissions that can be expected due to errors in the underlying input data. Moreover, a simple case study was conducted to illustrate a potential application of the emission calculation tools.

Before commencing the research, an extensive literature review was conducted to determine acceptable modelling techniques, deficiencies in current practice, and research activities currently underway. Information from this literature review was used to guide the research work, particularly when using MOBILE5 to model vehicle emissions. A detailed description of each of the major research tasks comprising this work is contained in Chapter 4. Chapter 5 describes the analytical tools developed to model vehicle emissions, while Chapters 6 and 7 summarize the results of the vehicle emissions analysis for the National Capital Region. In the remainder of the current chapter, the study area is described, as well as the travel demand model used to forecast travel behaviour in Ottawa-Hull.

Figure 3-1 Research Methodology

3.2 DESCRIPTION OF STUDY AREA

The National Capital Region (NCR) encompasses two provinces and over one million people. It includes high density urban development, suburban homes, and rural farmland, as well as natural parks and wildlife corridors. In terms of political boundaries, the study area comprises the Region of Ottawa-Carleton (RMOC), the Communauté Urbaine de l'Outaouais (CUO) and parts of the Municipalité Régionale des Collines-de-l'Outaouais (MRC). Figure 3-2 illustrates the extent of the National Capital Region, with the province of Quebec falling to the north of the Ottawa River, and the Province of Ontario falling to the south. In this figure, the Region of Ottawa-Carleton and its 11 municipalities will be replaced by the new City of Ottawa in 2001.

The political centre of Canada, the National Capital Region has a high concentration of government workers. However, the region has also seen tremendous growth in the technology sector, with the number of "high-tech" workers predicted to exceed government workers sometime in the year 2000. To accommodate the growing number of workers in the region, residential development is occurring at a rapid pace. The traffic patterns resulting from this development have been modelled to investigate potential deficiencies in the transportation system and plan for future growth.

Figure 3-2 Map of study area

3.3 MODELLING TRAVEL BEHAVIOUR IN OTTAWA-HULL

The travel demand model for the Region of Ottawa-Carleton was developed using the software package EMME/2. In EMME/2, a user-equilibrium approach is used to assign vehicle trips to the transportation network. Volume-delay functions model the effect of congestion, describing the increase in travel time that results due to increasing traffic volumes.

The model forecasts travel behaviour for the PM peak hour only. In the model, the study area is divided into 258 traffic zones, each with different socio-economic characteristics. The zones increase in size the further one travels from the downtown core, reflecting the more dispersed land-use patterns associated with suburban and rural zones. The traffic zone system is shown in Figure 3-3.

In EMME/2, all modelling is performed at the zonal level, using data from the 1995 Origin-Destination Survey, as well as data from employment studies, parking surveys, and traffic counts. Regression equations are used to predict the number of productions and attractions associated with each traffic zone, based on the zone's population and employment characteristics. A gravity model distributes trips between traffic zones, while a modal split model estimates the number of auto person, auto driver, and transit trips. To facilitate the modelling process, a number of EMME/2 macros have been developed.

Further information regarding the EMME/2 software can be found in the user's manual (INRO 1999). A detailed description of the Ottawa-Hull model is contained in the report, *Development of the 1995 Trans Model* (RMOC 1999).

Figure 3-3 Traffic Zone System

4 INPUT DATA PREPARATION

4.1 INPUT DATA REQUIREMENTS

Vehicle emission models require extensive input data in order to achieve accurate results. In addition to data describing travel activity, such models require knowledge of the vehicle fleet, climate, and fuel characteristics of the study area. Table 4-1 describes the sources of data that were used to model vehicle emissions in the National Capital Region.

Table 4-1 Data Requirements

Description	Source
Travel data <ul style="list-style-type: none"> • vehicle operating mode • intra-zonal trips • vkt by time of day 	<ul style="list-style-type: none"> • 1995 National Capital Region Origin-Destination Survey (for documentation, refer to ADI Ltd. 1996) • TRANS travel demand model for the National Capital Region (for documentation, refer RMOC 1999)
Digitized road networks	<ul style="list-style-type: none"> • Region of Ottawa-Carleton (internal data) • Statistics Canada (Statistics Canada 1997) • National Atlas Base Maps (NRCan 2000)
Commercial vehicle data	<ul style="list-style-type: none"> • 1996 Classification and Occupancy Counts (RMOC internal data) • Montreal Emissions Study (MTQ 1995) • Region of Ottawa-Carleton Bridge Study (internal data) • National Capital Region Goods Movement Study (Delcan 1991)
Minimum and maximum temperature, ambient temperature	<ul style="list-style-type: none"> • Environment Canada (Environment Canada 1983-1999; Environment Canada 1983; Environment Canada 1998b)
Fuel data	<ul style="list-style-type: none"> • Environment Canada (Philpott 1993)
Vehicle age distribution	<ul style="list-style-type: none"> • Environment Canada (Philpott 1993) • Natural Resources Canada (NRCan 1998)
Vehicle fuel type	<ul style="list-style-type: none"> • Natural Resources Canada (NRCan 1998) • Montreal Emissions Study (MTQ 1995)

The 1995 Origin-Destination (OD) Survey was the primary source of travel data used in the analysis. This survey represents the most recent travel data available for the National

Capital Region, and as a result, 1995 was chosen as the base year for all modelling work. The 1995 OD Survey was conducted on behalf of TRANS, a multi-jurisdictional transportation planning committee with members from the Region of Ottawa Carleton, National Capital Commission, Ministry of Transportation of Ontario, OC Transpo, Société de transport de l'Outaouais, Ministère des transports du Québec, and Communauté urbaine de l'Outaouais. The survey captured the trip-making characteristics of residents of the National Capital Region, in both Ontario and Quebec. Demographic data were also recorded, linking travel patterns to the socio-economic characteristics of the trip-maker and associated household.

Another important source of information was the 1996 Classification and Occupancy counts. This data allowed vehicle mix ratios to be computed for different roadway categories. Environment Canada provided much of the non-travel related data for modelling vehicle emissions, including the vehicle age distribution, fuel characteristics, and ambient temperature.

Further information regarding the data used in the analysis can be found in the following sections which describe the different research activities that were undertaken as part of the modelling effort. These activities include:

- selecting analysis periods
- selecting a road classification scheme
- determining the vehicle mix on different road categories
- estimating external trips not captured in the 1995 OD Survey
- estimating the amount of travel associated with intra-zonal trips
- analyzing vehicle operating mode characteristics
- analyzing temperature data
- determining the vehicle age distribution for Ottawa-Hull

4.2 ANALYSIS PERIODS

Pollution from motor vehicles is measured in many different ways; hourly, daily, monthly, and annual emission rates are frequently reported in the literature. While annual rates are often cited to emphasize the critical nature of the problem, daily rates are generally sufficient for analyzing the impact of policies aimed at reducing emissions. On

the other hand, cost-benefit analyses may require a longer time-frame to assess the financial implications of the proposed solutions.

The EMME/2 model used at the Region of Ottawa-Carleton for forecasting travel demand applies only to the PM peak hour. However, daily emission rates can be obtained by generating trip tables from the 1995 OD Survey database for different time periods throughout the day. Although these emission rates apply only to 1995, future emission rates can be determined by factoring the PM peak hour emission rates to account for emissions during the entire day.

Modelling daily emissions, however, is not a simple task. Travel activity varies throughout the day. Likewise, temperatures rise and fall, influencing emission rates. To capture this variation, it is important to model different periods of the day independently. Although it is possible to model emissions on an hourly basis, this level of detail is time-consuming and unlikely to improve emission estimates sufficiently to justify the additional work required. Instead, the day was divided into five periods, and a representative hour was selected from each for modelling travel activity within EMME/2. The time periods chosen for analysis are shown in Table 4-2. These periods correspond to the time periods commonly used at the Region of Ottawa-Carleton to summarize travel data. The early morning, midday, and evening periods are considered off-peak periods with lighter travel demand and traffic volumes. In contrast, the AM and PM peak periods correspond to the daily commuter “rush hour”, and are typically characterized by heavy congestion and slower travel speeds. As a general rule, off-peak and peak hour travel should be modelled separately, and many authors recommend at least four analysis periods for modelling daily emissions (U.S EPA 1992; De Rouville 1992; Stopher and Fu 1997).

To choose a representative hour for each analysis period, the 1995 OD Survey database was used to generate a table summarizing the total number of auto driver trips occurring throughout the day. A “moving average” technique was then employed to compute hourly trip volumes based on 15 minute intervals. From this information, a representative hour was selected with a volume loosely equal to the average hourly volume for the time

period under consideration. The AM and PM peak hours were also determined using this technique. Additional detail can be found in Appendix B.

Table 4-2 Analysis Periods used to Model Vehicle Emissions

Analysis Period	Time Interval	Representative Hour
Early Morning	4:00 a.m. - 7:00 a.m.	5:30 a.m. - 6:30 a.m.
AM Peak Period	7:00 a.m. - 9:30 a.m.	8:00 a.m. - 9:00 a.m.
Midday	9:30 a.m. - 3:30 p.m.	12:30 p.m. - 1:30 p.m.
PM Peak Period	3:30 p.m. - 6:00 p.m.	4:45 p.m. - 5:45 p.m.
Evening	6:00 p.m. - 4:00 a.m.	8:00 p.m. - 9:00 p.m.
AM Peak Hour	7:30 a.m. - 8:30 a.m.	N/A
PM Peak Hour	4:15 p.m. - 5:15 p.m.	N/A

Table 4-3 shows the amount of travel occurring within the representative hour compared to the period as a whole. This table was produced using travel distances from EMME/2 and TransCAD GIS which were imported into the 1995 OD Survey database as described in Section 4.8. The values in Table 4-3 were later used to compute vehicle emissions. Since emissions were only calculated for the representative hour, the data in Table 4-3 was used to factor emission estimates to account for travel occurring within the analysis period as a whole. It should be noted that travel from external trips is omitted from Table 4-3 since trips into and out of the National Capital Region were not adequately captured in the OD Survey. However, it is assumed that the percentage of external trips occurring within the representative hour will be approximately the same as the values depicted in Table 4-3, which are based on trips that remain entirely within the study area. Likewise, intra-zonal trips are excluded from the values in Table 4-3 since intra-zonal trips were analyzed separately, and did not require factoring.

Table 4-3 Distribution of Travel Within Analysis Periods

Time Period	Vehicle-Kilometers Travelled		% of Travel in Representative Hour
	Analysis Period	Representative Hour	
Early Morning	866,617	335,805	38.7
AM Peak Period	2,879,284	1,100,253	38.2
Midday	3,030,487	495,157	16.3
PM Peak Period	3,280,917	1,391,457	42.4
Evening	3,308,037	466,374	14.1

* excludes external trips and intra-zonal trips

The use of representative hours to model daily travel demand involves a certain degree of error. While the average travel speed for the AM peak period was found to be 50.4 km/hr, the AM peak hour has an average travel speed of 42.9 km/hr. In comparison, the average travel speed during the PM peak period was found to be 49 km/hr, compared to 45.6 km/hr during the peak hour. It is assumed that the hour chosen to represent the peak period also represents travel during the peak hour, which occurs sometime within the period. However, as Table 4-4 shows, congestion levels vary even within a relatively short time interval. Consequently, while a single hour can be chosen to represent travel within a larger time span, it must be understood that such an approach cannot account for the more subtle changes in travel activity which occur throughout the interval.

Table 4-4 Comparison of Assignment Results from Representative Hour

Time Period	Veh-km Travelled	Veh-min Travelled	Total Number of Trips*	Average Trip Length (min)	Average Trip Distance (km)	Average Travel Speed (km/hr)
AM Peak Period	1 530 481	1 819 331	111 706	16.3	13.7	50.4
AM Peak Hour	2 001 666	2 805 362	132 030	21.3	15.2	42.8
PM Peak Period	1 974 840	2 409 928	133 958	18.0	14.7	49.0
PM Peak Hour	2 165 937	2 861 018	142 918	20.0	15.2	45.6

* excludes intra-zonal trips which are not assigned in EMME/2

According to Table 4-4, congestion is less severe during the AM peak period, while travel is distributed more uniformly during the PM peak period.

4.3 ROAD CLASSIFICATION SCHEME

Typically, roads are classified according to their location and function. While local and collector roads provide access to adjoining land uses, arterials and freeways are designed to move large numbers of motorists from one area of the city to another, and thus fulfill a mobility function within the transportation system. For this reason, the mix of vehicles using a road varies depending on the type of road and its location within the study area. Likewise, vehicle operating characteristics can be related to the road classification.

In the travel demand model for the National Capital Region, links are classified according to their lane capacity and posted speed limit. Although travel demand models often contain the functional classification of each link, this information is not available in the Ottawa model, making it more difficult to group links with similar characteristics.

Initially, a link classification scheme was devised which classified roads according to their capacity, as well as their posted speed limit. However, this scheme was later discarded in favour of a simpler classification scheme based solely on the road capacity.

Reasons for adopting the simpler scheme were numerous:

- the mix of vehicles using arterial and collector roads was found not to vary with the posted speed limit (refer to Section 4.4)
- on roads with similar capacities, vehicle operating mode fractions were relatively unaffected by the posted speed limit, particularly for the PM peak hour. Since the PM peak hour is the only time period modelled in EMME/2, it is the only time period for which operating mode fractions are required
- the simpler scheme is easier to understand, and follows conventional classification schemes which do not depend on the posted speed limit
- although the more complicated scheme did have a significant amount of travel associated with each road category, the percentage of travel in each category appeared to be a function of the road location. For example, most travel in rural areas was found to occur on high speed roads, while the majority of travel in the downtown core occurred on low speed roads. Since speed limits are closely linked to the surrounding land use, there is little value in classifying roads according to travel speed

A lane capacity of 1000 was selected as the boundary between “minor” and “major” arterial/collectors. Table 4-5 describes the relationship between the link capacity used in

EMME/2 and the corresponding link characteristics. As Table 4-5 indicates, roads with a lane capacity below 1000 are generally characterized by frequent traffic signals, on-street parking, and at-grade intersections. In contrast, roads with a lane capacity of 1000 or greater tend to have fewer traffic signals, and may also have a raised median to separate traffic movements.

Using the traffic zone tags in EMME/2, links were also classified according to their location within the study area. Four land-use categories were selected, each with different travel characteristics: core, urban, suburban, and rural. Appendix C contains a list of traffic zones with the corresponding land-use designation. The classification scheme used in the analysis is described in Table 4-6.

Later, links were further subdivided according to province in order to distinguish between vehicle emissions originating in Ontario and Quebec. However, road operating characteristics were assumed to be independent of the provincial designation, depending only on the road's function and surrounding land use.

Table 4-5 Guidelines to Assign Link Nominal Capacities to NCR Roads (RMOC 1999)

Road Classification	On Street Parking	Operation	CBD	Location	Freq. Signals	Few Signals	At Grade Intersections	Raised Median	Grade Sep. Intersections	Example	Capacity per Lane
Centroid Con.		2 way									See note 1
Local	x	2 way					x				400
Collector	x	2 way		x	x		x			Percy	400
Collector	x	2 way	x	x		x	x			Jockvale Rd.	600
Arterial	x	2 way			x		x			Elgin (2 directions)	400
Arterial		2 way	x		x		x			Queen Street	600
Arterial		2 way	x		x		x			Bank (no left turns etc)	800
Arterial		1 way	x		x		x			Slater	800
Arterial	x	2 way					x			Wellington @ Parkdale	600
Arterial		2 way		x	x		x			Parkdale	800
Arterial		2 way		x	x		x	x		Merivale @ Baseline	1000
Arterial		2 way		x	x		x	x		Hunt Club (western part)	1200
Parkway		2 way				x				Q. Eliz. & Co. By Dr.	800
Parkway		2 way		x		x	x			Ottawa R. & Island P.	1000
Parkway		2 way		x		x	x	x	x	Airport Parkway	1200
Highway		2 way									
highway		2 way		x	x		x			Hwy 31 @ Hunt Club	800
Highway		2 way		x		x	x			Hwy 16 @ Hunt Club	1000
Highway		2 way			x		x			Hwy 16 at Woodroffe	1200
Highway		2 way					x			Rural highways	1600
Bus lane-urban		2 way								Slater, Albert, Maisonneuve	See note 2
Bus lane-Hwy		2 way								Hwy 17, Orleans	See note 2
Transitway		2 way								Transitway	See note 2
Hwy 417		1 way	x	x				x		ramps	1200
Hwy 417		2 way	x	x				x	x	CBD - lanes - much weaving	1600
Hwy 417		2 way		x				x	x	lanes - little weaving	1800

Notes

- 1 Centroid connector capacity set to 1000.
- 2 Transit only facilities do not use lane capacity. To flag these facilities, a capacity of 1400 is reserved for these facilities.

Table 4-6 Link Classification Scheme Used in Analysis

Area	Facility	Lanes	Capacity (veh/hr)	Number of Links	Total Length (km)	Percentage
Core	local	2	400	230	49.2	16
	minor arterial/collectors*	2+	600-800	726	163.27	53
	major arterial/collectors	2+	1000-1200	85	17.61	6
	freeways and rural highways	2+	1600-1800	32	11.99	4
	transit-only links	N/A	N/A	25	11.75	4
	centroid connectors	N/A	N/A	190	56.38	18
	TOTAL	N/A	N/A	2099	310.2	100
Urban	local	2	400	1339	492.89	25
	minor arterial/collectors*	2+	300-800	1530	722.69	36
	major arterial/collectors	2+	1000-1200	344	208.5	10
	freeways and rural highways	2+	1600-1800	138	90.88	5
	transit-only links	N/A	N/A	142	129.79	6
	centroid connectors	N/A	N/A	680	356.86	18
	TOTAL	N/A	N/A	6132	2001.61	100
Suburban	local	2	400	611	233.97	18
	minor arterial/collectors*	2+	600-800	551	383.58	30
	major arterial/collectors	2+	1000-1200	167	217.57	17
	freeways and rural highways	2+	1600-1800	80	108.36	8
	transit-only links	N/A	N/A	24	58.56	5
	centroid connectors	N/A	N/A	310	295.3	23
	TOTAL	N/A	N/A	2461	1297.34	100
Rural and External	local	2	400	66	23.93	1
	minor arterial/collectors*	2+	600-800	270	337.45	8
	major arterial/collectors	2+	1000-1200	761	1794.64	43
	freeways and rural highways	2+	1600-1800	235	1219.2	29
	transit-only links	N/A	N/A	10	11.26	0
	centroid connectors	N/A	N/A	156	770.98	19
	TOTAL	N/A	N/A	2529	4157.46	100
OVERALL TOTAL				13221	7766.61	N/A

* minor arterials/collectors also include links with a capacity of 400 and more than 2 lanes

Although Table 4-6 appears to indicate that suburban and rural areas have a greater proportion of high capacity roads than other areas of the city, caution should be used when reaching this conclusion. In general, the EMME/2 model is less detailed the further one travels from the downtown core. Indeed, every street in the central business district is included in the EMME/2 model, while minor roads are often excluded from rural and suburban zones. Moreover, centroid connectors are used to represent local roads omitted from the model, which will also influence the results presented in Table 4-6. Although the length of roads represented in the model could be compared to the actual length of roads in the National Capital Region, the exercise has little merit. Since all trips within the region are accounted for in the model, the overall amount of travel should be similar to that experienced in reality, even if the travel routes are not identical.

4.4 BACKGROUND TRAFFIC

The EMME/2 transportation planning model used at the Region of Ottawa-Carleton is capable of predicting future passenger vehicle and transit trips. However, commercial vehicle trips are not considered. Indeed, travel activity associated with taxis, school buses, inter-city buses, and heavy vehicles cannot be predicted using the EMME/2 model. Moreover, the EMME/2 traffic assignment algorithm does not take into account the increased congestion resulting from such trips. As a result, the travel times estimated by EMME/2 are subject to error, since the true volume of traffic using the network is unknown.

Error also arises when estimating vehicle emissions. A significant portion of mobile source emissions can be attributed to taxi, bus, and commercial vehicle trips. Since the vehicles associated with such trips have different emission characteristics, they must be analyzed separately. The MOBILE5 emission model recognizes 8 vehicle categories; when completed, MOBILE6 will incorporate up to 26 categories.

To accurately model vehicle emissions, the amount of travel associated with each vehicle category must be known. As a result, it was necessary to determine the mix of vehicles using the transportation network in Ottawa-Carleton. To do so, Classification and Occupancy counts from 1996 were used. Although the travel demand model in EMME/2 is based on the 1995 Origin-Destination Survey, 1995 traffic counts were not used since several screenlines were omitted from the 1995 count. However, all screenlines were counted in 1996.

The first step of the process was to summarize the count data in Microsoft Excel. All count stations with anomaly records (i.e. construction, lane closures) were omitted from the analysis to ensure that the observed vehicle mix was representative of typical conditions. In all, 226 count stations were analyzed. Vehicles were divided into eight separate categories, including:

- passenger vehicles
- light trucks

- heavy trucks
- buses (inter-city, school)
- OC Transpo buses
- STO buses
- taxis
- other vehicles

These categories correspond to the vehicle classifications used in the Classification and Occupancy counts, which are less detailed than those required by the MOBILE model. As a result, subsequent adjustments were required before the data could be used to predict mobile source emissions.

The mix of vehicles using a particular road depends on many factors, including the type of road, its location in the city, and the time of day. In general, the counts took place over an 11 hour period: from 7:00 AM to 10:00 AM, from 11:30 AM to 1:30 PM, and from 3:00 PM to 6:00 PM. Since the count data was summarized according to the AM peak period (7:00 AM to 9:30 AM) and PM peak period (3:30 PM to 6:00 PM), it was decided to use these analysis periods without attempting further data disaggregation. A midday count volume was calculated by subtracting the AM and PM peak period volumes from the 8-hour total volume. Although the resulting volume corresponds to only part of the midday period, the proportion of each vehicle type in the traffic stream should be relatively unaffected.

To account for the variation in vehicle mix associated with different road classifications and development patterns, SPSS was used to determine road categories with similar vehicle mix characteristics. Although many complex classification schemes were developed, these were rejected due to small sample sizes and inconclusive statistical evidence that such schemes were warranted. In the end, the following classifications for location and facility type were selected:

- Location: downtown core, urban, suburban, rural
- Facility Type: local, arterial/collector, freeways/rural highways

Arterial and collector roads were combined into one category due to similar operating characteristics. Likewise, freeways and rural highways were combined, since both function as high-speed routes for accessing or traversing the city of Ottawa. Freeways and rural highways were not disaggregated by location, since vehicles using these facilities often cross several areas, causing the vehicle mix to be similar regardless of location. More importantly, the sample size was insufficient to accurately determine trends at a finer level of detail.

Figure 4-1 and Table 4-8 illustrate the results of the vehicle mix analysis. Table 4-8 also indicates the assumptions that were made regarding the vehicle mix on arterial/collector streets during the early morning and evening periods, as well as the vehicle mix on local streets. These assumptions are based on trends identified in the 1995 OD Survey, miscellaneous traffic counts in the Ottawa region, experience in other cities, and common sense. Additional detail can be found in Appendix D, including values for the standard deviation, standard error of the mean, and confidence interval. Several points should be noted:

1. To determine the mix of vehicles at a particular count station, ratios were developed for each vehicle category. These ratios were computed by dividing the number of vehicles of type j by the number of passenger vehicles and multiplying by 100. Although ratios based on the total traffic volume are more easily understood (i.e. 10% of the traffic volume is heavy trucks), ratios based on the number of passenger vehicles are more easily implemented in the EMM/2 model. Since the model only estimates passenger vehicle trips, the number of taxis, buses, and trucks can be calculated directly from the appropriate ratio, instead of first calculating the total traffic volume. As a result, error is reduced.
2. Initially, an attempt was made to use linear regression to find a relationship between the volume of trucks, buses and taxis using a particular road and the posted speed limit, road capacity, location, and observed volume of passenger vehicles. However, this approach was abandoned for several reasons, including:
 - high correlation between independent variables
 - variable co-efficients with counter-intuitive signs (i.e. negative instead of positive)
 - low "goodness of fit" statistics for certain vehicle categories

- the traffic volumes used to develop regression equations were counted over several hours, and do not correspond to the hourly traffic volumes estimated by EMME/2
 - the complexity of the regression approach did not seem to be warranted
3. It was assumed that 80% of light trucks are passenger vehicles, while 20% are used for commercial purposes. This split will obviously vary depending on the type of road and its location. However, without data to identify such trends, the assumption was applied at all count stations. According to the *Canadian Passenger Transportation Indicator* bulletin, the Royal Commission on Passenger Transportation also assumes that 80% of light-duty trucks are used for passenger transportation (Environment Canada 2000b). Classification and Occupancy statistics published by the Region of Ottawa-Carleton use a similar assumption, while commercial vehicle statistics from the 1989 National Capital Region Goods Movement Study (Delcan 1991) confirm that the assumption is reasonable. The report states that in 1989, commercial vehicle trips represented almost 11% of the private vehicle trips made daily. Using data from the 1996 Classification and Occupancy counts, and assuming that 20% of light trucks are used for commercial purposes (in addition to heavy trucks), the average ratio of commercial vehicles to private vehicles on arterials, collectors, and freeways was computed for different areas of the city. From the results presented in Table 4-7, it appears that the light truck assumption is reasonable. However, because the ratios in Table 4-7 correspond to traffic volumes and not vehicle trips, it is impossible to make further conclusions regarding the accuracy of the light truck assumption. Data from the Transportation Association of Canada's *Urban Indicator Series* shows that commercial vehicles account for approximately 10% of the daily travel on arterial roads and freeways in Ottawa-Hull, further confirming the validity of the light truck assumption (TAC 1999).

Table 4-7 Ratio of Commercial Vehicles to Private Vehicles, Multiplied by 100

Facility	AM Peak	PM Peak	Midday
Core - Collectors/Arterials	7.6	5.7	7.0
Urban - Collectors/Arterials	7.8	6.0	8.4
Suburban - Collectors/Arterials	10.7	8.3	12.3
Rural - Collectors/Arterials	17.0	14.8	22.5
Freeways and Rural Highways	11.3	9.4	14.0

* Based on data from the 1996 Classification and Occupancy Counts

* Assumes that 20% of light trucks are used for commercial purposes

4. All ratios are based on a 5% trimmed mean in order to minimize the impact of count stations with abnormally high or low ratios. To compute the 5% trimmed mean, 5% of the records at the high and low end of the observed range are removed from the sample.

5. Only data from roads representative of the EMME/2 transportation network for Ottawa-Hull were included in the analysis. Since the majority of roads in the EMME/2 model are collectors and arterials, count data from low volume local roads were excluded from the data set. Such roads are typically omitted from transportation models and replaced by centroid connectors. In all, 19 count stations were removed from the data set because the observed volumes were extremely low. In such cases, one truck might be observed during a three hour interval, representing 25% of the total volume counted!

Figure 4-1 Vehicle Mix As a Function of Facility Classification and Time of Day

Table 4-8 Results of the Vehicle Mix Analysis**Ratio of Heavy Trucks, Light Trucks, Taxis, Other Vehicles and Non-Transit Buses to Passenger Vehicles***

Area	Facility	Heavy Trucks					Light Trucks				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	2.1	2.8	2.3	1.3	0.7	23.0	24.2	23.7	21.8	19.6
	Local	1.1	1.4	1.2	0.7	0.4	20.7	21.8	21.3	19.6	17.6
Urban	Collector/Arterial	2.0	2.7	3.0	1.3	0.7	24.3	25.6	26.9	23.6	21.2
	Local	1.0	1.4	1.5	0.7	0.4	21.9	23.0	24.2	21.2	19.1
Suburban	Collector/Arterial	3.3	4.4	5.7	2.2	1.1	29.7	31.3	33.1	30.4	27.4
	Local	1.7	2.2	2.9	1.1	0.6	26.7	28.2	29.8	27.4	24.7
Rural	Collector/Arterial	7.1	9.5	14.1	7.0	3.5	35.7	37.6	41.8	38.9	35.0
	Local	3.6	4.8	7.1	3.5	1.8	32.1	33.8	37.6	35.0	31.5
Freeways and Rural Highways		4.2	5.6	7.6	3.9	2.0	27.2	28.6	32.2	27.7	24.9

Area	Facility	Other Vehicles					Non OC Transpo/STO Buses				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	0.5	0.5	0.5	0.5	0.5	0.6	1.2	0.8	0.9	0.5
	Local	0.5	0.5	0.5	0.5	0.5	0.2	0.3	0.2	0.2	0.1
Urban	Collector/Arterial	0.4	0.4	0.3	0.3	0.3	0.4	0.7	0.5	0.5	0.3
	Local	0.4	0.4	0.3	0.3	0.3	0.2	0.4	0.3	0.3	0.2
Suburban	Collector/Arterial	0.5	0.5	0.4	0.5	0.5	0.0	1.1	0.6	0.5	0.0
	Local	0.5	0.5	0.4	0.5	0.5	0.0	1.1	0.6	0.5	0.0
Rural	Collector/Arterial	0.6	0.6	0.7	0.5	0.5	0.0	1.4	0.9	0.9	0.0
	Local	0.6	0.6	0.7	0.5	0.5	0.0	1.4	0.9	0.9	0.0
Freeways and Rural Highways		0.3	0.3	0.4	0.3	0.3	0.3	0.6	0.5	0.5	0.3

Area	Facility	Taxis				
		Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	2.2	4.4	5.5	4.0	4.0
	Local	2.2	4.4	5.5	4.0	4.0
Urban	Collector/Arterial	0.6	1.1	1.2	1.9	1.9
	Local	0.6	1.1	1.2	1.9	1.9
Suburban	Collector/Arterial	0.2	0.3	0.3	0.3	0.3
	Local	0.2	0.3	0.3	0.3	0.3
Rural	Collector/Arterial	0.0	0.0	0.1	0.1	0.1
	Local	0.0	0.0	0.0	0.0	0.0
Freeways and Rural Highways		0.2	0.3	0.4	0.3	0.3

* ratio is multiplied by 100; passenger vehicles = auto + 80% light trucks

Assumptions:**Collectors/Arterials/Freeways/Rural Highways**

Ratio = 5% trimmed mean based on observed data (assumed to be more representative of overall population)
20% of light trucks are used for commercial purposes, 80% are assumed to be passenger vehicles

Night Ratios:

Heavy Trucks - Ratio = 0.5 * PM peak hour ratio (partially based on 1999 ADR counts on bridges)
Light Trucks - Ratio = 0.9 * PM peak hour ratio (assume commercial light trucks are reduced by 50%)
Taxis - Ratio = Same as PM peak hour ratio (partially based on 1995 OD Survey trends)
Other Vehicles - Ratio = Same as PM peak hour ratio (no reason to assume trends will change)
Non-Transit Buses - Ratio = 0.5 * PM peak hour ratio for freeways, and urban/core arterials
Ratio = 0 for rural/suburban arterials (assume no school buses at night)

Early AM Ratios

Heavy Trucks - Ratio = 0.75 * AM peak hour ratio (partially based on 1999 ADR counts on bridges)
Light Trucks - Ratio = 0.95 * AM peak hour ratio (assume commercial light trucks are reduced by 25%)
Taxis - Ratio = 0.5 * AM peak hour ratio (partially based on 1995 OD Survey trends)
Other Vehicles - Ratio = Same as AM peak hour ratio (no reason to assume trends will change)
Non-Transit Buses - Ratio = 0.5 * AM peak hour ratio for freeways, and urban/core arterials
Ratio = 0 for rural/suburban arterials (assume no school buses in early morning)

Local Roads

Ratios are based on a small number of count locations. Where appropriate, adjustments have been made to reflect anticipated trends and to eliminate anomalies in the count data. Since only a small number of count locations were available, all values should be used with caution. Accuracy statistics are not available, but are expected to indicate large standard deviations and confidence intervals.

Heavy Trucks - Ratio = 0.5 * arterial/collector ratio
(assume commercial vehicles are less likely to travel on local roads than passenger vehicles -- ie intercity truck trips, truck trips between commercial establishments, etc.)
Light Trucks - Ratio = 0.9 * arterial/collector ratio (assume commercial light trucks are reduced by 50%)
Taxis - Ratio = Same as arterial/collector ratio for core, urban, and suburban local roads
Ratio = 0 for rural local roads
Other Vehicles - Ratio = Same as arterial/collector ratio (no reason to assume trends will change)
Non-Transit Buses - Ratio = 0.25 * arterial/collector ratio for local roads in the downtown core
Ratio = 0.5 * arterial/collector ratio for urban local roads
Ratio = Same as arterial/collector ratio for suburban and rural local roads
(difference in ratios reflects type of bus -- ie. tourist versus school bus)

As illustrated in Figure 4-1, the ratio of heavy trucks to passenger vehicles is highest during the midday period for all roadway classifications. During the PM peak period, this value drops by almost 50%, a drop which may be attributed to the greater number of passenger vehicles on the road at this time, as well as a decrease in the number of local delivery trips. As expected, the proportion of heavy trucks is higher on rural roads and freeways. Rural areas also have the highest ratio of light trucks to passenger vehicles, likely due to the importance of light trucks in rural activities such as farming. Similar to heavy trucks, the ratio of light trucks to passenger vehicles peaks during the midday period, although the drop during the afternoon period is less severe. Since approximately 20% of light trucks can be classified as commercial vehicles, this trend seems reasonable.

In contrast, the ratio of taxis to passenger vehicles is highest in the downtown core, becoming almost negligible in suburban and rural areas. In such areas, car ownership is higher and taxis service, where available, is prohibitively expensive. However, rural and suburban areas have a higher ratio of buses to passenger vehicles. While few intercity buses use rural or suburban roads, school buses are common. Not surprisingly, the highest ratios are observed during the morning peak period. Ratios are lower during the afternoon peak period, since most children have already returned home by mid-afternoon. In more built-up areas, students have access to public transit, reducing the need for school buses. However, tour buses and intercity buses can be frequently observed, particularly in the downtown core.

It should be noted that ratios were not computed for intra-urban buses since the EMME/2 transportation planning model contains bus route information which can be used to compute a more accurate estimate of the number of transit vehicles using a particular road. Unfortunately, the bus routes correspond to the PM peak hour. As a result, transit travel may be overpredicted during off-peak periods when express routes are no longer in service. However, despite this error, the transit routes in EMME/2 were felt to provide a more accurate means of estimating transit vehicle-kilometers of travel than applying generic ratios to all links.

Once the vehicle mix was determined, the results were incorporated into the EMME/2 model in order to achieve more realistic estimates of travel behaviour. In EMME/2, a regular traffic assignment is first performed, ignoring the impact of heavy vehicles, buses, and taxis. Using the volume of passenger vehicles assigned to each link, a "background" traffic volume can be computed, based on the ratios in Table 4-8. This background traffic is then converted to passenger car units using the conversion factors in Table 4-9. These conversion factors were selected using recommendations from the ITE Traffic Engineering Handbook (ITE 1992), the Canadian Capacity Guide to Signalized Intersections (Tepley 1995), and the Highway Capacity Manual (TRB 1994).

Table 4-9 Passenger Car Equivalency Factors Used In EMME/2 Assignments

Road Facility	Vehicle Type	Passenger Car Equivalency Factor [*]
Freeways	Trucks	2.0
	Buses	1.6
Arterials/Collectors	Trucks	2.0
	Buses	1.75

To determine the impact of including commercial vehicle travel in the assignment process, a traffic assignment was completed for the PM peak hour using a trip table derived from the 1995 OD Survey. The results of this assignment are presented in Figure 4-2 and Table 4-10.

^{*} Since heavy vehicles have a greater impact on traffic operations, passenger car equivalency factors are used to convert heavy vehicles to passenger car units. An equivalency factor of "2" indicates that one heavy vehicle is equivalent to two passenger vehicles in the traffic stream.

PM Peak Hour - Selected Background Traffic Statistics

Background traffic as a fraction of the TOTAL link volume:

	Core	Urban	Suburban	Rural	All Zones
Minimum	0.00	0.00	0.00	0.00	0.00
Maximum	0.99	1.00	0.99	0.89	1.00
Average	0.17	0.14	0.16	0.17	0.15
Weighted Avg	0.14	0.12	0.13	0.16	0.13

Volume of background traffic added:

Minimum	0
Maximum	1046
Average	65

Percentage increase* in volume due to background traffic:

Minimum	0.0
Maximum**	N/A
Weighted Avg	15.6

* (background traffic + passenger vehicles) / passenger vehicles * 100%

** Links commonly used for transit routes may have a percentage increase in volume much greater than 100% if the volume of passenger vehicles is low

Figure 4-2 Selected Background Traffic Statistics - PM Peak Hour

Table 4-10 PM Peak Hour Assignment With and Without Background Traffic

Criteria	Traffic Assignment Without Background Traffic	Traffic Assignment With Background Traffic	Percentage Difference
Total trips (excluding intra-zonal)	142,917	142,917	0 %
Total vehicle-kilometers travelled	2,156,917	2,165,937	0.4 %
Total vehicle-hours travelled	43,746	47,683	9 %
Average trip length (min)	18.4	20.0	9 %

In order to retain the integrity of the transportation model, it is important that the inclusion of background traffic have only a minor impact on the number of passenger vehicles assigned to each link. Otherwise, the model must be re-calibrated. Fortunately, the total number of vehicle-kilometers travelled was not affected by the background traffic volume, and it can be concluded that vehicle routes remain virtually unchanged despite a significant increase in travel time. An examination of screenline traffic volumes yields a similar conclusion; the volume of traffic across any given screenline varies by less than 1% for outbound traffic and less than 6% for inbound traffic. Results of the screenline analysis can be found in Appendix D.

During the off-peak period, the effect of background traffic is reduced. According to Table 4-11, the total amount of vehicle-hours travelled changes by less than 0.6%.

Table 4-11 Early Morning Period Traffic Assignment With and Without Background Traffic

Criteria	Traffic Assignment Without Background Traffic	Traffic Assignment With Background Traffic	Percentage Difference
Total trips (excluding intra-zonal)	20,164	20,164	0 %
Total vehicle-kilometers travelled	422,085	422,062	0 %
Total vehicle-hours travelled	6486	6526	0.6 %
Average trip length (min)	19.3	19.4	0.6 %

In EMME/2, centroid connectors* represent local roads that have been excluded from the model. However, such links are assigned a high capacity since every vehicle trip is loaded onto the transportation network via centroid connectors. As a result, when modelling travel demand, centroid connectors were assumed to have a vehicle mix representative of arterial/collector roads, rather than local roads. However, when modelling vehicle emissions, the vehicle mix for local roads was applied. To investigate the impact of this assumption on traffic assignments in EMME/2, a simple sensitivity test was conducted for the PM peak hour. Table 4-12 presents the results. As this table shows, the vehicle mix on centroid connectors has minimal impact on the assignment results.

Table 4-12 Impact of Background Traffic Assumed for Centroid Connectors

Criteria	Arterial/Collector Vehicle Mix on Centroid Connectors	No Background Traffic on Centroid Connectors	Percentage Difference
Total trips (excluding intra-zonal)	142,917	142,917	0 %
Total vehicle-kilometers travelled	2,165,937	2,162,522	0.2 %
Total vehicle-hours travelled	47,683	47,339	0.7 %
Average trip length (min)	20.0	19.9	0.7 %

* Centroid connectors are imaginary links that are used to "load" trips onto the transportation network from traffic analysis zones. These links represent the local road network which is not included in the transportation model. For additional detail, refer to Section 4.7 or Appendix A.

As described in Appendix A, the transportation modelling process involves four distinct stages: trip generation, trip distribution, modal split, and traffic assignment. In the modelling process, results from the traffic assignment stage are used to distribute trips between zones and determine the modal split; several iterations are required before convergence is achieved. Although the effects of background traffic should be accounted for in all stages of the modelling process, this is not recommended for the Ottawa-Hull model, since the model was originally calibrated without considering the impact of trucks, taxis, and buses. While the use of background traffic has minimal impact on travel behaviour when assigning trips from the OD Survey, it could have a significant impact on trip distribution and modal split if used in the modelling process due to increased travel times. To avoid this problem, trip tables produced after the model has converged can be re-assigned to the transportation network, taking into account congestion from non-passenger vehicles. This results in improved travel times without jeopardizing the integrity of the model.

In theory, incorporating taxis, bus, and commercial vehicle trips into the assignment process should produce more realistic travel time predictions. Unfortunately, average speed estimates from travel demand models are notoriously inaccurate (Suhriebier et al. 1997; Roden 1996; Dowling Associates 1997; Kurth 1996; Stopher and Fu 1996), and it is unclear whether the inclusion of bus, taxis, and commercial vehicle traffic will improve modelled travel times. However, as improvements are made to speed estimation techniques, it is certain that travel time estimates based on the true volume of traffic using the road will be more accurate than those based on the volume of passenger vehicles. As a result, the benefit of including background traffic in EMME/2 assignment procedures is significant, even though the travel times used in this research may or may not represent an improvement over previous estimates, depending on the accuracy of the travel time functions used.

Regardless of the benefits of including background traffic in the assignment process, the vehicle mix is an essential element for modelling vehicle emissions. To predict vehicle emissions in Ottawa-Carleton, the vehicle mix ratios developed from the Classification

and Occupancy counts were modified to correspond to the vehicle categories used in the MOBILE5 model. These categories include:

- LDGV - light-duty gas vehicles (less than 6000 lb)
- LDDV - light-duty diesel vehicles (less than 6000 lb)
- LDGT1 - light-duty gas trucks (less than 6000 lb)
- LDGT2 - light-duty gas trucks (between 6001 and 8500 lb)
- LDDT - light-duty diesel trucks (between 0 and 8500 lb)
- HDGV - heavy-duty gas vehicles (greater than 8500 lb)
- HDDV - heavy-duty diesel vehicles (greater than 8500 lb)
- MC - motorcycles

It was assumed that 99.4% of light-duty vehicles are gas-fuelled, while 0.6% are diesel-fuelled. It was further assumed that 96.9% of light-duty trucks are gas-fuelled, while 3.1% use diesel fuels. These assumptions are based on trends identified by analyzing the vehicle ownership data for Ottawa-Hull provided by Natural Resources Canada (NRCan 1998).

Additional assumptions were required for the heavy-duty vehicle categories. These assumptions are based on data from the 1989 National Capital Region Goods Movement Study, as well as a 1999 Heavy Vehicle Study concerning truck movement over the Ottawa River bridges. Information was also derived from a vehicle emissions study conducted in Montreal (MTQ 1995). It was assumed that 75% of the vehicles identified as heavy trucks in the Classification and Occupancy Counts can be classified as HDGV or HDDV in the MOBILE5 model. Of these vehicles, 5% are assumed to be gasoline-fuelled, while 95% are assumed to use diesel. These values are based on data from the Montreal Study, which appear reasonable for the National Capital Region. The remaining 25% of the heavy trucks identified in the Classification and Occupancy Counts fall into the LDGT2 and LDDT categories. It was assumed that 10% of these trucks use diesel fuel, while 90% use gasoline. Diesel-fuelled light-duty passenger trucks are also classified as LDDT, giving a ratio of LDDT to LDGT2 of 0.6, similar to that observed in the Montreal Study. Light duty passenger trucks using gasoline fuel are classified as LDGT1.

In the National Capital Region Goods Movement Study, it was found that heavy trucks and tractor-trailers account for 16% of the commercial truck travel in the National Capital Region (Delcan 1991). Medium trucks account for 16% of the travel, while light trucks account for 68%. However, trucks weighing between 2000 and 7000 kg are included in the medium truck category. In contrast, the boundary between light and heavy vehicles in MOBILE5 is 4000 kg (8500 lb). If we assume that vehicle weights are uniformly distributed, approximately 50% of the vehicles classified as medium trucks in the Goods Movement Study correspond to heavy-duty vehicles in MOBILE5. The remaining 50% can be classified as light-duty trucks. As a result, approximately 75% of the medium and heavy vehicles from the Goods Movement Study fall into the HDGV/HDDV vehicle categories in MOBILE5. It is these same heavy and medium vehicles that are classified as heavy trucks in the Classification and Occupancy Counts, leading to the assumption that 75% of the vehicles defined as heavy trucks in the Classification Occupancy Counts correspond to the HDGV and HDDV categories. Indeed, if “x” is the number of trucks, the Goods Movement Study shows that:

- $0.16x = \# \text{ of heavy trucks and tractors}$
- $0.16x = \# \text{ of medium trucks}$
- $0.68x = \# \text{ of light trucks}$
- $0.5 * 0.16x = \# \text{ of medium trucks that can be classified as HDGV/HDDV}$
- $0.5x * 0.16x + 0.16x = \# \text{ of heavy and medium trucks that can be classified as HDGV/HDDV}$
- $0.16x + 0.16x = \text{total number of heavy and medium trucks}$
- $(0.5x * 0.16x + 0.16x) / (0.16x + 0.16x) = 0.75x = \text{fraction of heavy and medium trucks that can be classified as HDGV/HDDV}$

The Bridge Study conducted in 1999 shows comparable results. Of the trucks crossing the Ottawa River Bridges, 27% were 2-axle, 37% were 3-axle, and 36% were tractor-trailer combinations. Similar to the Classification and Occupancy Counts, light trucks were analyzed separately. If we assume that trucks with three or more axles fall into the MOBILE5 heavy vehicle categories, 73% (37% + 36%) of the total trucks observed can be classified as HDGV or HDDV.

In the Classification and Occupancy counts, the “other” vehicle category can include motorcycles, tractors, lawn equipment, and other miscellaneous vehicles. For the purpose of analyzing vehicle emissions, it was assumed that all “other” vehicles could be classified as motorcycles. Certainly, this assumption involves some degree of error, however, for all road facilities, the ratio of “other” vehicles to passenger vehicles is less than 0.005. Consequently, any error is likely to be minor. It was also assumed that school buses, inter-city buses, and tour buses are diesel-fuelled. With only a limited number of such buses in the National Capital Region, the impact of this assumption is expected to be minor.

The vehicle mix categories used to model greenhouse gas emissions need not be the same as those used in the MOBILE5 model. Indeed, the vehicle mix categories can be defined by the user, based on the fuel consumption relationships that are available. In this research, vehicle categories from the Classification and Occupancy Counts were used wherever possible to simplify the analysis. Fuel consumption equations were available for the following vehicle classes:

- light-duty gasoline cars and trucks
- heavy-duty diesel trucks
- heavy-duty gasoline trucks
- diesel buses

Fuel consumption equations were not available for light-duty diesel vehicles. Since such vehicles comprise only a small fraction of the vehicle fleet, it was assumed that all light-duty vehicles were gasoline-fuelled. The proportion of heavy-duty gas and diesel vehicles was determined by combining the appropriate MOBILE5 vehicle categories.

The vehicle mix ratios used to model vehicle emissions are summarized in Appendix D.

4.5 EXTERNAL TRIPS

To estimate the vehicle emissions produced during a typical Autumn day, it is necessary to assign hourly trip tables to the transportation network which are representative of the travel which occurs throughout the day. While the 1995 Origin-Destination Survey

captures trips made by residents of the National Capital Region, trips into or out of the region by non-residents are ignored. In 1993, a roadside travel survey was conducted to determine the number of “external” trips which either originate or terminate outside the National Capital Region. From this survey, an external trip matrix was developed for the PM peak hour to be used in traffic assignments. However, no such matrix exists in the EMME/2 databank for periods other than the PM peak hour. As a result, external trip matrices had to be developed for each of the remaining analysis periods.

To investigate the variation in external trips throughout the day, traffic counts at the region’s outer-most screenlines were analyzed. The number of inbound and outbound passenger vehicles was determined and used to compute a ratio to the corresponding number of vehicles observed during the PM peak hour. The goal of this analysis was to establish factors for modifying the PM peak hour external trip table to estimate external trips during the day. Table 4-13 presents the results of the screenline analysis. A list of the screenlines used in the analysis can be found in Appendix E, along with the count data used to establish the screenline ratios.

In Table 4-13, three different ratios have been calculated by varying the way in which the screenline data was summarized. The first ratio was computed by averaging the individual ratios associated with each external screenline. Since traffic volumes vary by screenline location, a weighted average was also computed to reflect the relative importance of each screenline included in the analysis. In Table 4-13, the ratios were weighted by the total number of inbound and outbound trips observed to cross the screenline during the count period. However, it is also possible to apply weights based on the daily screenline volume, the PM peak hour volume, or even the volume observed during the analysis period. In any event, it was found that each of the weighting methods produced similar results.

The third ratio in Table 4-13 also ensures that more active screenlines are weighted heavier than screenlines with lighter traffic volumes. This ratio was computed by dividing the total number of trips entering or leaving the National Capital Region during the period of interest by the number of trips observed during the PM peak hour.

Table 4-13 Ratio of Hourly Trips to PM Peak Hour Trips

Direction	Analysis Period	Representative Hour	Screenline Average Ratio ¹	Weighted Average Ratio ²	Total Trip Ratio ³
INBOUND	PM PEAK HOUR	16:15 to 17:15	1.00	1.00	1.00
	AM PEAK HOUR	7:30 to 8:30	2.11	1.96	1.92
	PM PEAK PERIOD	16:45 to 17:45	1.03	1.03	1.03
	AM PEAK PERIOD	8:00 to 9:00	1.68	1.55	1.52
	EARLY MORNING	5:00 to 6:00		Data not available	
	EVENING	20:00 to 21:00		Data not available	
	MIDDAY	12:30 to 1:30	0.92	0.92	0.92
OUTBOUND	PM PEAK HOUR	16:15 to 17:15	1.00	1.00	1.00
	AM PEAK HOUR	7:30 to 8:30	0.32	0.36	0.35
	PM PEAK PERIOD	16:45 to 17:45	1.00	0.99	0.99
	AM PEAK PERIOD	8:00 to 9:00	0.33	0.37	0.35
	EARLY MORNING	5:00 to 6:00		Data not available	
	EVENING	20:00 to 21:00		Data not available	
	MIDDAY	12:30 to 1:30	0.40	0.45	0.44

Notes:¹ Based on the average ratio of all screenlines analyzed² Computed by weighting the ratio for each screenline by the percentage of inbound/outbound traffic observed to cross the screenline³ Computed by dividing the total number of trips observed during the analysis period by the number observed during the PM peak hour

An examination of the ratios in Table 4-13 reveals important trends in travel behaviour in the National Capital Region. While inbound trips are more common in the morning, outbound trips dominate during the afternoon, reflecting the predominant direction of travel into and out of the National Capital Region over the course of the day. As a traffic generator, the City of Ottawa tends to attract trips in the morning as people travel into the city for work or personal business. Returning home in the afternoon, these same people are responsible for the large number of outbound trips observed during the PM peak period.

Although an attempt was made to compare the data in Table 4-13 to trends found in the 1995 OD Survey database, the exercise proved impossible. While the OD Survey captures the external trips of local residents who work outside the National Capital Region, it does not include trips from non-residents who work inside the Region. Since the city of Ottawa acts as an employment generator, it is likely that most external work-related trips result from people living outside the study area. Consequently, the 1995 OD Survey database can be used to analyze outbound external trips in the morning and inbound external trips in the afternoon, but is of little value in analyzing external trips in the dominant direction of travel.

After computing the factors in Table 4-13 using screenline count data, it was discovered that the 1993 external travel survey described earlier had also captured external trips during the AM peak period. Since the travel patterns were not required for the Region of Ottawa-Carleton's EMME/2 model, the results were not stored in the EMME/2 databank. However, at some point, an AM peak hour external trip matrix had been developed which could be imported into EMME/2. Although no documentation could be found describing how this matrix had been computed, the travel flows appeared realistic, and it was decided that, for the AM peak hour, it would be more accurate to use the matrix based on the 1993 survey results than adjust the PM peak hour matrix using the factors in Table 4-13. However, to test the validity of the factor approach, two traffic assignments for the AM peak hour were performed, one using the factors in Table 4-13, and the other using the external trip matrix from the 1993 survey. The results of this analysis are shown in Table 4-14.

Table 4-14 AM Peak Hour Travel Activity For Different External Trip Matrices

External Trip Matrix	Veh-KM Travelled	Veh-Min Travelled	Total Number of Trips*	Average Trip Length (min)	Average Trip Distance (km)	Average Travel Speed (km/hr)
Factor Approach	2,046,109	2,845,083	132,694	21.4	15.4	43.2
1993 Travel Survey	1,969,897	2,764,854	131,541	21.0	15.0	42.7
Adjusted 1993 Travel Survey	2,001,666	2,805,362	132,031	21.3	15.2	42.8

* excludes intra-zonal trips which are not assigned in EMME/2

Later, it was discovered that the AM peak hour external trip matrix had not been factored to account for traffic growth between 1993, the year the external travel survey took place, and 1995, the year the OD Survey occurred and the base year for the analysis. To adjust the AM peak hour external trip matrix appropriately, growth factors were obtained by importing the 1993 and 1995 PM peak hour external trip matrices into a Microsoft

Access database. Using Microsoft Access, factors were developed for internal to external trips, external to internal trips, and external to external trips. In each case, the factors were found to depend only on the external zone where the trip originated or terminated. These factors were then applied to the 1993 AM peak hour matrix. Since several months of work had been based on the unfactored matrix, a sensitivity analysis was performed to determine the magnitude of the resulting error. As Table 4-14 shows, the difference in travel activity, while noticeable, is relatively small. Indeed, use of the 1993 AM peak hour external trip matrix is unlikely to affect the travel time and distance results obtained before the error was corrected. Additional detail can be found in Appendix E.

Although an external trip matrix for the AM peak hour had been developed from the 1993 external travel survey, no such matrix existed for the midday period. Indeed, the 1993 roadside survey took place only during the morning and afternoon. As a result, the factors in Table 4-13 were used to generate an external trip table for the midday period. While the inbound ratio was applied to trips beginning outside the region (external to internal trips), the outbound ratio was applied to trips beginning inside the region (internal to external trips). For trips passing through the region (external to external trips), the smaller of the two ratios was applied. Since the factors in Table 4-13 were computed using a variety of techniques, a decision had to be made regarding the most appropriate factor to use. In the end, the total trip ratio was selected. Reasons for this choice include:

- simplicity of use
- screenlines with low traffic volumes are weighted less heavily
- consistent with summing traffic volumes across screenline count stations.
Since the screenlines are arbitrarily defined, variations in screenline ratios may not be important
- accounts for variation in travel activity between screenlines (values are quite similar to the ratios weighted by daily traffic volume)
- consistent with the method of applying the ratios to all inbound/outbound trips

Unfortunately, factoring the PM peak hour external trip table has certain drawbacks.

While factors ensure that the number of external trips is realistic, there is no guarantee that the distribution of external trips into and out of the National Capital Region remains constant throughout the day. For example, while many people may leave the city in the

afternoon for destinations to the west of the region, in the morning, different screenlines may be used more heavily. Indeed, it is impossible to assume that the amount of travel at a given screenline remains unchanged relative to other screenlines in the region.

Moreover, the most external screenlines in the region do not occur at regional boundaries. Consequently, traffic counts at these locations may also reflect local traffic in addition to people travelling into or out of the region. Ideally, the most external screenlines would form a cordon around the National Capital Region. However, such is not the case. Indeed, screenlines on the Quebec side of the region were not considered. However, although the factors in Table 4-13 are based on only a sample of roads leading out of the region, there is no reason to suspect that the sample is not representative of other such roads in the area. While the factor approach has several deficiencies, it is believed to be a reasonable method for computing external trip tables in situations where more detailed information is not available.

The classification and occupancy counts used to generate the ratios in Table 4-13 typically take place between 7:00 a.m. and 6:00 p.m. As a result, data are not available for the early morning and evening periods. However, it was assumed that external travel to and from the National Capital Region during the evening period would be similar to travel during the PM peak hour, although with reduced volumes. Likewise, it was assumed that travel during the early morning would follow a pattern similar to travel during the AM peak hour. Consequently, external trip matrices for the early morning and evening periods could be developed by factoring the AM and PM peak hour matrices to account for the reduced level of travel during off-peak periods. These factors were based on the assumption that a reduction in travel between the peak and off-peak periods would be reflected by a similar reduction in the number of external trips. For example, if 50,000 trips occur during the AM peak hour and only 10,000 trips occur during the early morning, an 80% reduction in the number of AM peak hour external trips will produce a reasonable estimate of the number of external trips taking place in the early morning.

Using this assumption, factors were developed for each of the time periods lacking screenline count data. For the early morning period, a factor of 0.16 was used to adjust

the AM peak hour external trip matrix. For the evening period, a factor of 0.36 was applied to the PM peak hour matrix. In the same way, factors were applied to the AM and PM peak hour matrices to obtain matrices for the AM and PM peak periods. In this case, a factor of 0.85 was applied to the AM peak hour external trip matrix, while a factor of 0.90 was applied to the PM peak hour matrix.

Table 4-15 illustrates the percentage of external trips occurring in each analysis period. Once the external trip matrices were developed, they could be added to the trip tables derived from the 1995 OD Survey database for trips within the National Capital Region. The resulting trip tables could then be assigned to the transportation network to estimate travel time and distance, as well as generate travel data for calculating vehicle emissions.

Table 4-15 Percentage of External Trips Compared to Total Trips

Period	Total Trips in Representative Hour*	External Trips in Representative Hour	% of External Trips
Early Morning	20,164	1338	6.6
AM Peak Period	111,706	7112	6.4
Midday	64,864	6468	10.0
PM Peak Period	133,958	9616	7.2
Evening	53,458	3846	7.2
PM Peak Hour	142,918	10,684	7.5
AM Peak Hour	131,541	8367	6.4

* excluding intra-zonal trips; analysis based on use of unadjusted 1993 AM peak hour external trip matrix

4.6 SENSITIVITY ANALYSIS

To determine the impact of the background traffic and external trip assumptions described in Sections 4.4 and 4.5, a sensitivity analysis was performed. For each analysis period, the background traffic was increased and decreased by 10%, keeping all other factors constant. Likewise, the external traffic was increased and decreased by 10% to measure the sensitivity of the assignment results. As Figure 4-3 and Table 4-16 show, the background traffic assumption has little impact on the overall number of vehicle-kilometers travelled or the average trip length. Although travel times are affected, the

impact is still quite small. In contrast, the external trip assumption impacts both travel times and distances, as well as the number of vehicle-kilometers and vehicle-minutes travelled. Any modification to the external trip table will obviously cause a change in the overall amount of travel in the region. Since external trips tend to be of longer duration, it is not surprising that average trip lengths are also influenced.

Not only is the magnitude of the change in travel time or distance important, but also the direction of change. As anticipated, an increase in background traffic causes an increase in travel time, the result of increased congestion on the transportation network. For this reason, the background traffic assumption has a larger impact in the AM and PM peak hours, when the road network is already quite congested. During the off-peak hours, traffic flows are light; roads are operating well below capacity. As a result, the inclusion of commercial vehicles in the assignment process has only a minor influence on vehicle speed.

Not surprisingly, a decrease in background traffic has the opposite effect. As the number of commercial vehicles decreases, travel speeds increase. From the results of the sensitivity test, it is also evident that decreasing the number of external trips causes a decrease in the overall amount of travel, as well as the average travel time and distance due to the longer duration of most external trips.

It is impossible to know with certainty the actual level of background traffic using the transportation network. Likewise, further studies are required to determine the appropriate number of external trips associated with each analysis period. However, the results of the sensitivity analysis indicate the magnitude of the error that can be expected. For the background traffic assumption, the error is likely to be small. For the external trip assumption, the error is much larger. Since vehicle emissions are directly proportional to the number of vehicle-kilometers travelled, such error may influence the accuracy of emission estimates for Ottawa-Hull.

Figure 4-3 Sensitivity Test Results

Table 4-16 Sensitivity of Assignment Results to Background Traffic and External Trip Assumptions

Analysis Period	Scenario	Veh Km Travelled	Veh Min Travelled	Total Trips	Travel Time (min)	Distance (km)	% Change Compared to Base Scenario				
							Veh Km Travelled	Veh Min Travelled	Total Trips	Travel Time (min)	Distance (km)
AM Peak Hour	Base	1969897	2764854	131541	21.0	15.0					
	Background +10%	1971356	2801325	131541	21.3	15.0	0.07	1.32	0.00	1.32	0.07
	Background -10%	1968128	2730089	131541	20.8	15.0	-0.09	-1.26	0.00	-1.26	-0.09
	External +10%	2020867	2828006	132378	21.4	15.3	2.59	2.28	0.64	1.64	1.94
	External -10%	1918498	2703473	130704	20.7	14.7	-2.61	-2.22	-0.64	-1.59	-1.99
PM Peak Hour	Base	2165937	2861018	142918	20.0	15.2					
	Background +10%	2167576	2887040	142918	20.2	15.2	0.08	0.91	0.00	0.91	0.08
	Background -10%	2164844	2833652	142918	19.8	15.1	-0.05	-0.96	0.00	-0.96	-0.05
	External +10%	2231174	2940315	143986	20.4	15.5	3.01	2.77	0.75	2.01	2.25
	External -10%	2100489	2781519	141849	19.6	14.8	-3.02	-2.78	-0.75	-2.05	-2.29
Midday	Base	835941	855409	64864	13.2	13.7					
	Background +10%	885785	857441	64864	13.2	13.7	-0.01	0.24	0.00	0.24	-0.01
	Background -10%	886182	854043	64864	13.2	13.7	0.04	-0.16	0.00	-0.16	0.04
	External +10%	924680	888968	65511	13.6	14.1	4.38	3.92	1.00	2.90	3.35
	External -10%	847140	822945	64217	12.8	13.2	-4.37	-3.80	-1.00	-2.83	-3.41
Evening	Base	698782	676117	53458	12.6	13.1					
	Background +10%	698857	676566	53458	12.7	13.1	0.01	0.07	0.00	0.07	0.01
	Background -10%	698806	675748	53458	12.6	13.1	0.00	-0.05	0.00	-0.05	0.00
	External +10%	722022	694489	53842	12.9	13.4	3.33	2.72	0.72	1.98	2.59
	External -10%	675737	657888	53073	12.4	12.7	-3.30	-2.70	-0.72	-1.99	-2.60
Early Morning	Base	416980	387684	20164	19.2	20.7					
	Background +10%	416979	387960	20164	19.2	20.7	0.00	0.07	0.00	0.07	0.00
	Background -10%	416983	387355	20164	19.2	20.7	0.00	-0.08	0.00	-0.08	0.00
	External +10%	425112	393950	20298	19.4	20.9	1.95	1.62	0.66	0.95	1.28
	External -10%	408867	381425	20031	19.0	20.4	-1.95	-1.61	-0.66	-0.96	-1.29

* based on use of 1993 unadjusted AM peak hour external trip matrix

4.7 INTRA-ZONAL TRIPS

The inability of travel demand models to accurately account for travel on local streets is one of the major deficiencies of using such models to estimate vehicle emissions. Travel demand modelling is typically performed on a zonal basis. Each zone produces and attracts trips, with the zone centroid representing the centre of activity. Trips with an origin in one zone and a destination in another zone are loaded onto the transportation network using centroid connectors. These links represent local roads which have been excluded from the model. Once trips have been loaded onto the network, all travel is assumed to occur on the collector and arterial roads present in the model. At the end of the trip, centroid connectors are again used to represent travel on local roads: travel which is necessary in order to reach a particular destination. Not surprisingly, the use of centroid connectors inherently leads to error since some trips involve a greater degree of travel on local roads than others. For longer trips, the proportion of travel on local roads will be relatively small, making the use of centroid connectors appropriate. As trip lengths decrease, the level of error rises.

However, of greater significance is the exclusion of intra-zonal trips in the assignment process. Since local roads are represented by centroid connectors, intra-zonal trips are not assigned to the transportation network. It has been estimated that 15% of all urban travel occurs on local roads (Suhrbier et al 1991; U.S. DOT 1994; Miller et al. 1995). As a result, an accurate estimate of vehicle emissions cannot be made without accounting for travel on such facilities. While it is difficult to avoid the inaccuracy associated with centroid connectors, it is possible to estimate the amount of travel from intra-zonal trips travel which cannot be estimated using models such as EMME/2.

Since the database for the 1995 Origin-Destination Survey contains the origin and destination co-ordinates of each trip captured in the survey, a geographic information system (GIS) can be easily used to find the trip length of intra-zonal trips. In this research, TransCAD GIS* was used to geo-code trip origins and destinations. Using the shortest path algorithm within TransCAD, a macro was written to compute the corresponding trip lengths. It was assumed that intra-zonal trips would be relatively unaffected by traffic congestion, regardless of the time of day. As a result, use of the shortest path algorithm was deemed appropriate.

Figure 4-4 illustrates the procedure that was followed for estimating intra-zonal travel in Ottawa-Hull. After querying the 1995 OD Survey database to develop intra-zonal trip tables, a digital road network for the study area was obtained. This road network was converted into a ESRI shape file which could be imported into TransCAD. Since one-way links were not coded properly in the original file, a map of Ottawa-Hull was used to manually identify one-way links in the transportation network, including freeway on- and off-ramps. In addition, the transportation network was modified in such a way that no trip origin or destination could be attached directly to a freeway segment. Instead, freeways could only be accessed via on- or off-ramps.

* For additional information on the use of TransCAD GIS, the reader is referred to the TransCAD user's manual (Caliper 1996)

Figure 4-4 Flowchart of TransCAD Shortest Path Macro

Using UTM co-ordinate information to geocode trip origins and destinations, two point layers were created and attached to the transportation network. The original trip table was then modified so that it could be used in conjunction with a macro designed to automate the trip length calculations. Specifically, the macro identifies the origin and destination of each trip in the transportation network node layer, computes the shortest path, and stores the resulting distance. Additional documentation can be found in the macro source code in Appendix F.

Initial attempts to use the macro revealed that several digitized road links were not properly attached to the transportation network, leading to extremely large trip distances. After up-dating the network to correct these errors, the analysis was repeated. Table 4-17 illustrates the number of trips that could be analyzed using the GIS technique. In total, 10% of the trips in the National Capital Region can be classified as intra-zonal.

Table 4-17 Intra-Zonal Trip Analysis

	Ottawa-Carleton	Outaouais	External
Number of intra-zonal trips in 1995 OD Survey database	7919	3577	149
Number of trips where origin co-ordinates = destination co-ordinates	1197	674	112
Number of trips that could not be geo-coded	29	0	0
Number of trips that could be analyzed in TransCAD GIS	6693 (84.5%)	2903 (81.2%)	37 (24.8%)

Figure 4-5 shows a typical TransCAD road network with geocoded origins and destinations*. For illustrative purposes, the shortest path between an origin and destination pair has been computed and labelled in the diagram. A network connector is

* Due to the quality of the black and white print-out, the trip origins may not be evident in Figure 4-5. In general, the location of trip origins and destinations coincide (i.e. the origin of one trip in the database is the destination of another trip)

also shown, which is used to connect the origins and destinations to the nearest node on the transportation network so that the shortest path can be determined.

Figure 4-5 Typical TransCAD Road Network with Geocoded Origins and Destinations

Figure 4-6 to Figure 4-8 illustrate the digitized road networks used in the analysis. The Ottawa road network in Figure 4-6 was obtained from the Region of Ottawa-Carleton, while the Hull road network in Figure 4-7 is based on data from Statistics Canada (1997). The provincial road network in Figure 4-8 was obtained from Geogratis, an internet site maintained by Natural Resources Canada providing access to Canadian geographic information (NRCan 2000). Since the networks were derived from different sources, it is not surprising that their appearance and level of detail are slightly different. Indeed, the accuracy of the networks is highly dependent on the data source, as well as the frequency with which the data-sets are updated to reflect on-going changes in the transportation system.

Figure 4-6 Region of Ottawa-Carleton Road Network

Figure 4-7 Outaouais Road Network

Figure 4-8 Ontario/Quebec Provincial Road Network

Before presenting the results of the intra-zonal trip analysis, it should be noted that distance values had previously been computed for intra-zonal trips in the National Capital Region and stored in the OD Survey database. However, the distance values were based on a simplified “factor” approach in which GIS was used to compute the length of a small sample of trips in a particular area. The actual trip distance over the transportation network was then compared with the straight line distance between the trip origin and destination. Factors developed from this procedure were subsequently applied to all intra-zonal trips in the database.

Unfortunately, much of the documentation describing this work could not be found. Since the accuracy of the factor approach could not be verified, it was decided to repeat the analysis using TransCAD GIS, thus illustrating one possible application of GIS in transportation planning. Figure 4-9 illustrates the results. As this figure shows, the

difference between the two approaches is small, although the factor approach consistently tends to underestimate trip lengths compared to the GIS approach. In general, the largest difference between the two approaches occurs in rural zones, where trip lengths tend to be greatest. In cases where the difference is significant, it is generally the GIS approach which predicts the larger distance. While this finding may be due to the errors discussed in Section 4.7.1, it may also be true that trips in rural zones are not well-suited to the factor approach, since roads are generally more dispersed. In terms of travel activity, the GIS approach predicts 376,000 vehicle-kilometers of travel in the National Capital Region from intra-zonal trips, while the factor approach predicts 340,000, a difference of 10.6%.

Given the current capabilities of today's geographic information systems, there seems to be little merit in pursuing the factor approach further. Using GIS, it is possible to analyze several thousand trips at once, eliminating the uncertainty associated with the factor approach and reducing the time required to compute distance values.

GIS-Based Approach for Computing Intra-zonal Trip Lengths Compared to Factor Approach

Ontario Zones¹

District	GIS-Based Distance ²		Factor-Based Distance ²		Difference ³		Sample Size	Total Trips	VKT - GIS	VKT - Factor
	Average	Weighted Avg	Average	Weighted Avg	Average	Maximum				
Core	0.90	0.90	0.86	0.87	0.25	3.32	229	4529	4,082	3,927
Urban	1.38	1.38	1.27	1.28	0.30	3.95	1940	40602	56,320	52,060
Suburban	1.72	1.71	1.53	1.52	0.34	2.60	1361	28392	48,549	43,120
Rural	8.07	7.97	7.40	7.34	0.97	7.54	3134	18977	151,228	139,291
TOTAL	4.58	2.81	4.19	2.57	0.63	7.54	6664	92700	260,178	238,398

Quebec Zones¹

District	GIS-Based Distance ²		Factor-Based Distance ²		Difference ³		Sample Size	Total Trips	VKT - GIS	VKT - Factor
	Average	Weighted Avg	Average	Weighted Avg	Average	Maximum				
Core	0.70	0.71	0.68	0.69	0.07	0.22	32	638	454	442
Urban	1.36	1.36	1.20	1.20	0.28	3.31	1088	21191	28,765	25,522
Suburban	1.33	1.34	1.10	1.11	0.30	2.83	304	6664	8,951	7,414
Rural	7.99	5.04	7.10	4.42	1.23	11.85	1478	15491	78,052	68,532
TOTAL	4.72	2.64	4.19	2.32	0.77	11.85	2902	43984	116,257	101,909

NOTES:

¹ Excludes trips with inaccurate co-ordinate information; excludes trips occurring in external zones

² All averages are based on the trips occurring in each district, not average zonal characteristics

³ Computed using absolute values

Figure 4-9 Comparison of Trip Length Calculations

In Figure 4-9, average distance values were obtained by averaging the length of each intra-zonal trip in the OD Survey database for which origin and destination co-ordinates were available. In contrast, weighted averages were computed by dividing the total

number of vehicle-kilometers travelled by the total number of trips represented in the database. While the first average only considers trips within the survey sample, the second takes into account all intra-zonal trips in the National Capital Region which are represented by the sample. As Figure 4-9 shows, the two averages are approximately equal.

Trips that could not be analyzed in TransCAD GIS due to inaccurate co-ordinate information were assigned a distance value equal to the average zonal trip length. Since it is unlikely that the length of one trip would be affected by the relative importance of other trips within the database, the distance values were assigned based on the survey sample, rather than considering the number of trips represented by the sample. If an average zonal trip length could not be computed, a trip length was assigned based on the area of the city in which the trip occurred (core, urban, suburban, or rural). For external trips, an average trip length of 40 km was assumed, roughly based on the average trip length of the 37 external trips with meaningful distance values.

It should be noted that applying the average zonal distance to trips with the same origin and destination co-ordinates may be subject to error. Although such an occurrence is likely due to a coding error in the database, it could also indicate that the origin and destination are situated close together. In this situation, the trip distance would be quite small, and applying an average zonal distance would be inappropriate.

The purpose of the intra-zonal trip analysis was primarily to determine the amount of travel associated with trips not assigned to the transportation network in the EMME/2 model. This information was required to improve the accuracy of vehicle emission estimates for the National Capital Region. In addition, the data were used in the linked trip analysis which was undertaken to determine the start mode of vehicular trips within the region. Both of these applications require a knowledge of the average travel speed. It was assumed that, for intra-zonal trips, drivers would use a combination of local, collector, and arterial roads, with a high proportion of the travel occurring on local roads. While local roads remain relatively uncongested throughout the day, arterial and collector

roads are both influenced by peak period travel demand. Travel speeds are also influenced by the location of travel within the study area.

To compute an average travel speed for intra-zonal trips, traffic zones in the EMME/2 model were divided into districts. An intra-zonal travel speed for each district was then determined by averaging the travel speed for origin-destination pairs within the district. For example, the EMME/2 travel speed between traffic zones in the district of Orleans was used to compute an average travel speed which was subsequently applied to all intra-zonal trips occurring within the district. It was assumed that trips occurring entirely within the district of Orleans would have similar characteristics to trips occurring entirely within the traffic zones that make up Orleans. For external zones, an average speed of 90 km/hr was assumed. As Figure 4-10 shows, the travel speeds estimated by this approach appear reasonable. Although intra-zonal travel speeds could be approximated as the travel speeds on centroid connectors, this approach fails to account for travel on arterial and collector roads, which have different speed characteristics.

Average Travel Speed* (km/hr) for Inter-Zonal Trips Within Each District
(Measured in EMME/2)

District	AM OFF PEAK	AM PEAK PERIOD	MIDDAY	PM PEAK PERIOD	PM OFF PEAK
Ottawa Inner Area (Includes CBD)	36.6	32.2	35.9	32.3	36.2
Ottawa CBD	30.6	27.3	30.1	27.7	30.4
Ottawa West - North	53.0	43.1	49.0	40.0	51.9
Ottawa West - South	50.2	43.5	48.6	41.3	49.7
Ottawa East	44.8	39.6	43.4	38.3	44.3
Ottawa South	43.9	41.1	43.6	40.2	43.9
South Urban Community - Nepean	48.0	47.9	47.9	47.3	47.9
South Urban Community - Gloucester	59.4	59.4	59.4	59.1	59.4
Kanata	54.3	50.8	53.7	49.8	54.0
Stittsville	42.7	42.6	42.7	42.5	42.6
Orleans	47.0	45.2	46.7	43.9	46.8
Rural Ontario (West)	70.5	65.5	69.9	63.4	70.6
Rural Ontario (East)	71.1	70.8	71.1	69.3	71.1
Hull Inner Area (Includes CBD)	30.2	25.5	30.2	21.1	30.2
Hull	46.2	40.5	45.3	37.3	46.2
West Gatineau	41.4	39.8	41.4	36.1	41.8
East Gatineau	53.3	52.6	53.2	51.1	53.3
Aylmer	47.4	45.8	47.3	45.0	47.1
Rural Quebec (East)	68.3	66.5	67.3	65.0	68.3
Rural Quebec (West)	67.9	66.5	67.9	66.2	67.9
External Zones (Ontario)**	90.0	90.0	90.0	90.0	90.0
External Zones (Quebec)**	90.0	90.0	90.0	90.0	90.0

* These speeds were used to compute the trip duration of intra-zonal trips within each region

** An average speed of 90 km/hr was assumed for external trips

Figure 4-10 Average Travel Speed

Results from the intra-zonal trip analysis are presented in Figure 4-11. This table was generated after travel time and distance data had been added to the OD Survey database for all intra-zonal trips in the National Capital Region, including those with inaccurate origin and destination co-ordinates. These data were subsequently used to predict the starting mode of trips within the region, and to estimate vehicular emissions. This analysis is described in detail in Section 4.8 and Chapter 7 respectively.

Intra-Zonal Trip Summary
(excluding external zones)

Time	Location	VKT	Veh-Min Travelled	Total Trips	Sample Size	Avg. Distance (km)	Avg. Duration (min)	Avg. Speed (km/hr)
Early Morning	core	81	141	108	6	0.75	1.31	34.39
	Rural	10674	9198	1432	192	7.46	6.43	69.63
	Suburban	865	1031	601	27	1.44	1.71	50.36
	urban	1163	1532	823	39	1.41	1.86	45.54
AM Peak Hour	core	389	798	406	23	0.96	1.97	29.30
	Rural	22845	20292	3266	469	7.00	6.21	67.55
	Suburban	4155	5227	2770	130	1.50	1.89	47.70
	urban	7490	10851	5463	266	1.37	1.99	41.42
AM Peak Period	core	1009	2045	1093	57	0.92	1.87	29.62
	Rural	52549	46787	7140	1041	7.36	6.55	67.39
	Suburban	8302	10382	5580	265	1.49	1.86	47.98
	urban	14162	20397	10137	491	1.40	2.01	41.66
Midday	core	1254	2245	1547	76	0.81	1.45	33.52
	Rural	95063	82344	12797	1815	7.43	6.43	69.27
	Suburban	15706	18806	9295	447	1.69	2.02	50.11
	urban	27970	36812	20854	1037	1.34	1.77	45.59
PM Peak Hour	core	357	708	510	28	0.70	1.39	30.21
	Rural	30485	27914	4228	598	7.21	6.60	65.53
	Suburban	5973	7571	3709	176	1.61	2.04	47.34
	urban	7790	11676	5780	287	1.35	2.02	40.03
PM Peak	core	982	1977	1125	61	0.87	1.76	29.80
	Rural	70132	64169	9771	1387	7.18	6.57	65.58
	Suburban	13041	16632	8068	388	1.62	2.06	47.04
	urban	17711	26535	13048	650	1.36	2.03	40.05
Evening	core	1368	2393	1507	73	0.91	1.59	34.31
	Rural	100042	85913	13017	1942	7.69	6.60	69.87
	Suburban	21463	25989	12691	600	1.69	2.05	49.55
	urban	26091	33887	18712	902	1.39	1.81	46.20

* All distance/duration values are weighted by the total number of trips

Time	VKT	Veh-Min Travelled	Total Trips	Sample Size	Avg. Distance (km)	Avg. Duration (min)	Avg. Speed (km/hr)
Early Morning	12783	11903	2964	264	4.31	4.02	64.44
AM Peak Period	76022	79610	23949	1854	3.17	3.32	57.30
Am Peak Hour	34880	37167	11904	888	2.93	3.12	56.31
Midday	139993	140207	44493	3375	3.15	3.15	59.91
PM Peak Period	101866	109313	32012	2486	3.18	3.41	55.91
PM Peak Hour	44605	47869	14226	1089	3.14	3.36	55.91
Evening	148964	148183	45927	3517	3.24	3.23	60.32
TOTAL	479629	489215	149345	11496	3.21	3.28	58.82

* All distance/duration values are weighted by the total number of trips

Location	VKT	Veh-Min Travelled	Total Trips	Sample Size	Avg. Distance (km)	Avg. Duration (min)	Avg. Speed (km/hr)
Core	4695	8801	5379	273	0.87	1.64	32.01
Urban	87097	119163	63575	3119	1.37	1.87	43.85
Suburban	59378	72840	36235	1727	1.64	2.01	48.91
Rural	328459	288412	44156	6377	7.44	6.53	68.33
TOTAL	479629	489215	149345	11496	3.21	3.28	58.82

* All distance/duration values are weighted by the total number of trips

Figure 4-11 Intra-Zonal Trip Summary

4.7.1 Evaluation of GIS as an Analytical Tool in Transportation Planning

Geographic information systems (GIS) have many potential applications in the field of transportation planning. The benefits of GIS are indeed significant: visualization of analysis results, improved communication with decision-makers, new analytical tools for investigating travel behaviour. In this study, trip lengths were estimated based on the

actual distance travelled over the transportation network, a significant improvement over previous analytical techniques.

However, while the use of GIS has many advantages, deficiencies were also observed, influencing the accuracy of the analysis results. Co-ordinate data in the 1995 OD Survey database was found to have several errors. Indeed, as Table 4-17 shows, 16.5% of the intra-zonal trips lacked accurate co-ordinate information and could not be analyzed. In some cases, all the trips in a household had the same origin and destination. In other cases, the origin and destination of a trip were found to be on opposite sides of a freeway, an unlikely occurrence for intra-zonal trips. In such cases, trip lengths were observed to increase significantly, particularly if roads crossing over the freeway were some distance away.

Errors were also encountered with the way in which origins and destinations were attached to the transportation network. In a handful of instances, the connector link for an origin or destination would cross a freeway link, causing the trip to begin or end on the wrong side of the freeway. In addition, origins and destinations are attached to the road network at the nearest node. However, most trips do not begin at an intersection, but rather at a mid-block location. As a result, the shortest path algorithm will tend to underpredict intra-zonal trip lengths, although not significantly. Furthermore, if an origin or destination falls between two streets, it will automatically be attached to the nearest node, even if the node falls on the wrong street. Consequently, trip lengths are affected.

Other errors are associated with the digitized transportation networks used in the analysis. Although turn restrictions are commonly used to restrict vehicular movements at critical intersections, such restrictions were not identified in the digitized road networks.

Problems also existed with the provincial road networks used to analyze intra-zonal trips occurring in external zones. Since only major highways were included in the provincial networks, the process of attaching trip origins and destinations to the nearest node resulted in large connector links which may or may not be representative of the actual route travelled. Fortunately, the number of intra-zonal trips associated with external zones was extremely small. Moreover, trips within external zones will not contribute to

emissions in the National Capital Region, and need only be considered in the linked trip analysis.

As the preceding discussion indicates, much of the error associated with the GIS analysis can be eliminated by improving the quality of the underlying data. In the end, the emissions associated with intra-zonal travel were found to be extremely low. Indeed, less than 3% of the travel in the National Capital Region is associated with intra-zonal trips. However, the work described in this chapter illustrates how geographic information systems can be incorporated into the transportation planning process as a valuable tool for analyzing travel behaviour. While limitations certainly exist, GIS continues to offer significant advantages over traditional analytical techniques, and it is hoped that GIS will be used more frequently in the future to improve the quality of transportation planning activities.

4.8 OPERATING MODE FRACTIONS

4.8.1 Background

Engine temperature is an important determinant of vehicle emissions. At the beginning of a trip, the engine operates in a transient condition, causing emissions to be higher. As the engine and emission control system warm to stabilized conditions, vehicle emissions are reduced. In general, three modes of vehicle operation are defined: hot transient, cold transient, and stabilized. Depending on the temperature of the engine when the vehicle is turned on, the vehicle operates in either a hot or cold transient mode for the initial portion of the trip. This transient mode is followed by a stabilized mode of operation, which is characterized by lower emissions. According to the U.S. Environmental Protection Agency (1994), the vehicle reaches the stabilized operating mode after approximately 8 minutes of travel in urban driving conditions.

Whether a trip is defined as hot or cold start depends on the length of time the engine has been turned off prior to the trip (referred to as the “soak time”), as well as the type of emission control system present on the vehicle. For vehicles equipped with catalytic

converters, the soak duration must be less than an hour for the trip to be classified as hot start. After an hour, the catalytic converter has essentially reached a cold-start condition, and must be heated to optimal temperature before it can function at peak efficiency. On the other hand, vehicles without catalytic converters achieve stabilized conditions at lower operating temperatures, and can thus be turned off for up to four hours before the trip is classified as cold start (U.S. EPA 1994).

4.8.2 Operating Mode Fractions in the National Capital Region

While the MOBILE5 model provides default operating mode fractions based on the Federal Test Procedure, it is preferable to use local data where available. Consequently, a study was undertaken to determine the operating mode characteristics of travel in the National Capital Region, and to assess the potential improvement that can be achieved by using local operating mode data to estimate vehicle emissions. Several steps were required to attain these goals. Figure 4-12 illustrates the procedure followed. Since the mode of operation depends on the length of time the engine has been turned off prior to use, a linked trip analysis was performed, enabling each trip in the 1995 OD Survey database to be classified as either hot start or cold start, depending on the condition of the vehicle engine at the beginning of the trip. Linked trips form part of a trip chain, in which the vehicle makes several stops before reaching its ultimate destination. Intermediate trips within the chain are defined as hot start, since the engine has not yet cooled to ambient temperatures. While linked trips generally refer to trips made by the same individual, in this analysis, trips were considered to be linked based on the condition of the vehicle engine. Thus, successive trips in the same vehicle by different drivers could still be considered linked depending on the length of time the vehicle was idle between trips.

Figure 4-12 Operating Mode Analytical Procedure

By calculating the time between successive vehicle trips, a trip can be identified as cold or hot start. However, while the 1995 OD Survey contains the start time of each trip, the duration of the trip is not recorded. As a result, the length of the soak time between successive trips is unknown. To estimate the trip duration, traffic assignments were

performed in EMME/2 for each analysis period using trip tables derived from the OD Survey database. As discussed in Section 4.2, representative hours were used to model the travel activity within each time period, reducing the number of traffic assignments required. The average travel time and distance for each origin-destination pair were imported into the OD Survey database using macros written specifically for this task. Similar data for intra-zonal trips was also entered, based on the GIS analysis described in Section 4.7. The macro used to enter the travel time and distance data can be found in Appendix G. This macro allows users to link trip records in the OD Survey database with the appropriate travel time and distance data, taking into account the origin and destination of the trip, as well as the time the trip occurred. In the database, 763 records (out of a total of 83,072) lacked the origin and destination data needed to assign travel time and distance values. As a result, average values were assigned based on the time period in which the trip occurred.

It should be noted that EMME/2 data for the PM peak hour had previously been entered into the OD Survey database and assigned to trips occurring throughout the day. However, travel times and distances during heavily congested conditions are unlikely to be representative of travel during off-peak periods. For this reason, a new analysis was conducted, taking into account the range of traffic conditions experienced over a 24-hour period.

After updating the OD Survey Database, a Microsoft Access macro was developed to calculate the length of time between successive vehicle trips and classify the trips accordingly. The source code for this macro can be found in Appendix G. To account for the percentage of vehicles in the fleet without emission control devices, the analysis was repeated twice. Initially, it was assumed that all vehicles were equipped with catalytic converters. As a result, trips were classified as cold start if the soak duration exceeded one hour. The analysis was then repeated, with all vehicles assumed to operate without catalytic converters. Accordingly, trips were only classified as cold start if the vehicle was idle for more than four hours before the trip began.

The number of cold start trips between each origin-destination pair was computed by combining the above results based on the actual fraction of vehicles equipped with emission control devices. For the 1995 Canadian vehicle fleet, 94% of the vehicles were assumed to have catalytic converters. This assumption is based on data from Environment Canada (Philpott 1993), as well as results from a vehicle inspection programme conducted across Canada between 1991 and 1995 (Environment Canada 1997a). Of the 8221 vehicles inspected, 89% were equipped with catalytic converters. However, the proportion of vehicles with catalytic converters in the 1995 fleet will be higher than 89% due to fleet turnover during the study period. It should also be noted that the inspection programme was voluntary. As a result, new model vehicles are likely under-represented in the sample, since there is little incentive for new car owners to participate in an inspection clinic. Further detail concerning the catalytic converter assumption can be found in Appendix G.

To combine the cold start trip tables, the following equation was used:

Equation 4-1
$$C_{ij} = C_{ij \text{ 4 hr soak}} + 0.94 (C_{ij \text{ 1 hr soak}} - C_{ij \text{ 4 hr soak}})$$

where C_{ij} = Number of cold start trips from zone i to zone j
 $C_{ij \text{ 4 hr soak}}$ = Number of cold start trips assuming no vehicles have catalytic converters
 $C_{ij \text{ 1 hr soak}}$ = Number of cold start trips assuming all vehicles have catalytic converters

Because vehicles with catalytic converters operate in the cold start mode if the engine has been turned off for more than an hour, trips are more likely to be classified as cold start. In contrast, vehicles without catalytic converters require over four hours for the engine to cool completely. As a result, some of the trips that would be classified as cold start if the vehicle had a catalytic converter are classified as hot start. For this reason, $C_{ij \text{ 1 hr soak}}$ will always be greater than $C_{ij \text{ 4 hr soak}}$. It should also be noted that hot start trip tables were not computed. Rather, travel in the hot start mode was calculated as the total amount of transient travel minus the amount of travel in the cold start mode.

Figure 4-13 presents the results of the linked trip analysis. In this figure, the proportion of trips in the cold start mode is identified for different trip purposes. These data can be used to compute cold start trip tables by factoring the total number of trips between origin-

destination pairs appropriately. Figure 4-14 provides an estimate of the amount of travel in each of the three operating modes for different time periods throughout the day. These estimates were developed using the travel time and distance data imported into the OD Survey database in conjunction with the trip classification from the linked trip analysis (hot or cold start). Assuming that the vehicle operates in a transient mode of travel for the first 8.4 minutes of the trip, the vehicle-kilometers of travel associated with each operating mode could be computed. Overall, 46.5% of the travel in the National Capital Region occurs in the stabilized mode, while 38% occurs in the cold start mode, and 15.5% occurs in the hot start mode. In contrast, the default operating mode fractions in MOBILE5 show a greater proportion of travel in the hot start mode and a lower proportion of travel in the cold start mode. A comparison of operating mode fractions from various sources is presented in Section 4.8.3.

Trips in the National Capital Region by Trip Purpose and Time of Day

Trip Purpose	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	Overall Day
Home-based work	38,211	127,050	68,020	54,291	52,821	107,663	59,532	386,747
Home-based school	370	9,746	5,182	12,050	2,115	6,426	8,266	36,858
Home-based shop	621	7,194	1,335	84,819	14,795	36,676	60,618	189,927
Home-based other	10,221	69,762	33,551	96,815	37,754	87,082	180,515	444,395
Non home-based	4,801	52,924	26,990	128,548	38,973	86,618	60,858	333,749
OVERALL	54,223	266,676	135,078	376,523	146,459	324,466	369,788	1,391,676

Percentage of Cold Start Trips Assuming 94% of the Fleet has Catalytic Converters

Trip Purpose	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	Overall Day
Home-based work	99.1	98.9	99.3	81.6	94.7	95.3	94.1	94.7
Home-based school	94.4	98.7	98.6	90.4	92.0	92.4	91.7	93.3
Home-based shop	67.1	80.1	84.8	61.5	32.1	36.6	49.6	53.6
Home-based other	90.8	83.1	85.6	64.6	34.5	38.3	65.9	63.5
Non home-based	9.8	8.7	7.3	44.1	66.6	64.1	50.1	44.3
OVERALL	89.2	76.3	77.3	60.2	65.4	65.0	65.7	67.0

Notes:

Trips within the AM and PM peak hour are also part of the AM and PM peak period

External trips and trips with inaccurate origin/destination records are excluded

Figure 4-13 Results of the Linked Trip Analysis

Travel Summary, Assuming 94% of Vehicles have Catalytic Converters

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
Vehicle-Km Travelled								
Cold Start	356,824	1,086,243	554,238	1,268,126	495,520	1,082,797	1,460,633	5,254,623
Hot Start	36,222	299,760	147,515	711,838	220,328	490,081	615,888	2,153,789
Stable	486,354	1,569,445	781,314	1,190,374	841,143	1,809,906	1,380,480	6,436,559
TOTAL	879,400	2,955,448	1,483,067	3,170,339	1,556,990	3,382,783	3,457,001	13,844,971
% of Vehicle-Km Travelled								
Cold Start	40.6	36.8	37.4	40.0	31.8	32.0	42.3	38.0
Hot Start	4.1	10.1	9.9	22.5	14.2	14.5	17.8	15.6
Stable	55.3	53.1	52.7	37.5	54.0	53.5	39.9	46.5
TOTAL	100	100	100	100	100	100	100	100

Percentage of Daily VKT Occurring in each Time Period

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
% of Total VKT	6.4	21.3	10.7	22.9	11.2	24.4	25.0	100.0

Notes:

Trips within the AM and PM peak hour are also part of the AM and PM peak period

External trips and trips with inaccurate origin/destination records are excluded

Figure 4-14 Travel by Operating Mode -- 1995 OD Survey

Once cold start trip tables were computed by classifying trips in the 1995 OD Survey database, it was possible to assign the cold start portion of the trips to the transportation network using a special type of auto assignment in EMME/2. In this way, the proportion of travel in each of the three operating modes could be determined for every link in the transportation network. Each analysis period was considered separately, allowing daily trends to be identified. The EMME/2 assignment algorithm uses a cutoff operator to assign only the first 8.4 minutes of a trip to the transportation network, using the same travel paths produced during a full assignment of both hot and cold start trips. Since external trips were not captured in the OD Survey, it was necessary to factor the external trip tables in EMME/2 to estimate the number of cold start external trips. Trips that begin outside the National Capital Region will have reached a stabilized mode of operation before entering the study area. As a result, the start mode is not important. However, external trips which begin inside the National Capital Region will be in a transient state for the first 8.4 minutes of the trip. To determine the number of cold start external trips, the values in Figure 4-13 were applied to the external trip matrix for each analysis period. Since the external trips could not be separated by trip purpose, a composite cold start trip fraction was applied, corresponding to all trip purposes combined.

Figure 4-15 to Figure 4-21 illustrate the results of the EMME/2 analysis. Further detail can be found in Appendix G. Since a single hour was used to model the travel activity within each analysis period, the operating mode fractions vary from those presented in Figure 4-14, which were derived using trip records corresponding to the entire analysis period. More importantly, however, the values in Figure 4-14 ignore the spatial distribution of operating mode patterns, and were estimated by simply calculating the amount of travel in the hot start, cold start, and stabilized modes for each trip in the OD Survey database, based on the trip duration and start mode. By assigning cold start trip tables to the transportation network, the variation in operating mode fractions by facility classification is revealed.

Travel behaviour during the AM peak period is clearly reflected in the operating mode fractions depicted in Figure 4-16. The majority of travel in the transient mode is cold start, since most vehicles have been idle overnight. As people travel to work in the morning from residential areas of the city, much of the cold start travel occurs on local roads in suburban communities. By the time the vehicles reach the freeway, they have warmed sufficiently to achieve a stabilized mode of operation. For this reason, freeways and other high capacity roads show a high proportion of travel in the stabilized mode. Likewise, much of the travel in the downtown core occurs in a stabilized mode of vehicle operation.

Unlike the AM peak period, the PM peak period has a high number of non-work related trips. As a result, the mode of operation is more difficult to predict intuitively. Freeway travel is typically in the stabilized mode, while travel on local roads is more likely to be in the transient mode. Compared to suburban zones, the downtown core has a higher proportion of travel in the start mode, reflecting the travel patterns of workers as they travel from downtown to home, reaching a stabilized mode of operation outside the urban core.

Figure 4-15 to Figure 4-21 show how operating mode fractions are influenced by both the type of road facility and its location in the study area. Significant variation is also shown by time of day. In all cases, the operating mode fractions are quite different from the

default values in MOBILE5. Consequently, there exists considerable potential for improving vehicle emission estimates by using local operating mode data. This topic is addressed in detail in Section 6.3.3, which describes the enhanced accuracy that can be achieved by substituting local data for MOBILE5 default values.

Figure 4-15 Operating Mode Summary - Early Morning Period

Figure 4-16 Operating Mode Summary – AM Peak Period

Figure 4-17 Operating Mode Summary – Midday Period

Figure 4-18 Operating Mode Summary – PM Peak Period

Figure 4-19 Operating Mode Summary - Evening Period

Figure 4-20 Operating Mode Summary – AM Peak Hour

Figure 4-21 Operating Mode Summary – PM Peak Hour

4.8.3 Comparison to Other Studies

To evaluate how travel in the National Capital region compares with other urban centres, a brief literature review was conducted. In MOBILE5, 27.3% of the travel is assumed to be in the hot start mode, 20.6% in the cold start mode, and 52.1% in the stabilized mode. In contrast, 15.5% of the travel in the National Capital Region is predicted to be in the hot start mode, 38% in the cold start mode, and 46.5% in the stabilized mode. While the split between stabilized and transient travel is reasonably close, the National Capital Region has a much higher proportion of travel in the cold start mode, possibly indicating a reduced tendency for linked trips. However, results from other studies suggest that the MOBILE5 default values may be out of date.

Venigalla et al. (1995a) report on findings from a number of studies. In general, cold start trips were found to be more common than hot start trips, although the results are influenced by the type of emission control system assumed. Using data from the 1990 Nationwide Personal Transportation Survey conducted in the United States, Venigalla et al. (1995a) found that 79.7% of home-based work trips, 54.4% of home-based other trips, and 44.1% of non home-based trips begin in the cold start mode. These values correspond to cities with a population comparable to the National Capital Region. In the National Capital Region, nearly 95% of home-based work trips begin in the cold start mode (refer to Figure 4-13), a higher proportion than reported by Venigalla et al. (1995a). However, the two studies show similar results for non-home-based trips. The tendency towards fewer hot start trips in the National Capital Region may be attributed to limitations of the linked trip macro, as discussed in Section 4.8.6. However, other location-specific factors such as the urban layout, type of employment, or demographics may also influence the results.

Venigalla et al. (1995a) also found that the highest proportion of cold start trips occurs in the morning, a trend which is reflected in the National Capital Region. Trip purpose was found to be the best explanatory variable for variance in the percentage of cold start trips, followed closely by the time of day in which the trip occurs.

In similar study conducted by Venigalla et al. (1995b), it was observed that the MOBILE5 operating mode mix generally underestimates the portion of travel in the cold transient mode. In the study, the authors again used data from the 1990 Nationwide Personal Transportation Survey. Each trip was analyzed separately by dividing the trip into transient and stabilized portions based on the standard cut-off point of 8 minutes. The travel associated with each portion of the trip was then aggregated according to the trip purpose and used to compute operating mode fractions. Overall, 31.2% of the total vehicle-kilometers of travel was predicted to be in the cold transient mode. The hot transient mode accounted for nearly 18.7% of the vehicle-kilometers of travel, while the stabilized mode accounted for 50.1%. In general, these values are similar to those obtained for the National Capital Region, although minor differences are observed. Table 4-18 summarizes the operating mode fractions reported by Venigalla et al. (1995b), as well as the MOBILE5 default values, and the values obtained for the National Capital Region.

Table 4-18 Comparison of Operating Mode Fractions

Operating Mode	Proportion of Travel		
	MOBILE5 Default	Venigalla et al. (1995b)	National Capital Region*
Hot Transient	27.3%	18.7%	15.5%
Cold Transient	20.6%	31.2%	38.0%
Stabilized	52.1%	50.1%	46.5%

* Obtained by analyzing data in OD Survey database, not from EMME/2 traffic assignment of cold start trip tables

As Venigalla et al. (1995b) explain, the MOBILE5 default operating mode fractions were derived from the Federal Test Procedure, which was introduced in the early 1970's. Since that time, the vehicle fleet has changed dramatically, as have urban travel patterns. Indeed, the number of vehicles equipped with catalytic converters has increased substantially. Since such vehicles are afforded a soak time of only an hour before the trip is defined as cold start (compared to four hours for vehicles without catalytic converters), the number of cold start trips has increased. The level of congestion on the road network will also influence the study results. The slower the travel speed, the shorter the distance

travelled in the transient mode before the vehicle warms to optimal temperature.

Conversely, as travel speeds increase, a greater proportion of travel will occur in the cold or hot start mode.

A final study conducted by Chatterjee et al. (1996) illustrates how operating mode fractions vary by functional class of road, geographic location, and time of day for Sacramento, California. The research methodology for the study was similar to the approach adopted in this investigation. A travel demand model was used to assign the cold and hot start portion of trips to the transportation network. It was found that the proportion of travel in the cold transient mode was generally lower the higher the functional classification of the road. Operating mode fractions were observed to vary by geographic location as well as by time of day in more or less predictable patterns. Similar to the National Capital Region, the majority of travel in the cold start mode occurred in rural and suburban zones during the morning peak period, and the central business district during the afternoon peak period. Moreover, it was concluded that the operating mode fractions were “substantially different from the FTP default values embedded in the MOBILE model” (Chatterjee et al. 1996, 101). A comparison of the Sacramento and NCR studies is presented in Figure 4-22 for the AM Peak Period. Operating mode fractions are also shown by time of day for all road facilities combined. The results are remarkably similar. For further details concerning the Sacramento study, the reader is urged to consult the original report.

Study Area	Location (All roads combined)	AM Peak Period**		
		% Hot	% Cold	% Stable
National Capital Region	Core	16.3	25.9	57.9
	Urban	13.4	34.9	51.7
	Suburban	9.2	36.9	53.9
	Rural	3.5	19.6	76.9
	All	10.2	29.7	60.2
Sacramento, California*	Core	11.8	29.2	59.0
	Fringe	12.4	33.0	54.6
	Outlying Business District	14.6	44.2	41.1
	Suburban	12.4	34.2	53.4
	Rural	14.9	6.0	79.1
	All	10.7	29.7	59.6

* Data excludes travel on local roads and freeway to freeway ramps

** NCR - 8:00 am - 9:00 am; Sacramento - 6:00 am - 10:00 am

Study Area	Time of Day (All roads combined)	% Hot	% Cold	% Stable
National Capital Region*	Early Morning	2.4	35.0	62.6
	AM Peak Period	10.2	29.7	60.2
	Midday	18.1	25.3	56.6
	PM Peak Period	11.1	24.4	64.5
	Evening	16.3	30.2	53.5
Sacramento, California	Daily (weighted average)	13.2	27.9	58.9
	6:00 am - 10:00 am	10.7	29.7	59.6
	10:00 am - 5:00 pm	19.0	24.2	56.8
	5:00 pm - 9:00 pm	19.0	23.6	57.4
	9:00 pm - 6:00 am	9.0	34.9	56.1
	24-Hour Period	17.2	25.8	57.0

* Based on data for representative hour

Study Area	Road Classification (All areas combined)	AM Peak Period**		
		% Hot	% Cold	% Stable
National Capital Region	Local*	19.4	50.9	29.7
	Centroid Connectors	16.2	56.0	27.8
	Minor Arterial/Collector	16.3	41.8	41.9
	Major Arterial/Collector	7.5	26.4	66.2
	Freeways/Rural Hwys	5.9	16.7	77.4
	All Roads	10.2	29.7	60.2
Sacramento, California	Local Roads	6.1	15.2	79.7
	Freeway Ramps	10.7	30.1	59.3
	Collectors	15.2	41.5	43.3
	Minor Arterials	13.4	39.9	46.7
	Major Arterials	15.7	48.6	35.8
	Expressways	12.0	31.7	56.3
	Freeways	18.6	55.5	25.9
	All Roads	10.7	29.7	59.6

* Excludes travel from intrazonal trips

** NCR - 8:00 am - 9:00 am; Sacramento - 6:00 am - 10:00 am

Figure 4-22 Comparison of Sacramento and NCR Operating Mode Fractions

4.8.4 Sensitivity Test

To test the impact of the catalytic converter assumption, a sensitivity test was conducted. Operating mode fractions were computed in EMME/2 assuming that the proportion of vehicles equipped with catalytic converters increased by 2%, decreased by 2%, and decreased by 4% compared to the base scenario of 94% fleet penetration. The results of the sensitivity test are presented in Figure 4-23 and Figure 4-24. As these figures show, the greatest sensitivity occurs in the off-peak periods. During the AM and PM peak period, many trips are work-related, and begin in the cold start mode. Since the vehicle has been idle for more than four hours, the type of emission control system is irrelevant. However, non-work trips are common during off-peak periods. Due to the nature of such trips, the vehicle is often parked for a shorter duration of time. If the time between successive trips is between 1 and 4 hours, the start mode classification will depend on whether or not the vehicle is equipped with a catalytic converter.

In general, as the percentage of vehicles equipped with catalytic converters increases, the number of cold start trips also increases. As a result, more travel takes place in the cold start mode, causing travel in the hot start mode to decrease by a proportional amount. However, the total amount of travel in the transient mode remains unchanged. Likewise, travel in the stabilized mode is unaffected by the catalytic converter assumption.

For the most part, the proportion of vehicles equipped with catalytic converters had only a minor influence on operating mode fractions, regardless of the road classification or time of day. Indeed, the maximum algebraic difference between operating mode fractions corresponding to the base scenario and operating mode fractions for each of the other scenarios was 1.5%. In terms of the percentage difference, a maximum difference of 7% was observed compared to the base scenario. However, for the majority of cases, the difference was much smaller, to the point of being negligible. Consequently, the assumed fleet penetration rate of 94% can be used with confidence, since any minor variation from this value is unlikely to affect the operating mode fractions significantly.

Figure 4-23 Percentage Change in Operating Mode Fractions Due to Catalytic Converter Assumption

Figure 4-24 Algebraic Change in Operating Mode Fractions Due to Catalytic Converter Assumption

4.8.5 Travel Summary for NCR

The travel time and distance values imported into the 1995 OD Survey database from EMME/2 have many potential applications in terms of understanding travel activity in the National Capital Region. Table 4-19 highlights various travel statistics that depend on accurate measurements of travel time and distance.

In addition, vehicle emissions can be computed using a trip-based approach provided travel speed and distance data are present in the OD Survey database. Since the base emission rates in MOBILE5 are derived from driving cycles representative of a typical trip in urban driving conditions, it has been argued that the trip-based approach to modelling vehicle emissions is more consistent with the emission rates in MOBILE5. Travel from individual trips is grouped into different categories based on the average travel speed. In this research, data in the OD Survey database was manipulated to form an output file similar to that produced by EMME/2 to compute vehicle emissions. The average travel speed, total vehicle-kilometers of travel, vehicle-kilometers of travel in the start mode, and vehicle-kilometers of travel in the cold start mode were output to Microsoft Excel. A text file was then produced that could be read by the emission calculation tools. The results of this analysis were used to compare the impact of different methods of aggregating travel data on vehicle emissions. A full description of this analysis can be found in Section 6.2.

Table 4-19 Summary of Travel in the National Capital Region

Analysis Period	Sample Size	Total Trips	Vehicle-Km Travelled	Vehicle-Hours Travelled	Average Travel Time (minutes)	Average Travel Distance (km)	Average Speed (km/hr)
Early morning	3,640	54,223	879,400	14,343	15.9	16.2	61.3
AM peak period	16,051	266,676	2,955,448	63,491	14.3	11.1	46.5
AM peak hour	8,065	135,078	1,483,067	32,156	14.3	11.0	46.1
Midday	22,228	376,523	3,170,339	57,706	9.2	8.4	54.9
PM peak hour	8,933	146,459	1,556,990	35,392	14.5	10.6	44.0
PM peak period	19,770	324,466	3,382,783	76,634	14.2	10.4	44.1
Evening	21,383	369,788	3,457,001	60,536	9.8	9.3	57.1
DAILY TOTAL	83,072	1,391,676	13,844,971	272,710	11.8	9.9	50.8

Notes:

Trips within the AM and PM peak hour are also part of the AM and PM peak period
 External trips and trips with inaccurate origin/destination records are excluded

4.8.6 Sources of Error

To classify trips as hot or cold start, the length of time between successive vehicle trips must be known. For the purpose of this analysis, the person using the vehicle is irrelevant. Instead, it is the condition of the vehicle that determines whether a trip is linked or not. For households with only one vehicle, the analysis is simple; all auto driver trips are considered, regardless of the trip-maker. If a vehicle is used to make two successive trips, it is the length of time between ~~the~~ trips that determines whether the trips are cold or hot start. The person making the trips need not be the same, and indeed, is ignored in the analysis. In this situation, it is assumed that all members of the household use the same vehicle, and thus, successive auto driver trips represent successive trips by the same vehicle, regardless of the person driving.

Unfortunately, households with more than one vehicle are more difficult to analyze. Without knowing which vehicle is driven by which driver, it is only possible to link trips together that have been made by the same individual. Although a vehicle may be used by more than one person throughout the day, the trips associated with each auto driver are analyzed independently, ignoring trips by other household members. It is assumed that each driver has a separate vehicle available for use, and that vehicle sharing does not occur. While this assumption appears reasonable for work-related trips, in the evening, it is likely that some sharing of vehicles does occur. For instance, a husband and wife may each drive separate vehicles to work, but in the evening, use the same vehicle for running errands. In this situation, it is assumed that the initial trip by each driver is cold start. Intermediate trips by other drivers are ignored, even if the vehicle is shared back and forth multiple times throughout the day. In households where the number of drivers equals the number of automobiles, the impact of this assumption is likely minor. While drivers may switch vehicles occasionally, it is expected that most drivers will use the same vehicle throughout the day. Since most vehicles are equipped with catalytic converters, the vehicle need only sit idle for an hour before the trip would be classified as cold start regardless of the person using the vehicle.

In households where the number of drivers exceeds the number of vehicles, the analysis becomes even more complex. In this situation, it is certain that vehicle sharing does occur, affecting the accuracy of the trip classifications. By analyzing the trips made by each auto driver independent of other auto driver trips within the household, a trip may be classified as cold start when in fact the vehicle engine is still warm from a previous trip made by a different household member. Consider the following series of trips made by a single vehicle equipped with a catalytic converter:

- Trip 1: Driver A returns home from work
- Trip 2: 20 minutes later, Driver B takes the vehicle to the store, and returns home 10 minutes later
- Trip 3: 45 minutes later, Driver A goes out to visit friends

The first trip would be classified as cold start, as would the second, even though the vehicle has not yet cooled to ambient temperatures. The third trip would also be defined as cold start since the trips made by Driver A and Driver B are considered independently in the linked trip analysis. In this case, the vehicle appears to have remained idle for more than an hour before Driver A uses the vehicle again, which in fact is not true. However, if the third trip had occurred only 10 minutes after the second trip, it would have been correctly classified as hot start. This short example reveals the deficiencies of the linked trip analysis. In general, the linked trip macro will tend to predict more cold start trips than occur in reality, leading to an overestimate of vehicle emissions. However, without additional data in the OD Survey database indicating the vehicle used for each auto driver trip within a household, it is impossible to classify trips more accurately. Suhrbier et al. (1995) likewise report the need to assume vehicle use characteristics when analyzing the proportion of trip starts by operating mode.

Fortunately, only 16% of the trips in the National Capital Region are made by individuals in households having fewer vehicles than drivers. Since only a portion of these trips will be classified incorrectly, the actual number of trips affected will be much lower than 16%. 37% of the trips in the National Capital Region correspond to households where the number of vehicles equals the number of drivers. Vehicle sharing is likely to occur, but less frequently, and primarily during the evening hours when vehicle emissions are lower.

Over 44% of trips in the study area are associated with households owning only one vehicle: trips that will always be classified correctly. Table 4-20 provides additional detail concerning the proportion of trips affected by the assumptions in the linked trip macro. While these assumptions will certainly affect the results of the analysis, their impact is likely to be minor. However, future surveys should be designed so that the start mode of all trips can be classified correctly.

Table 4-20 Automobile Ownership in the National Capital Region

	# of HH's in Sample	% of HH's in Sample	# of Auto Driver Trips in Sample	% of Auto Driver Trips in Sample	# of Auto Driver Trips in NCR	% of Auto Driver Trips in NCR
0 veh/HH	45	0.3	148	0.2	2999	0.2
1 veh/HH	7798	47.3	32,525	37.5	626,028	43.6
1+ veh/HH, # of veh = # drivers	4800	29.1	35,203	40.6	530,732	37.0
1+ veh/HH, # veh > # of drivers	3540	21.5	15,698	18.1	228,462	15.9
1+ veh/HH, # veh < # drivers	297	1.8	3089	3.6	47,852	3.3
TOTAL	16,480	100	86,663	100	1,436,073	100

An additional source of error concerns the operating mode fractions used for vehicles with different emission control devices. While the MOBILE5 model allows different operating mode fractions to be specified for vehicles with catalytic converters and those without, it was decided to use the same values for both vehicle classes, similar to the approach adopted for the default operating mode fractions in MOBILE5. Vehicles without catalytic converters should theoretically have a higher proportion of hot start trips due to the longer soak duration required to completely cool the vehicle to typical cold-start conditions. It is assumed that travel behaviour remains the same, regardless of the emission control technology present on the vehicle. As a result, the proportion of travel in the stabilized mode will be unchanged. However, the relative proportion of travel in the hot and cold start transient modes will certainly be affected. Given the complexity of modelling different vehicle categories separately, combined with the relatively small

number of vehicles without catalytic converters, it was decided to compute operating mode fractions based on the entire vehicle fleet combined. As a result, the operating mode fractions are weighted by the number of vehicles with and without catalytic converters. Despite the minor error associated with this approach, it is considered reasonable for estimating vehicle emissions.

It should be noted that the operating mode fractions computed in this study do not account for commercial vehicle trips. While operating mode fractions only affect emissions from light-duty vehicles in the MOBILE5 model, commercial vehicles certainly comprise a portion of the light-duty vehicle category. It is expected that commercial trips would typically be hot start, and that much of the travel would be in the stabilized mode. As a result, the operating mode fractions for the study area would likely show reduced travel in the cold transient mode.

In addition, operating mode fractions will vary if the threshold between stabilized and transient travel is changed from the EPA's recommended value of 8.4 minutes.

Automobile engines are constantly evolving. As engines are designed to warm up more rapidly, the proportion of travel in the transient mode will decrease, particularly on higher class roads such as freeways. Instead, travel in the cold start mode will be limited to the local road network immediately adjacent to the trip origin.

A final comment should be made regarding the boundary between transient and stabilized travel. According to the US EPA, the first 505 seconds of the Federal Test Procedure take place in the transient mode. However, the Federal Test Procedure involves a predefined driving cycle; the first 505 seconds of the cycle are equivalent to travelling a distance of 3.6 miles (5.76 km). Consequently, it is important to determine whether it is the length of time that defines when a vehicle has reached a stabilized operating mode, or the distance travelled. At higher speeds, the engine works harder. If the distance criterion is used, the vehicle will reach a stabilized mode more rapidly than if the time criterion is applied. In the bulk of the literature examined, the cutoff between transient and stabilized travel was defined in terms of travel time (U.S. DOT 1994; Venigalla et al. 1995b; Chatterjee et al. 1996). As a result, the 8.4 minute threshold was used in this research as well. Although

nothing could be found to suggest that the distance cutoff would be more appropriate, the subject warrants further investigation. In addition, it has been suggested that all trips shorter than 8.4 minutes be treated as though they were actually 8.4 minutes in length. Most excess emissions during the transient mode occur in the first minute of travel, yet the emissions are assumed to be uniformly distributed over the entire 8.4 minute period (DeCorla-Souza et al. 1994). If such an adjustment was made, vehicle emissions would increase.

4.9 TEMPERATURE DATA

Vehicle emissions vary throughout the year according to seasonal changes in travel activity and monthly temperature trends. Carbon monoxide emissions are generally a concern during the winter months, while smog is associated with hot summer weather. As a result, vehicle emissions can be calculated in many different ways, depending on the results desired. Often, a typical summer or winter day is analyzed. In other cases, temperature data is selected to reflect conditions when air quality is at its most critical level. Environment Canada outlines a procedure for estimating annual vehicle emissions (Philpott 1993).

Although air quality is of particular concern during the summer and winter, travel surveys are often conducted in the spring or fall so that the results are not affected by summer travel activity, school holidays, or winter storms. Indeed, the 1995 NCR Origin-Destination Survey was conducted between September and mid-December. As a result, travel activity captured in the survey is representative of a typical Autumn day. While it is possible to factor travel data to account for seasonal fluctuations, the information required to do so was not readily available for the National Capital Region. Consequently, emissions associated with winter and summer driving conditions were not analyzed. Instead, emissions were estimated for a typical Autumn day using temperature data for the month of October. This data was obtained from the monthly meteorological summary for the Ottawa International Airport compiled by Environment Canada (Environment Canada 1983-1999).

While vehicle speed and operating mode can be estimated using travel surveys and modelling techniques, temperature data are typically based on historical trends. According to the U.S. Environmental Protection Agency, temperature inputs for modelling vehicle emissions should be based on observations from the three years preceding the analysis year. Furthermore, all projections should use similar temperature values. However, in this analysis, data from 1983 to 1999 was used to compute average temperatures in the National Capital Region. Since temperature inputs are generally held constant when forecasting vehicle emissions, it was felt that a larger set of observations would produce more reliable temperature inputs. Nevertheless, it should be noted that the temperature data for the three years preceding 1995 resulted in hourly temperature values only $\frac{3}{4}$ of a degree warmer than values obtained using the larger observation set.

To determine the ambient temperature corresponding to each analysis period, hourly temperature data was summarized using Microsoft Excel. Average minimum and maximum daily temperatures were also computed. The results of this analysis are shown in Table 4-21. Figure 4-25 illustrates the hourly temperature observations during the month of October from 1983 to 1999. Climate data for the Ottawa International Airport for the period between 1953 and 1982 correspond closely to the values shown in Table 4-21 (Environment Canada 1983). Daily temperature extremes based on data from 1938 to 1990 also correspond closely to the average minimum and maximum temperatures in Table 4-21 (Environment Canada, 1998b).

Table 4-21 Dry-Bulb Temperature Observations During October, 1983 to 1999

Time	Average	Standard Deviation	Maximum	Minimum
0	6.5	4.5	20.8	-4.8
1	6.2	4.5	20.5	-5.1
2	5.9	4.5	20.4	-5.9
3	5.6	4.6	19.8	-5.7
4	5.3	4.6	18.8	-6.1
5	5.1	4.6	18.2	-5.9
6	4.9	4.6	16.3	-5.5
7	5.0	4.6	16.2	-5.4
8	5.9	4.4	16.5	-4.4
9	7.2	4.3	18.5	-2.2
10	8.4	4.5	21.1	-0.8
11	9.6	4.7	22.7	-0.4
12	10.4	4.8	24.4	0.2
13	11.0	4.9	25.7	-0.1
14	11.3	5.1	26.7	-0.3
15	11.5	5.1	25.5	0.1
16	11.2	5.1	25.2	0.1
17	10.4	4.9	23.8	-0.6
18	9.6	4.7	23.7	-1.3
19	8.8	4.6	23.5	-2
20	8.2	4.4	22.3	-3.6
21	7.7	4.4	22	-3.7
22	7.2	4.4	21.8	-3.6
23	6.8	4.4	21.4	-4.5
Daily Max	12.4	5.0	26.7	0.6
Daily Min	3.6	4.0	15.5	-6.1

Figure 4-25 Daily Temperature Fluctuations in October at the Ottawa Int'l Airport

Since temperature data at the Ottawa airport is reported on an hourly basis, there was some difficulty in deciding how to calculate the average temperature for each analysis period. A straight average temperature was computed by averaging all the temperature observations which fell within the analysis period. However, this technique does not account for the distribution of travel over the course of the day. At night, most travel occurs before 11 o'clock. As a result, the temperature value used to compute emissions should be weighted more heavily towards temperatures in the early evening.

To compute a weighted temperature value, the analysis periods were adjusted slightly to start and end on the hour. The average temperature for each hour was computed by averaging the temperature observations at the beginning and end of the hour. This value was then weighted by the amount of travel within the hour compared to the period as a whole. As Table 4-22 illustrates, the weighted temperature values are similar to temperatures observed during the representative hour which was selected to model travel

activity within the analysis period. However, although these representative hours may have travel speeds and congestion levels which are typical of the period represented, there is no guarantee that the corresponding temperatures are representative of the entire period, particularly if travel activity within the period is not distributed evenly. Consequently, the weighted temperature values were selected to compute vehicle emissions, which is consistent with the approach described in the MOBILE5 User's Guide (U.S. EPA 1994). Table 4-23 summarizes the temperature inputs used to estimate vehicle emissions in Ottawa-Carleton.

Table 4-22 Summary of Hourly October Temperatures, 1983-1999

Analysis Period	Time Interval	Representative Hour	Average Temperature During Time Interval	Average Temperature During Time Interval, Weighted by VKT	Average Temperature During Representative Hour
Early Morning	4:00 a.m. - 7:00 a.m.	5:30 a.m. - 6:30 a.m.	5.2 °C	5.0 °C	5.0 °C
AM Peak Period	7:00 a.m. - 9:30 a.m.	8:00 a.m. - 9:00 a.m.	6.1 °C	6.3 °C	6.6 °C
Midday	9:30 a.m. - 3:30 p.m.	12:30 p.m. - 1:30 p.m.	10.4 °C	10.6 °C	11.1 °C
PM Peak Period	3:30 p.m. - 6:00 p.m.	4:45 p.m. - 5:45 p.m.	11.0 °C	10.8 °C	10.6 °C
Evening	6:00 p.m. - 4:00 a.m.	8:00 p.m. - 9:00 p.m.	7.4 °C	8.2 °C	8.1 °C
AM Peak Hour	7:30 a.m. - 8:30 a.m.	N/A	N/A	N/A	6.0 °C
PM Peak Hour	4:15 p.m. - 5:15 p.m.	N/A	N/A	N/A	11.0 °C

Table 4-23 Temperature Values Used in MOBILE5 Analysis

Early Morning	5.0 °C
AM Peak Period	6.3 °C
Midday	10.6 °C
PM Peak Period	10.8 °C
Evening	8.2 °C
AM Peak Hour	6.0 °C
PM Peak Hour	11.0 °C
Maximum Daily Temperature	12.5 °C
Minimum Daily Temperature	3.7 °C

4.10 VEHICLE FLEET AGE DISTRIBUTION

As vehicles age, their control systems become less efficient, causing emissions to increase. To account for this phenomenon, MOBILE5 requires information regarding the vehicle age distribution and mileage accumulation rates for the area under investigation. In the MOBILE5c User's Guide, Environment Canada recommends the use of the default mileage accumulation rates in MOBILE5. However, use of regional-specific vehicle age distributions is strongly encouraged. In the MOBILE5c User's Guide, age distributions for light-duty cars and trucks are presented for each province in Canada. These

distributions are based on data from 1990, with adjustments made to remove the impact of fluctuations in the economy.

To obtain the vehicle age distribution for the National Capital Region, Natural Resources Canada was contacted for information. The Transportation Energy Use Division of the Office of Energy Efficiency was able to provide vehicle ownership data for the 1998 vehicle fleet in Ottawa-Hull. This information was imported into a Microsoft Access database to determine the age distribution of the vehicle fleet within the study area. The information also proved valuable in determining the fraction of diesel-fuelled light cars and trucks in the region, which was used to estimate the vehicle mix on local roads. Results of the analysis are presented in Figure 4-26 and Figure 4-27. As these figures illustrate, the Ottawa-Hull vehicle fleet closely resembles the Canadian fleet in terms of vehicle age.

Because MOBILE5 requires a vehicle age distribution corresponding to the month of July, the data in Figure 4-26 and Figure 4-27 were adjusted to reflect mid-year conditions using a simple averaging technique. In making this adjustment, it was assumed that the vehicle fleet data had been collected near the end of the year, since 1999 model year vehicles were found to represent a small proportion of the 1998 fleet. The adjusted distributions are illustrated in Figure 4-28 and Figure 4-29. As these figures show, the averaging process had the effect of smoothing the distribution curves. Furthermore, the percentage of new model year vehicles in the fleet is greater than zero, which is to be expected for the month of July.

Figure 4-28 and Figure 4-29 also show the vehicle age distribution for Ontario contained in the MOBILE5c User's Guide (Philpott 1993). As mentioned previously, these distributions are based on data from 1990, and have been smoothed to remove the effect of economic trends. Although it would be easy to conclude from Figure 4-28 and Figure 4-29 that the vehicle age distribution for Ottawa-Hull is radically different from the age distribution of the provincial fleet, it must be emphasized that the Ottawa-Hull data was not adjusted to remove economic impacts. Indeed, the recession of the early 1990's is clearly reflected in the Ottawa data, which may account for the significant difference

between the two distributions. Because the Ottawa-Hull data reflects economic trends, the validity of using this data to forecast future emissions is questionable. Certainly, economic cycles will continue into the future. However, the nature of such cycles is difficult to predict.

Checkel (1996) highlights the need to adjust vehicle age distributions to account for fluctuations in the economy. Moreover, Checkel (1996) indicates that vehicle age distributions, including those recommended by Environment Canada, are often shifted towards newer model vehicles. While older vehicles may be present in the fleet, they are often used less frequently. As a result, adjustments to the vehicle age distribution are necessary so that the values reflect the vehicle fleet observed on the transportation network.

Consequently, it was decided to use the Ontario vehicle fleet data compiled by Environment Canada for all emissions modelling work. As shown in Figure 4-26 and Figure 4-27, the vehicle age distribution for Ottawa-Hull agrees closely with the age distribution for the Canadian fleet. As a result, there is reason to believe that the Ontario and Ottawa-Hull distributions, once corrected for economic trends, will be similar as well. Although it is preferable to use local data when estimating vehicle emissions, the Ottawa-Hull vehicle ownership data from Natural Resources Canada reflects the prevailing economic conditions of the 1990's, and is thus of little value for forecasting future emissions unless appropriate adjustments are made. However, the data can be used to determine the influence of fleet turnover on emissions in the National Capital Region. The results of this sensitivity test are discussed in Section 6.3.4. Figure 4-30 and Figure 4-31 illustrate the Ontario and Ottawa-Hull vehicle age distributions for light-duty cars and trucks up to 25 years old as required by the MOBILE5 model. For comparison purposes, the default vehicle age distributions in MOBILE5 are shown in Figure 4-32. Additional information can be found in Appendix H.

Figure 4-26 Automobile Age Distribution – Unadjusted 1998 Vehicle Fleet Data

Figure 4-27 Light Truck Age Distribution – Unadjusted 1998 Vehicle Fleet Data

Figure 4-28 Comparison with 1990 Ontario Automobile Fleet

Figure 4-29 Comparison with 1990 Ontario Light Truck Fleet

Figure 4-30 Automobile Age Distribution for MOBILE5

Figure 4-31 Light Truck Age Distribution for MOBILE5

Figure 4-32 MOBILE5 Default Vehicle Age Distributions

5 DEVELOPMENT OF TOOLS

5.1 INTRODUCTION

Travel demand models predict travel activity; vehicle emission models estimate the pollution resulting from such activity. However, at present, there exists little integration between these models, and it is difficult to assess the impact that changes in travel activity can have on vehicle emissions: changes which ultimately impact air quality in urban areas, as well as society's quality of life.

Consequently, the primary purpose of this study was to develop a set of tools for forecasting vehicle emissions based on the output from the travel demand model, EMME/2. Towards this end, an EMME/2 macro, "travel.mac", was developed for summarizing key travel parameters, such as the number of vehicle-kilometers travelled and the average travel speed. This information is then read into the Emission Calculator, a Visual Basic program developed as a part of this research. Unlike travel.mac, the Emission Calculator is an independent program which functions outside the EMME/2 environment. Using the travel data output from travel.mac, the Emission Calculator computes vehicle emissions of HC's, CO, NO_x, and GHG's. Figure 5-1 describes the relationship between the two programs.

Figure 5-1 Estimating Emissions Using Output from EMME/2

5.2 EMME/2 MACROS

The purpose of the EMME/2 macro, “travel.mac”, is to produce an output file summarizing key travel data for use in the Emission Calculator, a program for computing vehicle emissions. The macro is designed to be as user-friendly as possible, although it should only be used by experienced EMME/2 modellers who are familiar with developing macros in the EMME/2 environment. Developed using the databank at the Region of Ottawa-Carleton, the macro can be readily adapted to other EMME/2 databanks with minor modification.

Upon execution, travel.mac produces two output files. The first describes the trip length distribution, the second identifies the amount of travel and average speed associated with each link or link type classification. Essentially, the macro assigns vehicle trips to the transportation network using an origin-destination trip matrix specified by the user. This matrix may be the result of a detailed modelling effort, beginning at the trip generation stage, or it may be based on origin-destination survey data. The resulting travel activity is then summarized and written to an output file for use in the Emission Calculator. Figure 5-2 provides a flow-chart of the macro design, while *The Emission Calculator User's Guide* contains the source code and documentation (Armstrong 2000). A sample output file is shown in Figure 5-3.

When using the macro, the user has several choices which must be specified at the time of macro execution. Specifically, the user can choose to analyze emissions on a link-by-link basis, or aggregate data according to the road classification, a practice frequently reported in the literature (U.S. EPA 1992; Stopher and Fu 1996; de Rouville 1992; Miller et al. 1992; U.S. DOT 1994). When aggregating data, the total number of vehicle-kilometers travelled can be simply added together. However, vehicle speeds must be weighted by the amount of travel. Furthermore, vehicle speed categories must be specified. In this way, travel on similar links at similar speeds can be grouped together for analysis, allowing MOBILE5 to account for the variation in emissions that occurs at different travel speeds. In MOBILE6, travel on different road facilities is to be grouped using 4 km/hr (2.5 mph) speed intervals. Similar speed intervals have been used when modelling emissions with MOBILE5 (Stopher and Fu 1996). Consequently, a 4 km/hr speed interval was selected for modelling vehicle emissions in the National Capital Region. However, the user is free to choose a different speed interval if so desired.

The vehicle trip matrix assigned to the transportation network generally excludes commercial vehicle travel. As a result, only travel from passenger vehicles is summarized in the output file. In addition to this information, the user can also choose to output transit travel data. The amount of travel activity from transit vehicles is computed using the transit routes and headways stored in the EMME/2 databank. However, since some users

may have travel data for other vehicle categories stored in EMME/2, this information can be written to the output file instead of transit data, if desired. If transit emissions are also needed, two separate model runs are required to take full advantage of the travel data stored in the EMME/2 databank. While the first model run can be used to capture travel from transit vehicles, the second can be used to summarize additional travel data stored in the model, regardless of the vehicle category to which the data applies.

Although the option is given to assign cold start travel to the transportation network, a cold start trip table may not be available. In this case, the user must estimate operating mode fractions from look-up tables, and the appropriate selection should be made at the start of the EMME/2 macro. The user must also specify a classification scheme which identifies links according to their location and function. This information is written to the EMME/2 output file, allowing the Emission Calculator to:

- account for vehicle mix ratios and operating characteristics which vary according to the road classification
- produce summary tables based on the classification scheme

In this research, macros were written to classify links based on their capacity and location in the 258 traffic zone system (refer to Section 4.3). However, to model vehicle emissions in other urban areas, a new classification scheme must be developed, uniquely suited to the transportation network being modelled and incorporating data available in the EMME/2 databank. While macros can be written to tag links according to their location and function, the user also has the option of storing the data in an extra link attribute, eliminating the need to create additional macros.

In addition to the link classification scheme, the user must also indicate whether “background” traffic should be taken into account. Since the trip tables assigned in EMME/2 generally contain passenger vehicle trips only, commercial vehicles are ignored in the assignment process, leading to inaccurate estimates of travel time and speed. In EMME/2, these commercial vehicles can be treated as background traffic: traffic which is not assigned to the transportation network, but which contributes to the overall level of network congestion, influencing assignment results. If commercial traffic is to be

accounted for in the assignment process, the volume of commercial vehicles can be either stored in an extra link attribute, or computed based on the volume of passenger vehicles assigned to the link. Such calculations take place in a special macro specified by the user. The macro is called after an initial traffic assignment has been performed in the main macro, `travel.mac`. The number of passenger vehicles resulting from the initial assignment are used to estimate background traffic volumes expressed in passenger car units. After the calculations have been performed, control returns to the main macro, and a new function table is batched in with the ability to account for both assigned vehicles and background traffic in calculations of travel time and speed. The traffic assignment is repeated, and the results are stored for future use.

In this research, vehicle mix ratios were used to compute the volume of background traffic observed on each link in the transportation network based on the number of passenger vehicles predicted from the initial traffic assignment in `travel.mac`. As discussed in Section 4.4, the mix of vehicles using a given road varies according to the type of road and its location in the urban area. As a result, a macro was written to perform the background traffic calculations. However, if the volume of commercial vehicles is already stored in the EMME/2 databank, the modeller can use this data directly, without creating a special macro to calculate the information.

Often, the functions used to estimate travel time and speed during the assignment process are calibrated to improve the accuracy of the traffic assignment. However, little is done to ensure that the travel speeds are realistic. For this reason, use of a speed post-processor is frequently recommended in the literature (Suhbier et al. 1997; Stopher and Fu 1997; U.S. DOT 1994). This post-processor can be used to adjust the travel speeds estimated from the volume-delay functions in EMME/2. To facilitate speed post-processing activities, all speed calculations in `travel.mac` are performed in a separate macro which is called immediately before results are written to the output file. Although post-processors were not employed in this research effort (refer to Section 6.5.3), the capability exists for the user to modify the speed macro to incorporate post-processors as new data become available. Since the MOBILE5 input file uses the same travel speed for all vehicle

categories, transit travel speed is not required, unless the link is used for transit vehicles only.

Depending on the size of the transportation network, the volume of traffic to be assigned, and the type of output desired, travel.mac can take several hours to execute.

Consequently, a second macro was developed. This new macro permits several analysis periods to be analyzed sequentially, so that calculations can continue overnight without interruption. The macro inputs trip tables developed from the 1995 Origin-Destination Survey and adjusts them to include external trips. The macro also inputs cold start trip tables for vehicles with and without catalytic converters. These tables are then combined to account for the proportion of vehicles in the fleet equipped with emission control systems. Once the trip tables have been established, the macro then assigns the trips to the transportation network and summarizes the travel activity using much the same process as travel.mac described in Figure 5-2. Since every travel demand model is set up differently, the macro cannot be applied to other urban areas without significant modification.

Moreover, the macro can only be used with survey data; modelled trip tables cannot be analyzed. The macro travel.mac avoids these problems by forcing the user to create the necessary trip tables before the macro can be executed. For this reason, travel.mac can be easily applied elsewhere, although it is more cumbersome to use.

Figure 5-2 Flowchart of EMME/2 Emission Macro, "travel.mac"

Data aggregated by road classification:

Operating mode variable = 2						
Additional vkt variable = 1						
Number of link locations = 4						
Number of link types = 6						
Area,	Link,	Avg Speed,	Total-VKT,	Start-VKT,	Cold-VKT,	Transit-VKT
1,	1,	.000,	.000,	.000,	.000,	.000
1,	1,	7.468,	263.441,	147.284,	115.271,	5.660
1,	1,	9.157,	205.154,	108.973,	75.168,	2.380
1,	1,	14.533,	156.622,	100.719,	69.737,	.780
1,	1,	18.006,	199.782,	140.493,	120.168,	6.870
1,	1,	22.787,	418.666,	266.792,	219.879,	12.520
1,	1,	26.306,	332.152,	307.678,	268.411,	13.640
1,	1,	30.460,	1308.355,	1085.104,	812.264,	26.030
1,	1,	33.025,	1236.038,	987.413,	711.079,	120.870

Link by link analysis*:

Operating mode variable = 2									
Additional vkt variable = 1									
Number of link locations = 9									
Number of link types = 6									
Node ID		Area	Link	Speed	Vehicle Kilometers Travelled				
					Total	Start	Cold	Transit	
inode	jnode	@area	@link	@speed	u11	@start	ul3	ul2	result
1058	1067	1	2	33.2782	12.1001	10.3866	5.54898	.8	65.1138
1059	1050	1	2	35.123	29.4327	12.7135	11.7532	.28	92.3024
1059	1060	1	1	33.3333	0	0	0	0	35.3333
1059	1068	1	2	30.9412	64.9321	64.8442	50.7818	1.28515	215.784
1060	1061	1	1	33.3333	0	0	0	0	35.3333
1060	1069	1	1	33.3333	0	0	0	0	35.3333
1061	1052	1	1	33.2555	7.05041	7.05041	3.61713	0	52.9734
1061	1062	1	1	33.3333	0	0	0	0	35.3333
1062	1063	1	1	33.3333	0	0	0	0	35.3333
1062	1071	1	2	36.6531	89.6762	87.9537	68.7044	.71872	286.706
1063	1054	1	2	37.8084	92.9159	42.7085	23.2803	0	199.713
1063	1064	1	1	33.3333	0	0	0	0	35.3333
1064	1055	1	2	38.3342	12.0701	11.4967	8.38684	2.4	75.6878
1064	1065	1	1	33.3333	0	0	0	0	35.3333
1064	1073	1	2	37.0169	25.5633	23.3874	19.5316	1.76	110.259

Figure 5-3 Sample Output Files from Travel.mac

5.3 THE EMISSION CALCULATOR

Once travel data from EMME/2 has been summarized in an output file, the Emission Calculator is used to compute vehicle emissions. Programmed in Visual Basic, the

* Note that the second row of headings in the EMME/2 output file can be ignored. These headings are generated by the EMME/2 function used to create the output file. The headings refer to the link attributes where the data are stored. Likewise, the "result" column is ignored by the Emission Calculator.

Emission Calculator operates outside the EMME/2 environment, using MOBILE5 directly to model HC, CO, and NO_x emissions. Specifically, the Emission Calculator uses the Canadian version of the MOBILE5 model, and reference to MOBILE5 within this section should be interpreted accordingly. Further information regarding the use of MOBILE5 can be obtained from the appropriate user's guide (Philpott 1993; U.S. EPA 1994).

In general terms, the MOBILE5 input file is divided into three sections: the control section, which specifies how the emissions are to be calculated, the one-time data section, which contains data common to all scenarios, and the scenario section, which describes each scenario being modelled. After reading the output file produced by travel.mac and gathering information from the user, the Emission Calculator generates a MOBILE5 input file called M5.in. This file contains a control and one-time data section which is largely specified by the user. However, modifications are made to the trip length distribution, as well as the temperature and fuel data in the local area parameter (LAP) record. These modifications are based on data entered by the user at the start of the Emission Calculator. After modifying the control and one-time data sections, the Emission Calculator adds two records to the input file for each link (or link category) included in the EMME/2 analysis. The first record describes the vehicle mix observed on the link; the second identifies the average travel speed, operating mode fractions, ambient temperature, analysis year, and season. By treating each link (or link category) as a separate scenario in the MOBILE5 input file, the links are analyzed individually. As a result, the speed and operating mode characteristics of each link are considered explicitly in the modelling process.

Once M5.in has been created, the Emission Calculator checks to ensure that the output file, M5.out, does not exist. Otherwise, MOBILE5 will fail to run. The Emission Calculator then calls MOBILE5, waits for MOBILE5 to execute, and reads the resulting emission factors from the output file. These factors have been weighted to account for the mix of vehicles on each link, and can therefore be multiplied by the total vehicle-kilometers of travel to estimate vehicle emissions. At this point, the Emission Calculator

writes the emissions data to an output file using one of two formats as specified by the user:

- comma delimited summary table that can be imported into a spreadsheet
- link-by-link output format suitable for importing data into EMME/2

Depending on the options selected when using travel.mac to summarize travel activity, the Emission Calculator can compute emissions on a link-by-link basis, or use travel data that has been aggregated into different facility-type categories. The Emission Calculator also has the ability to model greenhouse gas emissions. Since MOBILE5 was developed to estimate criteria pollutants and not greenhouse gases, the Emission Calculator requires fuel consumption equations and greenhouse gas emission factors supplied by the user. In general, the Emission Calculator computes the fuel consumption per kilometer for each type of vehicle using a particular road as a function of the vehicle speed. These values are then multiplied by the corresponding vehicle-kilometers of travel to compute fuel consumption along the link. Multiplying the fuel consumption by the greenhouse gas emission factor produces an estimate of greenhouse gas emissions for each vehicle category. These emissions are then added together to obtain the greenhouse emissions for each link in the transportation network. The following section describes the fuel consumption equations and greenhouse gas emission factors in more detail.

A final note should be made regarding the use of MOBILE5 to estimate vehicle emissions. When modelling vehicle emissions based on output from travel demand models, the most common approach is to generate a set of MOBILE5 emission functions based on “standard” conditions for the study area (Anderson et al. 1996; Suhrbier et al. 1995). The functions often relate travel speed to vehicle emissions, and assume that all other inputs remain constant. However, this approach restricts the ability of the user to model the effect of inspection and maintenance programs, or changes to other input parameters. Moreover, the functions are only applicable to the specific area for which they were developed. Since the functions are time-consuming to produce and limit the flexibility of the modeller to examine different scenarios, it was decided to use MOBILE5 to compute vehicle emissions directly. Consequently, the user must be familiar with

MOBILE5 in order to produce a suitable input file for use in the Emission Calculator. However, it is anticipated that most modellers will have little difficulty generating an input file applicable to the study area. Moreover, this approach ensures that the Emission Calculator is not used blindly to predict vehicle emissions without understanding the modelling process.

Figure 5-4 describes the general design of the Emission Calculator. Additional documentation can be found in *The Emission Calculator User's Guide*, including the program source code, as well as sample input and output files (Armstrong 2000).

Figure 5-4 Simplified Schematic of the Emission Calculator

5.3.1 Input Files

Designed to be as user-friendly as possible, the Emission Calculator uses a windows interface to gather information from the user for estimating vehicle emissions. The user has the option of entering data via forms, or specifying the name of an input file containing the relevant information. Once the input file has been read, the contents are displayed in a form for modification by the user. Any changes to the data can be saved before continuing to the next step. Table 5-1 describes the input data required to run the Emission Calculator.

Table 5-1 Input Data Required by the Emission Calculator

Input Data	Applies To...	Details
Type of Analysis	Air Quality Pollutants and Greenhouse Gas Calculations	<ul style="list-style-type: none"> The user must choose whether to model greenhouse gas emissions or air quality pollutants (VOC's, CO, NO_x). Since greenhouse gases are not estimated in MOBILE5, two separate applications of the Emission Calculator are required to capture all vehicle emissions produced in the study area.
Type of EMME/2 Output File	Air Quality Pollutants and Greenhouse Gas Calculations	<ul style="list-style-type: none"> In the EMME/2 output file produced by travel.mac, travel data can be stored on a link-by-link basis, or aggregated according to the link classification. Since the format of the two output files is slightly different, the user must specify which type of analysis was performed in EMME/2 so that the Emission Calculator can read the data correctly. Other options selected during the EMME/2 analysis are stored in the output file and need not be repeated by the user (i.e. inclusion of transit or user-defined travel data, source of data for operating mode fractions, etc.)
Vehicle Mix	Greenhouse Gas Calculations	<ul style="list-style-type: none"> The Emission Calculator allows greenhouse gas emissions to be predicted for 14 user-defined vehicle categories. Consequently, flexibility exists for modelling new vehicle technologies. For each vehicle category, the amount of travel is expressed as a ratio to the passenger vehicle travel summarized in the EMME/2 output file, multiplied by 100. (It is assumed that the trip matrix assigned in EMME/2 contains passenger vehicle trips only. If commercial vehicle trips are assigned as well, appropriate adjustments should be made to the vehicle mix ratios). For example, if the vehicle fleet contains 5% heavy vehicles and 95% passenger vehicles (of which 20% are light trucks), the following ratios would be used: <ul style="list-style-type: none"> autos: 80 (80% of passenger vehicles are autos) light trucks: 20 (20% of passenger vehicles are light trucks) heavy vehicles: 5.26 (5 heavy vehicles : 95 passenger vehicles or $5/95*100$) <p>As this example shows, the ratios need not add to 100. Indeed, the ratios</p>

		<p>will only add to 100 if commercial vehicles are excluded from the analysis.</p> <ul style="list-style-type: none"> • Alternatively, if transit (or user-defined) vkt data is included in the EMME/2 output file, the amount of travel for a given vehicle category can be expressed as a ratio to the transit (or user-defined) travel. For example, transit vehicles should be assigned a ratio of 100 if transit vkt data is available in the output file. • Note that the vehicle mix should apply to the time period being analyzed. Moreover, a separate vehicle mix must be specified for each road classification • Vehicle categories should be selected which have unique fuel consumption characteristics. For this reason, heavy vehicles and light-duty passenger cars should not be included in the same vehicle category. Furthermore, vehicles which burn diesel and gasoline should not be grouped together, since different vehicle fuels produce different quantities of greenhouse gas emissions, and thus have unique greenhouse gas emission factors. For similar reasons, new technology vehicles should also be given a distinct vehicle category in order to account for different fuel consumption and emission characteristics.
Fuel Consumption Equations	Greenhouse Gas Calculations	<ul style="list-style-type: none"> • For each vehicle category, an equation describing the relationship between fuel consumption and average travel speed must be supplied. The equations are processed using MS Excel, which allows numerous equation formats to be used, including “nested if” structures. Using such equations, the user can specify a different fuel consumption equation for different speed ranges • As a research tool, the Emission Calculator was designed to be as flexible as possible. Fuel consumption data for new technology vehicles is currently unavailable; data for existing vehicle technologies continues to evolve as new research is undertaken. For this reason, fuel consumption equations were not incorporated into the program code but instead must be specified by the user. While this approach appears more cumbersome initially, the ability to model new and emerging vehicles technologies far outweighs the disadvantages. • Since the relationship between fuel consumption and average travel speed is likely to vary depending on the road classification, fuel consumption equations must be specified for each roadway category included in the EMME/2 output file. • It should be noted that MS Excel must be installed on the user’s computer in order to compute greenhouse gas emissions using the Emission Calculator. • Although it is possible to write computer code which is capable of parsing an equation entered as a text string so that the expression can be evaluated, it was deemed far simpler to use MS Excel to process the equations. The average speed is simply pasted into a spreadsheet cell. After modifying the equation to contain the appropriate cell reference, the equation is pasted into another cell and the expression is evaluated. The result is then read back into the Emission Calculator. • All fuel equations should estimate fuel consumption in units of litres/km
Greenhouse Gas Emission Factors	Greenhouse Gas Calculations	<ul style="list-style-type: none"> • For each vehicle category, a GHG emission factor must be supplied by the user. This factor allows greenhouse gas emissions to be predicted on the basis of fuel consumption, and is thus measured in grams of GHG produced per litre of fuel. The emission factor depends largely on the type of fuel, as well as the emission control system installed on the vehicle. While catalytic converters do not reduce CO₂ emissions, other greenhouse gases are

		<p>effected by the type of emission control system, including CH₄ and N₂O.</p> <ul style="list-style-type: none"> • The greenhouse gas emission factor estimates greenhouse gas emissions in units of CO₂ equivalents. To develop the emission factor, the amount of CO₂, CH₄, and N₂O produced per litre of fuel is estimated based on the type of fuel and vehicle classification. These values are then multiplied by the corresponding CO₂ equivalency factor. • The equivalency factors are based on the relative contribution of each gas to the greenhouse effect: 1 for CO₂, 21 for CH₄ and 310 for N₂O. <i>Canada's Greenhouse Gas Inventory</i> (Neitzert et al. 1999) contains a detailed list of CO₂, CH₄, and N₂O emissions per litre of fuel for different fuel types, vehicle categories, and emission control systems. Using this information, composite greenhouse gas emission factors can be computed. • For example, light-duty gas automobiles equipped with tier 1, three-way catalysts produce 2360 g of CO₂, 0.25 g of CH₄, and 0.21 g of N₂O for every litre of fuel consumed. Therefore, the greenhouse gas emission factor expressed in terms of CO₂ equivalents is: <ul style="list-style-type: none"> • $2360 \times 1 + 0.25 \times 21 + 0.21 \times 310 = 2430$ g of greenhouse gases / litre of fuel
Type of Output	Air Quality Pollutants and Greenhouse Gas Calculations	<ul style="list-style-type: none"> • Depending on the format of the EMME/2 output file containing the travel data, several different output formats can be specified. If travel data are stored for each vehicle link, the user has the option of creating an output file which can be imported into EMME/2 for further analysis, or creating a summary table based on the link categories specified in EMME/2. • On the other hand, if travel data in the EMME/2 output file have been aggregated into different link categories, only a summary table can be created. • The summary table produced from the link-by-link analysis of VOC's, CO, and NO_x contains a composite emission factor for each link category. These factors are computed by weighting the emission factors from the MOBILE5 analysis by the amount of travel on each link. • In addition to the format of the output file, the user must also specify level of detail desired. While detailed output files contain a wide range of information, files can also be generated containing only the amount of travel and corresponding vehicle emissions.
Vehicle Mix	Calculation of Air Quality Pollutants	<ul style="list-style-type: none"> • The vehicle categories used to model VOC's, CO, and NO_x correspond to the 8 vehicle categories in the MOBILE5 model. These categories include: light-duty gas vehicles, light-duty diesel vehicles, light-duty gas trucks (divided into two weight categories), light-duty diesel trucks, heavy-duty gas vehicles, heavy-duty diesel vehicles, and motorcycles. • The vehicle mix associated with different road classifications is specified in much the same way as the vehicle mix used to compute greenhouse gases. However, unlike the greenhouse gas vehicle mix, the amount of travel associated with each MOBILE5 vehicle category can be expressed as a ratio to both passenger vehicle and transit (or user-defined) travel, as long as such information is included in the EMME/2 output file.
Trip Length Distribution	Calculation of Air Quality Pollutants	<ul style="list-style-type: none"> • Used to compute running loss emissions, the trip length distribution indicates the proportion of travel occurring in trips of a certain duration. The Emission Calculator offers the user three choices for computing the trip length distribution. Specifically, the trip length distribution can be based on: <ul style="list-style-type: none"> • Output from the EMME/2 traffic assignment

		<ul style="list-style-type: none"> • Values specified by the user • MOBILE5 default values • Since travel.mac produces a separate output file containing the trip length distribution corresponding to the travel assignment in EMME/2, it is recommended that the user select the first option for modelling vehicle emissions. However, the remaining options can also be used in certain situations, for example, if the user creates a travel input file outside of EMME/2 for modelling intra-zonal travel. • It is assumed that the same trip length distribution applies to all travel in the study area. As a result, the trip length distribution is written to the one-time data section of the MOBILE5 input file, rather than the scenario section.
Temperature and Fuel Data	Calculation of Air Quality Pollutants	<ul style="list-style-type: none"> • The ambient temperature can have a significant impact on vehicle emissions. Likewise, fuel properties can influence the amount of emissions produced from mobile sources. The Emission Calculator provides a separate form for entering fuel and temperature data, as well as other miscellaneous information required for the analysis. Specifically, the user must enter: <ul style="list-style-type: none"> • Minimum daily temperature • Maximum daily temperature • Ambient temperature • Fuel volatility class • Fuel vapour pressure • Analysis year • Month for which emissions are desired • The analysis year defines the characteristics of the vehicle fleet. Knowing the typical vehicle age distribution, the model can account for the emission standards in effect at the time the vehicle was manufactured. Deterioration rates are then applied to determine the base emission rate for each model year vehicle present in the fleet. • The analysis month can be either January or July. If July is selected, the vehicle age distribution is adjusted to account for vehicle replacement during the first 6 months of the year. In addition, the effects of reformulated gas are modelled differently depending on the season. • Although temperature and fuel data are also found in the MOBILE5 input file, the records are overwritten by the Emission Calculator, allowing the user to analyze different time periods without changing the control and one-time data sections in the MOBILE5 input file. • For additional information regarding the temperature and fuel inputs, refer to Sections 4.9 and 7.2, as well as the MOBILE5 User's Guide (U.S. EPA 1994).
Operating Mode Fractions	Calculation of Air Quality Pollutants	<ul style="list-style-type: none"> • Operating mode fractions can be calculated in one of three ways: <ol style="list-style-type: none"> 1. If a cold start trip table was assigned to the transportation network in EMME/2, the proportion of travel in each operating mode can be calculated directly by the Emission Calculator for each link / link category 2. If a cold start trip table was not assigned in EMME/2, the user can create a look-up table by specifying operating mode fractions for each link classification. 3. If local data is not available, MOBILE5 default values can be assumed

MOBILE5 Input File (control and one-time data sections)	Calculation of Air Quality Pollutants	<ul style="list-style-type: none"> • The Emission Calculator models vehicle emissions of VOC's, CO, and NO_x using MOBILE5[*]. The MOBILE5 input file is divided into three sections: the control section, the one-time data section, and the scenario section. The control section identifies various options for modelling vehicle emissions, but does not contain data used in the emission calculations. In contrast, the one-time data section contains input data common to each of the scenarios described in the final section of the input file. • To use the Emission Calculator, the user must specify the location of a MOBILE5 input file containing both the control and one-time data sections. The Emission Calculator reads the input file, adjusts temperature and fuel values according to input from the user, and writes the data to M5.in, a file that can be read by MOBILE5. The user has complete flexibility to modify the control and one-time data sections to correspond to local conditions. In addition, different conditions can be modelled by changing the value of the input parameters. However, the scenario section of the MOBILE5 input file is generated by the Emission Calculator, and any scenario records in the original MOBILE5 input file will be overwritten. The Emission Calculator treats each link / link category as a separate scenario in the MOBILE5 input file. As a result, a scenario record and vehicle mix distribution are written to M5.in for each link / link category. These records are based on travel data from the EMME/2 analysis, as well as information supplied by the user. • Figure 5-5 contains a sample MOBILE5 input file. This figure indicates which input variables the user is free to modify, and which variables must be set to specific values so that the Emission Calculator can function properly. For example, the user can specify the vehicle age distribution, mileage accumulation rates, and type of inspection and maintenance programme. However, input variables describing the format of the MOBILE5 output file, M5.out, should not be altered. Otherwise, the Emission Calculator will be unable to read the resulting output file and summarize the results. • For further information regarding the format of the MOBILE5 input file, the user is urged to consult the MOBILE5 User's Guide (U.S. EPA 1994). The MOBILE5c User's Guide describes the Canadian version of the model (Philpott 1993).
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* Note that the Canadian version of MOBILE5 is used in the Emission Calculator.


```

1  MOBILE5c      PROMPT: Read all data from input file
2  Input File for Emission Calculator
3  TAMFLG: Use MOBILE5 default tampering rates
4  SPDFLG: One avg speed for each scenario, single trip length dist'n
2  VMFLAG: User supplies vehicle miles traveled mix for each scenario
3  MYMRFG: User supplies veh. Reg'n; Use default mileage accumulation
1  NEWFLG: Use default basic emission rates
1  IMFLAG: No IM programme
1  ALHFLG: No additional correction factors
1  ATPFLG: No anti-tampering programme
1  RLFLAG: Use uncontrolled refueling emission rates
2  LOCFLG: Use 1 LAP record for all scenarios
2  TEMFLG: User specifies ambient temperature
2  OUTFMT: 140 - column numerical format
4  PRFLG: Print HC, CO and NOx results
1  IDLFLG: Must be set to 1
3  NMHFLG: Calculate emissions for volatile organic hydrocarbons
2  HCFLAG: Print HC sum and components (g/mile)
      .031 .067 .062 .060 .067 .070 .080 .083 .081 .078
      .075 .067 .056 .043 .029 .018 .012 .008 .005 .003
      .001 .000 .000 .000 .004
      .051 .099 .084 .075 .076 .075 .074 .066 .061 .062
      .065 .057 .044 .036 .025 .015 .011 .008 .004 .003
      .002 .001 .001 .000 .005
      .054 .072 .072 .072 .072 .052 .050 .034 .054 .031
      .028 .080 .084 .049 .039 .030 .018 .023 .018 .015
      .009 .008 .009 .006 .026
      .023 .047 .047 .047 .047 .038 .033 .021 .026 .029
      .034 .064 .054 .058 .051 .038 .043 .041 .035 .029
      .021 .022 .022 .014 .117
      .031 .067 .062 .060 .067 .070 .080 .083 .081 .078
      .075 .067 .056 .043 .029 .018 .012 .008 .005 .003
      .001 .000 .000 .000 .004
      .051 .099 .084 .075 .076 .075 .074 .066 .061 .062
      .065 .057 .044 .036 .025 .015 .011 .008 .004 .003
      .002 .001 .001 .000 .005
      .034 .067 .067 .067 .067 .073 .061 .040 .041 .051
      .053 .066 .055 .057 .045 .019 .023 .028 .024 .016
      .011 .009 .007 .005 .016
      .144 .168 .135 .109 .088 .070 .056 .045 .036 .029
      .023 .097 .000 .000 .000 .000 .000 .000 .000 .000
      .000 .000 .000 .000 .000
      LAP RECORD C 72. 92. 11.0 11.0 20 1 1 1
      6.7 18.5 16.8 13.1 8.3 36.6
      START OF SCENARIO DATA SECTION

      -- TAMFLG CAN BE CHANGED BY USER*
      -- SPDFLG MUST BE SET TO 4
      -- VMFLAG MUST BE SET TO 2
      -- MYMRFG CAN BE CHANGED BY USER*
      -- NEWFLG CAN BE CHANGED BY USER*
      -- IMFLAG CAN BE CHANGED BY USER*
      -- ALHFLG MUST BE SET TO 1
      -- ATPFLG CAN BE CHANGED BY USER*
      -- RLFLAG CAN BE CHANGED BY USER*
      -- LOCFLG MUST BE SET TO 2
      -- WILL BE CHANGED BY E. CALC. BASED ON USER INPUT
      -- OUTFMT MUST BE SET TO 2
      -- PRFLG MUST BE SET TO 4
      -- IDLFLG MUST BE SET TO 1
      -- NMHFLG MUST BE SET TO 3
      -- HCFLAG MUST BE SET TO 2
      JULMYR.LDGV..my ages 1-10
      .LDGV..my ages 11-20
      .LDGV..my ages 21-25
      .LDGT1..my ages 1-10
      .LDGT1..my ages 11-20
      .LDGT1..my ages 21-25
      .LDGT2..my ages 1-10
      .LDGT2..my ages 11-20
      .LDGT2..my ages 21-25
      .HDGV..my ages 1-10
      .HDGV..my ages 11-20
      .HDGV..my ages 21-25
      .LDDV..my ages 1-10
      .LDDV..my ages 11-20
      .LDDV..my ages 21-25
      .LDDT..my ages 1-10
      .LDDT..my ages 11-20
      .LDDT..my ages 21-25
      .HDDV..my ages 1-10
      .HDDV..my ages 11-20
      .HDDV..my ages 21-25
      .MC....my ages 1-10
      .MC....my ages 11-20
      .MC....my ages 21-25
      Local Area Parameter record -- SCENARIO NAME MUST BE: "LAP RECORD" **
      Trip Length Distribution
      -- RECORD WILL BE MODIFIED BY EMISSION CALCULATOR
      -- THIS LINE MUST BE PRESENT IN THE INPUT FILE
      -- FOR EACH LINK/LINK CATEGORY, THE EMISSION CALC'R
      WILL COMPUTE A SCENARIO AND VEHICLE MIX RECORD

* CHANGES SHOULD ONLY BE MADE IF THE ONE-TIME DATA SECTION IS MODIFIED ACCORDINGLY
** TEMPERATURE AND FUEL DATA WILL BE MODIFIED BY THE EMISSION CALCULATOR

```

Figure 5-5 Sample MOBILE5 Input File for use in conjunction with the Emission Calculator

Figure 5-6 and Figure 5-7 illustrate some of the forms that make up the Emission Calculator. A complete set of forms can be found in Appendix I.

Emission Calculator

Trip Length Distribution

Read data from EMMF/2 form Read data from grid Use EMMF/2 default values Generate data from form

Trip Length	Percentage of VKT
Under 10 minutes	6.7
10 to 20 minutes	18.5
20 to 30 minutes	16.8
30 to 40 minutes	13.2
40 to 50 minutes	8.3
Over 50 minutes	36.5

The trip length distribution is based on the fraction of VKT associated with trips of a particular length. For example, the fraction of VKT corresponding to trips under 10 minutes should be calculated as the fraction of VKT that occurs in trips that end within 10 minutes of their start, not the fraction of VKT that occurs within the first 10 minutes of all trips.

Note: Percentage of VKT MUST add to 100!

Save data in file Restart Quit Continue

Figure 5-6 Sample Form Used in the Emission Calculator

Emission Calculator

Please select the type of output you would prefer.

☒ Data summarized by link classification
☐ Link by link output
☐ (suitable for input into EMMF/2)

☐ Greenhouse gas values only
☐ Greenhouse gas and fuel consumption data

Continue

Figure 5-7 Form for Selecting Output Format

6 SENSITIVITY TESTS

6.1 INTRODUCTION

Vehicle emission estimates can only be as accurate as the input data used in the emission calculations. For this reason, a series of sensitivity tests was conducted to determine the change in vehicle emissions that can be expected due to errors in the underlying input data, including the vehicle mix, travel speed, temperature, operating mode fractions, and method of data aggregation. Further information regarding the base assumptions used in the sensitivity calculations can be found in Section 7.2 and 7.3.

6.2 SENSITIVITY TO DATA AGGREGATION

To forecast the pollution derived from mobile sources, vehicle emission models depend on accurate travel data. However, the travel data required by such models can be summarized in different ways. When using MOBILE5, travel data is often aggregated according to the type of road and its location in the study area (U.S. EPA 1992; Stopher and Fu 1996; de Rouville 1992; Miller et al. 1992; U.S. DOT 1994). For example, freeway travel in the suburbs might be grouped together, since travel behaviour on such facilities is generally similar. The travel associated with each category is further subdivided into different speed ranges.

In contrast, some researchers have adopted a link-by-link approach to modelling vehicle emissions. This approach is of particular benefit when using travel demand models to estimate vehicle activity. By computing emissions on a link-by-link basis, it is possible to identify “hot spots” in the transportation network where vehicle emissions are abnormally high. Spatial patterns can be analyzed. Emissions can be calculated for any land use, facility type, or region of the city due to the inherent flexibility of the link-by-link approach. Indeed, emission values can be easily manipulated in models such as EMME/2 once the data have been stored in the model. Moreover, the spatial distribution of vehicle

emissions is of critical importance in air quality models, necessitating a link-by-link approach.

However, despite its advantages, the link-by-link approach is not without limitations. The base emission rates in MOBILE5 are obtained from laboratory tests which simulate urban driving conditions. Emissions are measured over a standard driving cycle with a predefined pattern of accelerations, decelerations, idling, and travel at constant speed. Consequently, the base emissions rates in MOBILE5 correspond to vehicle trips, and it has been asserted that the development of travel characteristics for individual segments of the highway network is inconsistent with the underlying structure of the MOBILE5 model (DeCorla-Souza et al. 1994). As Anderson et al. (1996) write:

... MOBILE5.C emissions factors are intended to apply over vehicle trips, so application of these factors to flows along shorter links is, strictly speaking, a misapplication. In the MOBILE5.C emissions functions, the most critical role of the trip length is in determining the proportion of the trip that occurs in each of the three operating modes. Transference of trip-based emissions factors to links may require only the assumption that the proportion of vehicles operating in each of the three modes does not vary across links. This assumption may introduce some error, since some links are more likely than others to carry vehicles that are within a few minutes of their cold-start locations. This problem is recognized, but the benefits of link-by-link emissions estimates outweigh the potential errors (75).

By assigning cold start trip tables, or applying operating mode fractions that vary by link classification, it is possible to overcome the limitations of the link-by-link approach discussed by Anderson et al. However, Anderson et al. fail to address the real concern: the travel speeds associated with the link-by-link approach are inconsistent with the trip-based travel speeds on which the MOBILE5 emission factors are based. A typical vehicle trip may involve travel on high-speed facilities as well as congested local roads. As a result, the average travel speed for the overall trip will be quite different from the speeds encountered on individual road segments, influencing the emission results. Indeed, the MOBILE5 User's Guide states that MOBILE model results are most applicable to scenarios "where vehicles are being operated over a variety of modes and are least

appropriate for conditions where all vehicle operation is in a single mode ... at a given speed” (U.S. EPA 1994, 2-52). While the trip based approach is consistent with this guidance, the link-by-link approach is not. Instead, vehicle emissions are computed for a single roadway segment with essentially uniform travel conditions.

DeCorla Souza et al. (1994) propose a method to compute vehicle emissions using a trip-based approach. This approach has the added advantage of facilitating the analysis of transportation control measures which can have a direct impact on vehicle operating modes, vehicle mix, and the trip length distribution. Moreover, travel on local roads from intra-zonal trips can be directly incorporated into the modelling process. In the link-by-link analysis, intra-zonal trips are excluded from the model output, and must be analyzed separately. However, the primary advantage of the trip-based approach lies in its ability to provide average speed estimates that are more consistent with the speed used in MOBILE5.

While the three approaches used to aggregate travel data are discussed in the literature, little could be found regarding the impact on vehicle emissions. To investigate the change in vehicle emissions that can be expected by varying the travel data, a sensitivity test was conducted. Travel activity was aggregated using each of the three approaches described above. In each case, the overall amount of travel remains the same, however, the travel is grouped under different speed categories. Section 6.2.1 describes the methodology used to conduct the analysis, while Section 6.2.4 compares the emission results.

6.2.1 Methodology

To compute vehicle emissions based on the link-by-link approach, the EMME/2 macro, travel.mac, was used to summarize travel activity for each analysis period. The impact of background traffic was included in the traffic assignment. In addition, a cold start trip table was assigned to the transportation network for use in calculating operating mode fractions. Trip tables were obtained from the 1995 OD Survey database, since the TRANS travel demand model predicts travel activity for the PM peak hour only.

After reading in the travel data, the Emission Calculator was used to determine the corresponding level of vehicle emissions. Within the Emission Calculator, operating mode fractions were computed based on the EMME/2 traffic assignment of a cold-start trip table, rather than using look-up tables derived from the operating mode analysis. Likewise, the trip length distribution was based on the EMME/2 assignment. Vehicle mix ratios were entered for each facility classification, allowing the proportion of travel by different vehicle classes to be defined. In addition, temperature values corresponding to each analysis period were applied, as described in Section 4.9 (refer to Table 4-23). The analysis year was set to 1995, while July was specified for the season. A fuel volatility of 14.4 psi was assumed, based on data from Environment Canada (Philpott 1993). Likewise, the vehicle age distribution recommended by Environment Canada was used for the analysis (refer to Section 4.10).

A similar procedure was adopted for the facility-based approach, in which travel activity was aggregated according to the link classification. The travel activity associated with each classification was further sub-divided into speed “bins” based on a 4 km/hr speed interval. For both the link-by-link and facility-based approaches, emissions were calculated for the representative hour only; factors were required to compute emissions for the entire analysis period based on the proportion of travel occurring in the representative hour compared to the period as a whole (refer to Table 4-3 in Section 4.2).

In contrast, the trip-based approach uses individual trip records from the 1995 Origin-Destination Survey to compute vehicle emissions, eliminating the need to factor emissions from the representative hour. Indeed, the EMME/2 macro, travel.mac, was not required for the trip-based approach, and no auto assignments were performed since travel time and distance data had previously been imported into the OD Survey database for the operating mode analysis discussed in Section 4.8. Consequently, the duration, distance, and average speed of each trip in the database was known.

Using a cut-off of 8.4 minutes as the threshold between transient and stabilized travel, each trip was divided into stabilized and transient portions, and the amount of travel associated with each was determined. This analysis was accomplished using the special

query capabilities of Microsoft Access which permit data fields to be generated by combining data from other fields based on user-defined criteria. Since the OD Survey captures only a sample of trips in the National Capital Region, factors were applied to each trip record to determine the corresponding amount of travel for the population as a whole. The trip classification from the linked trip analysis (Section 4.8) was used to determine whether the transient portion of travel occurred in the hot or the cold start mode. Speed categories were then defined, based on 1 km/hr increments. These categories allowed trips occurring at similar speeds to be grouped together.

It should be noted that prior to grouping trips into different speed categories, the trips were classified according to the location of the trip origin and destination. While this information was originally intended to provide additional data regarding the districts that produce the most emissions, in the end, the trip classification was ignored. However, should such information be required, the trip-based approach provides an easy method for determining the answer.

Once the travel data in the OD Survey database had been manipulated into a suitable form, the data were exported to Microsoft Excel. In Microsoft Excel, a space delimited (*.prn) file was created which could be read into the Emission Calculator. This file was identical to the file produced by travel.mac when aggregating travel data in EMME/2 according to the facility classification. As a result, the Emission Calculator could be used to model the vehicle emissions directly, without creating a new program to analyze the trip-based travel data from Microsoft Access. Trip length distributions computed by querying the OD Survey database were entered into the Emission Calculator using the form provided for this purpose. Since the trip-based approach does not consider travel on different road facilities, vehicle mix fractions were developed by weighting the vehicle mix for arterial/collector roads in different areas of the city by the relative amount of travel within each area. Table 6-1 shows the proportion of travel on different road facilities used to compute the composite vehicle mix for each analysis period.

Table 6-1 Proportion of Travel Associated with Different Land-Use Classifications

Area	Percentage of Travel				
	Early Morning	AM Peak Period	Midday	PM Peak Period	Evening
Downtown Core	10	10	8	9	8
Urban	42	45	40	42	41
Suburban	16	15	16	16	18
Rural	32	30	36	33	33

Because the 1995 OD Survey did not adequately capture external trips from individuals living outside the National Capital Region, external trips were analyzed separately in the trip-based approach using the external trip tables in EMME/2. The trip tables were imported into Microsoft Access and linked with the corresponding travel time and distance values previously stored in the OD Survey database. Emissions were then calculated using the trip-based approach described above. Due to the format of the EMME/2 trip tables, trips between origin-destination pairs were combined into a single record rather than analyzing each trip individually. Since the start mode of individual trips was unknown, the proportion of cold start trips between each origin-destination pair was computed using cold start trip fractions from the linked trip analysis described in Section 4.8. Although the linked trip analysis was based on trips occurring within the National Capital Region, it was assumed that similar fractions would apply for external trips. Since the external trips were not identified by trip purpose, a composite factor was applied, based on all trip purposes combined. For a given origin-destination pair, travel in the transient mode could thus be divided into cold and hot start portions.

Rather than combine travel from external trips with other travel in the database, external trips were analyzed separately for two important reasons. First, the trip length distribution of external trips was expected to be significantly different compared to trips occurring entirely within the National Capital Region. Second, the external trip tables from EMME/2 contain hourly trip data corresponding to the representative hour chosen to model travel activity. In contrast, the trip based-approach accounts for all trips within the analysis period. As a result, emissions from external trips were factored upwards based on the proportion of travel occurring in the representative hour compared to the analysis

period as a whole (refer to Table 4-3 in Section 4.2). The factors were derived by analyzing trips occurring within the National Capital Region, since it is expected that external trips would follow similar trends.

It should be noted that travel on external centroid connectors was excluded from the travel summary since this travel was also excluded in the link-by-link approach, as well as the facility-based approach. In Microsoft Access, a query was developed to remove the distance travelled on external centroid connectors from the overall distance travelled. For external zones with more than one centroid connector, an average length was used, even though one centroid connector may be used more heavily than others. As a result, the amount of travel associated with external trips may be slightly different from the amount predicted by the link-by-link and facility-based approaches, which simply exclude all travel on external centroid connectors as the travel summary is being created in EMME/2.

Table 6-2 and Table 6-3 provide a summary of external trips using the transportation network in the National Capital Region. The data in these tables correspond to the representative hour used to model travel activity.

Table 6-2 Summary of External Travel from EMME/2 External Trip Tables

Time Period	Veh-KM	Veh-Min	Trips	Avg Dist	Avg Time	Avg Spd
Early Morning	81,101	61,464	1332	60.9	46.1	79.2
AM Peak Period	429,836	360,530	7078	60.7	50.9	71.5
Midday	390,608	304,470	6468	60.4	47.1	77.0
PM Peak Period	583,389	508,417	9616	60.7	52.9	68.8
Evening	232,408	176,973	3846	60.4	46.0	78.8
PM Peak Hour	650,619	584,534	10684	60.9	54.7	66.8
AM Peak Hour	509,145	454,895	8327	61.1	54.6	67.2

* Includes travel on external centroid connectors!

* Travel summary corresponds to REPRESENTATIVE HOUR, not entire time period

Table 6-3 Summary of Operating Mode Fractions for External Trips

Analysis Period	Vehicle-Kilometers Travelled			% of Vehicle-Kilometers Travelled		
	Stabilized	Cold Start	Hot Start	Stabilized	Cold Start	Hot Start
Early Morning	65,813	4,429	536	93.0	6.3	0.8
AM Peak Period	349,914	18,888	6,196	93.3	5.0	1.7
Midday	308,203	18,692	12,358	90.8	5.5	3.6
PM Peak Period	453,689	35,752	19,506	89.1	7.0	3.8
Evening	176,734	17,014	8,883	87.2	8.4	4.4
AM Peak Hour	416,032	22,105	6,491	93.6	5.0	1.5
PM Peak Hour	508,654	38,750	20,501	89.6	6.8	3.6

* Excludes travel on external centroid connectors

* Assumes that all trips beginning in an external zone have reached a stabilized condition before entering the NCR

* For trips beginning in the NCR, composite start-mode fractions for each time period were applied

* Travel summary corresponds to REPRESENTATIVE HOUR, not entire time period

While the trip-based approach includes travel from intra-zonal trips directly, the EMME/2 analysis used to aggregate travel data does not. Indeed, travel from intra-zonal trips is excluded from the output file produced by travel.mac as travel is being summarized in EMME/2. For this reason, emissions from intra-zonal trips were analyzed separately using the trip-based approach described above. Trips were divided according to location (core, urban, suburban, rural), so that appropriate vehicle mix ratios could be applied. Unlike inter-zonal trips, intra-zonal trips occur entirely within the same land-use designation, eliminating the need to compute composite vehicle mix factors. Factors corresponding to local road facilities were used, although it is likely that some intra-zonal travel also occurs on collectors and minor arterials. After computing the emissions from intra-zonal trips, the results were added to the emissions obtained from the link-by-link and facility-based analysis to determine the overall level of vehicle emissions in the National Capital Region.

A final note should be made regarding the vehicle mix used to compute emissions. To determine the amount of travel from commercial vehicles, the amount of passenger vehicle travel is multiplied by vehicle mix ratios as discussed in Section 4.4. These ratios vary depending on the type of road and the surrounding land-use environment. In the trip-based approach, the proportion of travel on different road facilities is not known. Given the resulting difficulty in estimating commercial vehicle travel, the sensitivity analysis was conducted based on emissions from passenger vehicles only.

A comparison of the three approaches is shown in Table 6-4.

Table 6-4 Characteristics of the Three Approaches Used to Summarize Travel Data

	Link by Link	Data Aggregated by Road Classification	Trip-Based
Source of travel data, including operating mode fractions and trip length distribution	EMME/2 traffic assignment (travel.mac)	EMME/2 traffic assignment (travel.mac)	OD Survey database (using travel time and distance values from EMME/2)
Includes travel from intra-zonal trips	Analyzed separately using data from OD Survey	Analyzed separately using data from OD Survey	Yes
Includes travel from external trips	Yes	Yes	Analyzed separately using factored external trip tables from EMME/2
Emissions calculated for representative hour or entire period	Representative hour (factors applied to obtain emissions for entire period)	Representative hour (factors applied to obtain emissions for entire period)	Entire analysis period
Source of speed data	Average travel speed on individual links	Average travel speed on individual links	Average travel speed between origin-destination pairs

6.2.2 Trip Length Distributions

The trip length distribution has a significant influence on running loss emissions. The EMME/2 macro, travel.mac, computes the trip length distribution automatically during traffic assignments. However, the trip length distribution can also be calculated using the travel time and distance data stored in the OD Survey database. Figure 6-1 illustrates the trip length distributions that were used in the sensitivity analysis*. Differences between the distributions relate primarily to the type of trips included. In the trip-based approach,

* Note that the graphs in Figure 6-1 have different orientations in order to ensure that all data points are visible.

external trips are analyzed separately, thus requiring a unique trip length distribution. In contrast, EMME/2 produces trip length distributions which include travel from external trips, but exclude intra-zonal trips. Moreover, the EMME/2 distributions are computed based on traffic assignments corresponding to a representative hour. However, distributions from the OD Survey database incorporate all travel occurring within the analysis period. Not surprisingly, the trip length distribution for external trips shows a high proportion of travel in the longest trip length category. In contrast, intra-zonal trips are generally of shorter duration, causing a high proportion of travel to occur in the shortest trip length categories.

Trip Length Distribution Used in Mobile5
All Inter-zonal and Intra-zonal Trips in 1995 OD Survey Database
(excluding trips to/from external zones and trips with incorrect OD data)

Trip Length Distribution Used in Mobile5
Based on Assignment of Representative Hour in EMME/2
(includes inter-zonal and external trips, but excludes intra-zonal trips)

Figure 6-1 Trip Length Distributions Used in MOBILE5

Trip Length Distribution Used in Mobile5

Intra-zonal Trips Only
(excluding trips within external zones)

Trip Length Distribution Used in Mobile5

External Trips Based on Output from EMME/2
(derived by assigning representative hour for each time period)

Figure 6-1 Continued Trip Length Distributions Used in MOBILE5

6.2.3 Speed Comparison

The primary difference between the three approaches used to aggregate travel data lies in the way travel is summarized into different speed categories. For this reason, any difference in vehicle emissions should be explained by differences in travel speeds. A speed comparison was conducted for the PM peak hour to determine how travel speeds vary between the three approaches. Speeds during the early morning period were also investigated to assess the impact of traffic congestion on the speed results. The analysis was carried out in EMME/2 using traffic assignments for the PM peak hour (4:15 p.m. to 5:15 p.m.) as well as the hour from 5:00 a.m. to 6:00 a.m., representing travel during the early morning period. As a result, external trips are included in the analysis, while intra-zonal trips are not. Figure 6-2 and Figure 6-3 illustrate the proportion of travel in different speed categories for the PM peak hour and early morning period respectively.

Figure 6-2 Speed Distribution – PM Peak Hour

Figure 6-3 Speed Distribution – Early Morning Period

From these figures, it is apparent that the link-by-link approach encompasses a wider range of speeds. Indeed, a significant proportion of the overall travel occurs in the highest speed categories during the PM peak hour despite high levels of road congestion. In contrast, the trip-based approach shows speeds concentrated in the middle of the speed regime, an intuitive result since trips will likely involve some travel on both high and low speed facilities, producing an average travel speed between the two extremes. The early morning period shows a similar trend, although speeds are generally higher, as expected for travel during off-peak periods. However, the difference between the two speed distributions is magnified, with the link-based approach dominating for speeds less than 50 km/hr, and the trip-based approach dominating for speeds greater than 50 km/hr, up to a maximum speed of 85 km/hr. The average speed associated with each approach is shown in Table 6-5. As this table illustrates, the link-by-link approach generally produces a higher average speed.

Table 6-5 Speed Comparison: Trip-based Approach vs. Link-by-Link Approach

	Average Speed	
	PM Peak Hour	Early Morning
Total VKT / Total VHT	45.4 km/hr	64.7 km/hr
Average speed on each link weighted by the amount of travel ¹	55.7 km/hr	80.5 km/hr
Average trip speed weighted by the amount of travel ²	50.5 km/hr	67.8 km/hr

¹ Corresponds to the link-by-link approach

² Corresponds to the trip-based approach

Since the link-based approach has a high proportion of travel in the highest speed categories, we would expect NO_x emissions to be increased. Moreover, since the link-based approach also has a higher proportion of travel in the lowest speed categories, CO and HC emissions should increase as well. With more travel occurring near the middle of the speed range, the trip-based approach can be expected to predict lower emissions, since emissions of all three pollutants reach a minimum at speeds near 80 km/hr (refer to Figure 2-4 in Section 2.6.3.4).

6.2.4 Comparison of Emission Results

The results of the sensitivity analysis are shown in Figure 6-4 to Figure 6-11. These figures show the impact of travel data aggregation on VOC, CO, and NO_x emissions, as well as greenhouse gases. Additional data can be found in Appendix L. Ideally, the overall amount of travel predicted by the three approaches will be identical, since the travel activity is based on the same underlying data. Minor variations are observed however, primarily due to rounding. Moreover, while travel on external centroid connectors was automatically excluded from the analysis in EMME/2, manual manipulation of travel data was required when using the trip-based approach, a process which may have introduced a small degree of error in the overall amount of travel. However, in all cases, the difference in vehicle-kilometers of travel is less than 1%.

It should be noted that the emission estimates in Figure 6-4 to Figure 6-11 are slightly different from those presented in Chapter 7, which are based on a link-by-link analysis. In

Chapter 7, all travel in external zones is excluded from the summary diagrams. However, in this analysis, only travel on external centroid connectors was excluded. It was not realized until later that a limited number of highways outside the National Capital Region are included in the EMME/2 model. Consequently, the values in Figure 6-4 to Figure 6-11 include a small amount of travel in external zones. However, the results of the sensitivity analysis will be unaffected.

As expected, VOC emissions are highest when using the link-by-link approach, and lowest when the trip-based approach is applied. However, the difference between the two approaches is reduced as the day progresses, perhaps due to rising temperatures. A similar trend is observed for CO emissions, although the difference in emission estimates begins to increase in the evening period after decreasing consistently throughout the day. In contrast, NO_x emissions are affected most dramatically during off-peak periods, when travel speeds are higher. Since NO_x emissions are more sensitive to changes in travel speed as the travel speed increases above optimal conditions, the difference between the three approaches is magnified during the off-peak periods. In general, aggregating travel data by facility classification results in NO_x emission estimates similar to those predicted by the link-by-link approach. However, NO_x emissions predicted using the trip-based approach are noticeably lower, since trip-based travel speeds are typically lower than the maximum speed attained on any given highway segment. Indeed, NO_x emissions increase rapidly at the high end of the speed spectrum, causing emission levels to increase the greater the proportion of travel at the highest travel speeds.

Greenhouse gas emissions are also influenced by travel speed. Similar to NO_x emissions, greenhouse gases were found to be most sensitive to travel data aggregation during the off-peak periods. Since the corresponding speed distributions were also found to vary substantially during periods of low travel demand, the observed trends are not surprising. During congested conditions, the speed distributions are more similar, reducing the difference in greenhouse gas emission estimates. Given the direct relationship between greenhouse gas production and fuel consumption, trends in greenhouse gas emissions mirror trends in fuel consumption. As Figure 6-8 and Figure 6-9 show, the link-by-link

and facility-based approaches produce similar estimates of fuel consumption, as well as greenhouse gases. Emission estimates derived from the trip-based approach are typically lower, due to the greater proportion of travel near the middle of the speed range, where optimal fuel efficiency is achieved.

In terms of daily emissions, the trip-based approach predicts the lowest emissions, while the link-based approach predicts the highest. Since the link-based approach was used in all subsequent modelling work, it is important to keep in mind that the emission estimates will be slightly higher than if the trip-based approach was applied instead.

Similar results are reported in the literature. Stopher and Fu (1996) found that VOC emissions increased by 3.5%, CO emissions increased by 7.8%, and NO_x emissions increased by 4.2% when analyzing emissions on a link-by-link basis compared to aggregating travel data by facility classification. In a study conducted by DeCorla-Souza et al. (1994), elevated HC emissions were observed when using the link-based approach to model emissions compared to the trip-based approach. The authors of the study suggest that the difference between the two approaches may be a result of the speed distribution; for the link-based approach, a greater share of travel occurred in the lowest and highest speed categories, which are associated with higher emissions.

However, despite the potential for overpredicting vehicle emissions, the link-based approach has many advantages. As Anderson et al. (1996) claim, link-by-link emission estimates allow transportation planners to identify “hot spots” in the transportation network and seek appropriate remedies. The spatial distribution of vehicle emissions is an important input to air-quality models. Moreover, the link-by-link approach may lead to improved accuracy in provincial and national emission inventories (Anderson et al. 1996). The link-by-link approach is also more flexible and easy to apply, particularly when investigating the impact of transportation policies on vehicle emissions.

Aggregating travel data by facility classification is time-consuming; the EMME/2 macros takes several hours to execute. Likewise, the trip-based approach is more difficult to apply. Commercial vehicle trips cannot be accounted for unless the volume of passenger vehicles on a given link is known. Any policy that impacts travel times and distances, or

the overall amount of travel, can only be investigated in EMME/2, making the trip-based approach inappropriate for all but the most rudimentary investigations. Consequently, the link-by-link approach was adopted for this research project. Since the difference in vehicle emissions is relatively small (less than 10%), the advantages of the link-by-link approach far outweigh the potential drawbacks.

Figure 6-4 Comparison of Emission Estimation Techniques - VKT Summary

Figure 6-5 Comparison of Emission Estimation Techniques - VOC Summary

Figure 6-6 Comparison of Emission Estimation Techniques - CO Summary

Figure 6-7 Comparison of Emission Estimation Techniques - NO_x Summary

Figure 6-8 Comparison of Emission Estimation Techniques - GHG Summary

Figure 6-9 Comparison of Emission Estimation Techniques - Fuel Summary

Figure 6-10 Comparison of Daily Vehicle Emissions (VOC's, CO, and NO_x)

Figure 6-11 Comparison of Daily GHG Emissions and Fuel Consumption

6.2.5 Trip-Based Analysis Sensitivity Tests

To compute vehicle emissions using the trip-based approach, several assumptions are needed. The vehicle mix varies throughout the National Capital Region, depending on the type of road and the surrounding land-use environment. For trips that traverse multiple districts, a vehicle mix ratio is difficult to assign. For this reason, an average vehicle mix was applied to all passenger vehicle travel represented in the OD Survey database, regardless of the trip origin or destination. The vehicle mix was weighted by the amount of travel occurring in rural, suburban, urban, and downtown communities for the time period in question. To test the impact of this assumption, a different set of vehicle mix ratios was applied, taking into account the trip origin and destination. Travel occurring entirely within one land-use district was assigned the corresponding vehicle mix. For travel between two adjacent land-use districts (i.e. suburban to urban), the vehicle mix for the two districts was averaged together. Travel through several districts required a weighted average vehicle mix.

Fortunately, the more complex vehicle mix scheme could be abandoned: for the PM peak period, vehicle emissions increased by less than 0.15% for all three air quality pollutants. Consequently, there is virtually no benefit to be achieved by attempting to apply vehicle mix ratios based on the trip origin and destination. Rather, a single vehicle mix for the entire region should be used, based on the relative proportion of travel in different land-use districts. However, since the trip-based approach was only used to model passenger vehicle emissions, the corresponding vehicle mix sensitivity test only included passenger vehicles. Consequently, different results may be achieved if all vehicle categories are considered.

Another difficulty associated with the trip based approach concerns the absence of external vehicle trips in the OD Survey database. To account for external trips, external trip tables in EMME/2 were used to compute vehicle emissions during the five representative hours selected for analysis. These emissions were then factored to determine the amount of emissions produced during the overall analysis period. By analyzing external trips separately in the trip-based approach, a different trip length

distribution can be applied in the MOBILE5 model. Moreover, it is simpler to factor emissions from external trips if they are analyzed separately.

However, the EPA recommends that “one area-wide trip length distribution be used for all roadway classifications, due to the complexity of trying to develop separate distributions” (U.S. EPA 1992). To assess the potential change in vehicle emissions that would occur if external vehicle trips were combined with internal vehicle trips captured in the OD Survey, a simple sensitivity test was conducted for the representative hour corresponding to the PM peak period. While the total amount of vehicle activity at different travel speeds remains the same, a single trip length distribution is applied, showing a greater proportion of travel in the highest trip duration categories (refer to Figure 6-12). As a result, it is expected that VOC emissions will increase, since running loss emissions are higher the greater the trip duration. By analyzing internal and external vehicle trips combined, it was found that VOC emissions increased by less than 0.25%. Since the trip length distribution affects running loss emissions only, NO_x and CO emissions remain unchanged. Clearly, the increase in vehicle emissions is insignificant; there is no reason to combine external trips with internal trips when using the trip-based approach.

Although intra-zonal trips also have a different trip length distribution compared to other internal vehicle trips in the National Capital Region, it was decided to analyze all trips occurring within the National Capital Region together. Intra-zonal trips represent less than 4% of the total amount of travel. From the results obtained for external trips, it is unlikely that analyzing intra-zonal travel separately will have any appreciable effect on vehicle emissions when using the trip-based approach. Of course, if travel data is obtained from traffic assignments in EMME/2, intra-zonal travel must be analyzed independently, since intra-zonal trips are ignored during the traffic assignment process.

Figure 6-12 Comparison of Trip Length Distributions

6.3 CRITERIA POLLUTANTS

6.3.1 Introduction

Numerous sensitivity tests were conducted using MOBILE5 to compute vehicle emissions of CO, NO_x, and VOC's. Specifically, changes in the trip length distribution, operating mode fractions, vehicle age distribution, and temperature were examined.

6.3.2 Trip Length Distribution

One of the advantages of using EMME/2 to forecast travel demand is the ability to obtain a trip length distribution which reflects travel characteristics during the analysis period.

The trip length distribution describes the proportion of travel associated with trips of a particular duration. In this context, "trip length" refers to the trip duration, not the distance travelled. In MOBILE5, the trip length distribution influences running loss emissions. In general, running loss emissions increase as the trip progresses and the fuel

delivery system and engine become heated. Temperature, travel speed, and fuel volatility also affect HC emissions during vehicle operation.

To determine the benefit that can be achieved by improving the accuracy of the trip length distribution, a sensitivity test was performed for the PM peak hour. In the base scenario, the trip length distribution from EMME/2 was applied. The analysis was then repeated using the default trip length distribution in MOBILE5. The difference between the two trip length distributions is illustrated in Figure 6-13. Figure 6-14 presents the results of sensitivity analysis.

Figure 6-13 EMME/2 and MOBILE5 Trip Length Distributions

Trip Length Distribution Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Emme/2 Trip Length Distribution	2,127,230	3,225	29,285	2,798
Mobile5 Default Trip Length Distribution	2,127,230	3,231	29,285	2,798
Percentage difference	0.00	0.18	0.00	0.00
Passenger vehicles only				
Emme/2 Trip Length Distribution	1,917,455	2,924	26,838	2,065
Mobile5 Default Trip Length Distribution	1,917,455	2,929	26,838	2,065
Percentage difference	0.00	0.18	0.00	0.00

* excludes external travel

Figure 6-14 Trip Length Distribution Sensitivity Test

Since the trip length distribution affects running loss emissions only, CO and NO_x emissions are unchanged compared to the base scenario. While the amount of VOC's does increase, the change is essentially negligible. It is important to emphasize that VOC emissions are higher when the MOBILE5 distribution is applied. The PM peak hour traffic assignment for the National Capital Region predicts a lower proportion of travel associated with the highest trip duration category. As a result, VOC emissions are lower, reflecting the tendency of vehicles to produce more running loss emissions as the trip length increases.

Clearly, improvements to the trip length distribution do not warrant the use of sophisticated modelling procedures. Indeed, improving the accuracy of the trip length distribution is likely to result in a difference in VOC emissions of less than 1%. However, further analysis at different speeds and temperatures is needed to substantiate this

conclusion, since it is unknown whether running loss emissions are more sensitive to the trip length distribution at other temperatures and travel speeds. Regardless of the benefit of improving the trip length distribution, travel demand models will continue to be used to model vehicle emissions. Such models provide a flexible tool for evaluating the air quality impacts of changes to the transportation system. Since the trip length distribution is a natural outcome of the modelling process, there is no reason to substitute default MOBILE5 values when modelling vehicle emissions based on output from travel demand models such as EMME/2.

6.3.3 Operating Mode

The operating mode fractions used to compute vehicle emissions in MOBILE5 indicate the proportion of travel that occurs in the cold start, hot start, and stabilized mode. In the Emission Calculator, operating mode fractions can be computed in one of three ways:

1. assigning a cold start trip table to the transportation network
2. using values from a look-up table based on the road classification and time of day
3. applying the default operating mode fractions in MOBILE5

Vehicle emissions were computed for the PM peak hour using each of the three approaches outlined above to estimate operating mode fractions. The results are presented in Figure 6-15 to Figure 6-17.

In Figure 6-15, operating mode fractions are computed from look-up tables derived by assigning cold start trip tables to the transportation network. The proportion of travel in each operating mode depends on the type of road and its location in the study area. The vehicle emissions resulting from this approach are compared with the vehicle emissions obtained by assigning the same cold start trip table to the transportation network, and storing the amount of travel in each operating mode on a link-by-link basis. While the amount of travel in each operating mode will obviously vary from link to link even within the same road classification, a cold start trip table is not always available, requiring the use of look-up tables. As Figure 6-15 shows, the amount of error associated with the use of look-up tables was less than 2.5% for all vehicle emissions. CO and VOC emissions

were reduced, while NO_x emissions increased, indicating that the proportion of travel in the hot-start mode was slightly overestimated. In general, CO and VOC emissions are higher in the cold start mode; NO_x emissions are reduced.

Figure 6-16 illustrates the benefits of factoring a trip table to estimate the number of cold-start trips. This trip table can then be assigned to the transportation network to determine the amount of travel in each operating mode on a link-by-link basis. The results in Figure 6-16 were obtained by factoring the trip table for the PM peak hour based on the proportion of cold start trips associated with different trip purposes. The factors were derived from the linked trip analysis described in Section 4.8. Using this approach, 95,628 cold start trips were predicted. In contrast, the cold-start trip table developed from the linked trip analysis contained 97,489 trips, a difference of 1.9%*. As Figure 6-16 shows, the factored cold start trip table produces vehicle emission estimates within 1% of those obtained from assigning cold start trip tables from the linked trip analysis to the transportation network. Consequently, it can be concluded that factored cold start trip tables produce more accurate results than the use of look-up tables based on the road classification.

However, it should be noted that the cold start trip tables used in this analysis were based on the same underlying data. Use of factors may result in a different distribution of cold-start trips, but the overall number of cold start trips is largely unaffected. Consequently, larger differences are expected if the cold start trip fractions from this analysis are applied to trip tables derived from different underlying data.

Figure 6-17 shows the vehicle emissions that were obtained by applying MOBILE5 default operating mode fractions. As discussed in Section 4.8.3, the operating mode fractions in MOBILE5 assume a significantly higher proportion of travel in the hot start mode, which is reflected in the emission estimates. CO and VOC emissions are 6% to 7% lower using the MOBILE5 default values, while NO_x emissions are 3% to 4% higher.

* While the start mode percentages were based on all trips in the 1995 OD Survey database, the EMME/2 trip tables exclude intra-zonal trips, which may account for the variation between the two cold start trip tables.

Clearly, the use of MOBILE5 default operating mode fractions is not recommended. In situations where cold start trip tables are unavailable, the use of look-up tables is preferred, based on local data wherever possible. To further improve the accuracy of emission estimates, cold start trip tables can be computed by factoring the number of trips between origin-destination pairs based on the proportion of cold start trips associated with different trip purposes.

Operating Mode Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Actual operating mode	2,127,230	3,225	29,285	2,798
Operating mode from look-up tables	2,127,230	3,175	28,607	2,809
Percentage difference	0.00	-1.54	-2.32	0.38
Passenger vehicles only				
Actual operating mode	1,917,455	2,924	26,838	2,065
Operating mode from look-up tables	1,917,455	2,877	26,201	2,076
Percentage difference	0.00	-1.60	-2.37	0.50

* excludes external travel

Figure 6-15 Sensitivity Analysis: Operating Mode Fractions from Look-up Tables

Operating Mode Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Actual operating mode	2,127,230	3,225	29,285	2,798
Factored cold start trip table	2,127,230	3,204	29,107	2,796
Percentage difference	0.00	-0.65	-0.61	-0.09
Passenger vehicles only				
Actual operating mode	1,917,455	2,924	26,838	2,065
Factored cold start trip table	1,917,455	2,904	26,675	2,063
Percentage difference	0.00	-0.66	-0.61	-0.10

* excludes external travel

Figure 6-16 Sensitivity Analysis: Operating Mode from Factored Trip Tables

Operating Mode Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Actual operating mode	2,127,230	3,225	29,285	2,798
Mobile5 default operating mode fractions	2,127,230	3,008	27,084	2,899
Percentage difference	0.00	-6.73	-7.52	3.60
Passenger vehicles only				
Actual operating mode	1,917,455	2,924	26,838	2,065
Mobile5 default operating mode fractions	1,917,455	2,720	24,778	2,157
Percentage difference	0.00	-6.98	-7.68	4.44

* excludes external travel

Figure 6-17 Sensitivity Analysis: MOBILE5 Default Operating Mode Fractions

6.3.4 Vehicle Age Distribution

Fleet turnover rates are known to have a significant impact on emissions. The faster older vehicles are replaced by new model cars and trucks, the lower the emissions. To investigate the impact of fleet turnover on emission rates in the National Capital Region, two scenarios were analyzed using the Emission Calculator. In the first scenario, the vehicle age distribution for Ontario was applied. As discussed in Section 4.10, this distribution was developed by Environment Canada based on vehicle ownership data from 1990, and was smoothed to remove the effect of economic trends. In the second scenario, the vehicle age distribution for Ottawa-Hull was used instead. This distribution was developed using data from Natural Resources Canada, and is representative of the 1998 vehicle fleet. The data were not adjusted to remove the effect of recent economic cycles. As a result, the distribution shows a much higher proportion of older vehicles in the fleet, as people delayed buying new vehicles during the recession.

Figure 6-18 and Figure 6-19 show the results of the sensitivity analysis for the PM peak hour and early morning period respectively. These analysis periods were selected to represent travel conditions during the off-peak and peak periods, respectively. As Figure 6-18 and Figure 6-19 show, fleet turnover can have a significant impact on vehicle emissions. Failure to retire old vehicles from the fleet and replace them with new vehicles equipped with state-of-the-art emission control systems can cause considerable environmental damage in terms of air quality. During the PM peak hour, emissions of VOC's and CO are almost 30% higher. Although NO_x emissions are effected less dramatically, the increase is still significant. Similar results are evident for the off-peak period.

Vehicle Age Distribution Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Ontario Vehicle Fleet	2,127,230	3,225	29,285	2,798
Ottawa-Hull Vehicle Fleet	2,127,230	4,180	38,026	3,344
Percentage difference	0.00	29.61	29.84	19.50
Passenger vehicles only				
Ontario Vehicle Fleet	1,917,455	2,924	26,838	2,065
Ottawa-Hull Vehicle Fleet	1,917,455	3,822	35,073	2,579
Percentage difference	0.00	30.72	30.68	24.88

* excludes external travel

Figure 6-18 Vehicle Age Distribution Sensitivity Test – PM Peak Hour

Vehicle Age Distribution Sensitivity Analysis - Early Morning Period

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Ontario Vehicle Fleet	443,357	615	5,574	774
Ottawa-Hull Vehicle Fleet	443,357	816	7,296	911
Percentage difference	0.00	32.58	30.88	17.60
Passenger vehicles only				
Ontario Vehicle Fleet	389,276	545	5,046	501
Ottawa-Hull Vehicle Fleet	389,276	735	6,672	629
Percentage difference	0.00	34.85	32.21	25.74

* excludes external travel

Figure 6-19 Vehicle Age Distribution Sensitivity Test - Early Morning Period

To further test the impact of fleet turn-over, the analysis was repeated, using the default vehicle age distribution in MOBILE5. As Section 4.10 indicates, the vehicle fleet represented in MOBILE5 is quite different from the 1990 Ontario fleet. Figure 6-20 presents the results of the sensitivity analysis. Again, vehicle emissions are significantly higher compared to the base scenario. Since the MOBILE5 vehicle fleet contains a higher proportion of older vehicles, this result is not unexpected. Clearly, the accuracy of vehicle emission forecasts is highly dependent on the quality of vehicle ownership data; the effort required to obtain up-to-date, regional-specific data appears more than justified. Such data should include not only the age distribution of local vehicles, but also the mileage accumulation. By incorporating characteristics of the local vehicle fleet in the emission calculation process, the accuracy of vehicle emission estimates can be improved.

Vehicle Age Distribution Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Ontario Vehicle Fleet	2,127,230	3,225	29,285	2,798
Mobile5 Default Values	2,127,230	4,054	36,411	3,172
Percentage difference	0.00	25.69	24.33	13.36
Passenger vehicles only				
Ontario Vehicle Fleet	1,917,455	2,924	26,838	2,065
Mobile5 Default Values	1,917,455	3,682	33,369	2,410
Percentage difference	0.00	25.93	24.34	16.67

* excludes external travel

Figure 6-20 Sensitivity to MOBILE5 Default Vehicle Age Distribution

6.3.5 Temperature

Although it was beyond the scope of this investigation to examine the impact of non-travel related inputs, a simple sensitivity test was conducted to determine the magnitude of the change in vehicle emissions that can be expected by varying the temperature data. Using historical records from as far back as 1983, minimum and maximum temperature days for the month of October were selected. The temperature values recorded on October 5, 1991 and October 23, 1997 represent temperature extremes at the Ottawa International Airport for the month of October. Consequently, vehicle emissions during October should fall within the range defined by the minimum and maximum temperature days. To quantify this range, vehicle emissions were computed for the PM peak hour for both the minimum and maximum temperature day, as well as the “typical” day used for modelling vehicle emissions in the National Capital Region. Table 6-6 summarizes the temperature values used in the sensitivity analysis. The results of the analysis are presented in Figure 6-21.

Table 6-6 Minimum and Maximum Temperature Days

	Maximum Temperature Day	Minimum Temperature Day	Typical October Temperatures Assumed in Analysis
Date	October 5, 1991	October 23, 1997	N/A
Minimum daily temperature	10.9 °C	-6.1 °C	12.5 °C
Maximum daily temperature	26.7 °C	2.2 °C	3.7 °C
PM peak hour temperature	24.5 °C	1.4 °C	11 °C

Temperature Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Base Temperature	2,127,230	3,225	29,285	2,798
Minimum Temperature Day	2,127,230	3,292	34,400	3,028
Maximum Temperature Day	2,127,230	4,869	27,166	2,568
Minimum Temperature - % Change	0.00	2.07	17.46	8.23
Maximum Temperature - % Change	0.00	50.98	-7.24	-8.24
Passenger vehicles only				
Base Temperature	1,917,455	2,924	26,838	2,065
Minimum Temperature Day	1,917,455	2,984	31,575	2,280
Maximum Temperature Day	1,917,455	4,453	24,907	1,852
Minimum Temperature - % Change	0.00	2.06	17.65	10.37
Maximum Temperature - % Change	0.00	52.31	-7.20	-10.31

* excludes external travel

Figure 6-21 Temperature Sensitivity Test Results

From Figure 6-21, it is apparent that temperature plays an important role in determining vehicle emissions. The greatest change occurs on the maximum temperature day. Due to increased evaporation, VOC emissions increase by over 50%. On the other hand, CO and NO_x emissions are slightly lower. A different trend occurs for the minimum temperature day. As the ambient temperature drops from 11°C to 1.6°C, VOC emissions increase slightly. However, CO emissions increase by nearly 18% while NO_x emissions increase by approximately 10%. Although a more detailed analysis is required to determine temperature sensitivity under different operating conditions, the results in Figure 6-21 indicate why smog (of which VOC's are a precursor) is a concern in the summer months, while carbon monoxide creates problems in the winter.

6.4 GREENHOUSE GASES

6.4.1 Introduction

When computing greenhouse gas emissions, the Emission Calculator does not take into account the trip length distribution, ambient temperature, operating mode fractions, or vehicle age distribution. Indeed, the only inputs required are equations describing the relationship between fuel consumption and average travel speed and the greenhouse gas emission factors for each vehicle category.

6.4.2 Greenhouse Gas Emission Factor

Greenhouse gas emission factors are required to predict greenhouse gas emissions. These factors express the amount of emissions produced for each litre of fuel consumed during vehicle operation. In this research, greenhouse gas emission factors were obtained from an Environment Canada report entitled *Canada's Greenhouse Gas Inventory* (Neitzert et al. 1999). Greenhouse gas emission factors vary depending on the type of technology used to control vehicle emissions. Consequently, a composite greenhouse gas emission factor was developed, based on the assumption that 94% of the vehicle fleet was equipped with a catalytic converter in 1995. It was further assumed that each type of catalytic converter was equally represented in the vehicle fleet. The resulting emission factors were used to model greenhouse gas emissions in both 1995 and 2021, despite the likelihood of changes in the vehicle fleet composition and improvements in technology.

In the future, it can be assumed that all vehicles will have, at a minimum, the most advanced emission control technology that is currently available today. It was beyond the scope of this investigation to explore how changes in vehicle technology will influence air quality. However, a sensitivity test was conducted to determine the reduction in greenhouse gas emissions that could be attained if all vehicles in 2021 were equipped with state-of-the-art three-way catalysts. For light-duty gas automobiles, this results in a greenhouse gas emission factor of 2430 g/L, compared to 2457 g/L for the existing

vehicle fleet. As Figure 6-22 shows, the reduction in greenhouse gas emissions attributed to this change is minimal.

New vehicle technologies have the potential to reduce fuel consumption substantially, thereby lowering greenhouse gas emissions. However, equipping vehicles with state-of-the-art catalytic converters is likely to have minimal impact. While such devices may influence CH₄ and N₂O emissions, the primary greenhouse gas, CO₂, is not affected. Consequently, the market penetration of existing emission control equipment is unlikely to influence greenhouse gas emissions significantly. However, the adoption of new technology vehicles could have considerable impact. Although the impact of such vehicles was not considered in this investigation, future research in this area is certainly warranted as hybrid-electric vehicles and alternative fuels become more and more common.

Sensitivity Analysis - Adjusted 2021 GHG Emission Factors

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
GHG factors based on 1995 fleet	3,131,175	772,641	283,300	26,087
GHG factors: state-of-the-art cat.converters	3,131,175	765,463	283,300	26,087
Percentage difference	0.00	-0.93	0.00	0.00
Passenger vehicles only				
GHG factors based on 1995 fleet	2,818,623	647,912	262,248	0
GHG factors: state-of-the-art cat.converters	2,818,623	640,534	262,248	0
Percentage difference	0.00	-1.14	0.00	N/A

* excludes external travel

Figure 6-22 Greenhouse Gas Emission Factor Sensitivity Test

6.5 VARIABLES IMPACTING ALL POLLUTANTS

6.5.1 Introduction

Certain variables impact the calculation of greenhouse gas emissions, as well as criteria pollutants. Such variables are typically related to travel activity, and are thus modelled in EMME/2. Sensitivity tests were conducted for several of these variables, including: background traffic, travel speed, and trip table origin.

6.5.2 Background Traffic

Section 4.4 describes the methodology used to compute commercial vehicle traffic in the National Capital Region. This “background” traffic was applied to links in the EMME/2 model in order to improve the accuracy of travel time estimates used in the traffic assignment algorithm. To investigate the impact of background traffic on vehicle emissions, a sensitivity test was conducted for the PM peak hour, as well as the early morning period. As discussed in Section 4.4, the average travel time increases by almost 9% during the PM peak hour when the increased congestion from commercial vehicle traffic is taken into account. In contrast, the travel time increases by only 0.6% during the early morning period, since roads are generally operating well below capacity.

Figure 6-23 to Figure 6-26 present the results of the sensitivity analysis. During the PM peak hour, the introduction of background traffic causes travel speeds to be reduced. As a result, CO and VOC emissions increase, while NO_x emissions are reduced. A different trend emerges for the early morning period. Travel speeds decrease, causing vehicle emissions of all three pollutants to decrease as well. Since the change in travel speed is lower due to reduced congestion in the early morning, the change in vehicle emissions is also lower compared to emissions in the PM peak hour. Indeed, 90% of the travel in the early morning period occurs on links with a volume to capacity ratio of less than 0.5. In this range, the link is operating well below capacity; travel speeds are largely unaffected as additional traffic is added to the link from commercial vehicles.

Figure 6-27 shows the impact of background traffic on link volume to capacity ratios for the PM peak hour. From this figure, it is evident that the inclusion of background traffic forces more travel to occur under congested conditions. Since travel speed decreases rapidly at volume to capacity ratios approaching one, a significant reduction in travel speed is observed, influencing vehicle emissions.

The relationship between travel speed and vehicle emissions is non-linear in nature. In general, CO and HC emissions are highest at speeds approaching zero. As the average speed increases, vehicle emissions decrease (sharply at first, then more slowly) until a minimum is reached near 48 mph (77 km/hr). Above this speed, emissions increase (U.S. EPA 1994). NO_x emissions are also lowest near the middle of the speed spectrum. However, unlike CO and HC emissions, NO_x emissions increase rapidly at speeds above optimal, eventually surpassing emission rates observed at the low end of the speed spectrum.

When roads are operating below capacity, travel speeds are high. Indeed, over 40% of the travel in the early morning period occurs at speeds greater than 70 km/hr. Any decrease in speed causes a decrease in vehicle emissions as speeds approach optimal conditions. Links with travel speeds below optimal do experience an increase in vehicle emissions as travel speeds are lowered. However, this increase is more than offset by the decrease in vehicle emissions achieved by reducing travel speeds at the high end of the speed spectrum. Consequently, the inclusion of background traffic causes vehicle emissions to be reduced.

In contrast, heavily congested roads are often characterized by travel speeds below optimal. When background traffic is taken into consideration, travel speeds are reduced further, increasing vehicle emissions of CO and VOC's. However, NO_x emissions show a different trend. At travel speeds above optimal, NO_x emissions increase more rapidly than either CO or VOC's. As a result, a decrease in travel speed causes a large reduction in NO_x emissions. At travel speeds below optimal, NO_x emissions are affected less dramatically; a reduction in travel speed causes only a minor increase in vehicle emissions. Consequently, the reduction in vehicle emissions on links with travel speeds

above optimal outweighs the increase in vehicle emissions on links with travel speeds below optimal. The net result is a decrease in vehicle emissions as congestion from background traffic is taken into account.

Similar trends are observed for greenhouse gas emissions. When background traffic is accounted for, greenhouse gas emissions are increased due to higher fuel consumption resulting from lower travel speeds. In the PM peak hour, the change in greenhouse gas emissions is significant; during the early morning period, the change is negligible, since congestion is minimal and vehicle speeds are largely unaffected. Indeed, the early morning period shows a slight reduction in greenhouse gas emissions when background traffic is used in the assignment process. This counter-intuitive trend is likely due to the slightly greater amount of travel resulting from altered vehicle routes. In addition, travel speeds at this time tend to be greater than the optimal speed associated with maximum fuel efficiency. Any reduction in travel speed thus leads to a decrease in fuel consumption as vehicle speeds approach optimal. In contrast, travel speeds during the PM peak hour are largely below optimal, causing fuel consumption to increase as travel speeds are further reduced.

A sensitivity test was also conducted to determine the impact of the vehicle mix used on centroid connectors during the assignment process. As discussed in Section 4.4, the vehicle mix for arterial/collector roads was believed to be the most appropriate, due to the capacity assigned to centroid connector links. However, since centroid connectors represent local roads excluded from the model, the vehicle mix for local roads may also be appropriate. As Figure 6-28 to Figure 6-31 show, the vehicle mix assumption for centroid connectors has minimal impact on vehicle emissions.

Operating Mode Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
With Background Traffic	2,127,230	3,225	29,285	2,798
No Background Traffic	2,118,010	3,136	28,067	2,816
Percentage difference	-0.43	-2.77	-4.16	0.65
Passenger vehicles only				
With Background Traffic	1,917,455	2,924	26,838	2,065
No Background Traffic	1,909,675	2,845	25,728	2,088
Percentage difference	-0.41	-2.70	-4.14	1.10

* excludes external travel

Figure 6-23 Sensitivity to Background Traffic - PM Peak Hour

Operating Mode Sensitivity Analysis - Early Morning Period (Off-Peak)

	VKT	VOC's (kg)	CO (kg)	NOx (g)
All vehicles				
With Background Traffic	443,357	615	5,574	774
No Background Traffic	443,386	617	5,592	780
Percentage difference	0.01	0.19	0.31	0.70
Passenger vehicles only				
With Background Traffic	389,276	545	5,046	501
No Background Traffic	389,297	546	5,062	505
Percentage difference	0.01	0.22	0.31	0.83

* excludes external travel

Figure 6-24 Sensitivity to Background Traffic – Early Morning Period

Operating Mode Sensitivity Analysis - PM Peak Hour

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
With Background Traffic	2,126,661	529,426	194,571	17,500
No Background Traffic	2,117,422	513,997	188,927	16,967
Percentage difference	-0.43	-2.91	-2.90	-3.05
Passenger vehicles only				
With Background Traffic	1,917,455	445,237	180,239	0
No Background Traffic	1,909,675	432,351	175,023	0
Percentage difference	-0.41	-2.89	-2.89	N/A

* excludes external travel

Figure 6-25 GHG Sensitivity to Background Traffic - PM Peak Hour

Operating Mode Sensitivity Analysis - Early Morning Period

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
With Background Traffic	443,083	113,016	37,875	7,008
No Background Traffic	443,110	113,163	37,917	7,024
Percentage difference	0.01	0.13	0.11	0.22
Passenger vehicles only				
With Background Traffic	389,276	86,713	35,104	0
No Background Traffic	389,297	86,804	35,141	0
Percentage difference	0.01	0.10	0.10	N/A

* excludes external travel

Figure 6-26 GHG Sensitivity to Background Traffic – Early Morning Period

Figure 6-27 Impact of Background Traffic on V/C Ratios

Centroid Connector Vehicle Mix Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Arterial/collector vehicle mix	2,127,230	3,225	29,285	2,798
Local road vehicle mix	2,125,312	3,222	29,250	2,796
Percentage difference	-0.09	-0.09	-0.12	-0.07
Passenger vehicles only				
Arterial/collector vehicle mix	1,917,455	2,924	26,838	2,065
Local road vehicle mix	1,915,786	2,921	26,805	2,064
Percentage difference	-0.09	-0.09	-0.12	-0.06

* excludes external travel

Figure 6-28 Sensitivity To Centroid Connector Vehicle Mix - PM Peak Hour

Centroid Connector Vehicle Mix Sensitivity Analysis - Early Morning Period

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
Arterial/collector vehicle mix	443,357	615	5,574	774
Local road vehicle mix	443,189	615	5,573	774
Percentage difference	-0.04	-0.02	-0.03	-0.04
Passenger vehicles only				
Arterial/collector vehicle mix	389,276	545	5,046	501
Local road vehicle mix	389,128	545	5,045	500
Percentage difference	-0.04	-0.02	-0.03	-0.04

* excludes external travel

Figure 6-29 Sensitivity To Centroid Connector Vehicle Mix - Early Morning Period

Centroid Connector Vehicle Mix Sensitivity Analysis - PM Peak Hour

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
Arterial/collector vehicle mix	2,126,661	529,426	194,571	17,500
Local road vehicle mix	2,124,745	528,595	194,263	17,475
Percentage difference	-0.09	-0.16	-0.16	-0.14
Passenger vehicles only				
Arterial/collector vehicle mix	1,917,455	445,237	180,239	0
Local road vehicle mix	1,915,786	444,536	179,956	0
Percentage difference	-0.09	-0.16	-0.16	N/A

* excludes external travel

Figure 6-30 GHG Sensitivity To Centroid Connector Vehicle Mix - PM Peak Hour

Centroid Connector Vehicle Mix Sensitivity Analysis - Early Morning Period

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
Arterial/collector vehicle mix	443,083	113,016	37,875	7,008
Local road vehicle mix	442,914	112,981	37,863	7,006
Percentage difference	-0.04	-0.03	-0.03	-0.03
Passenger vehicles only				
Arterial/collector vehicle mix	389,276	86,713	35,104	0
Local road vehicle mix	389,128	86,687	35,093	0
Percentage difference	-0.04	-0.03	-0.03	N/A

* excludes external travel

Figure 6-31 GHG Sensitivity To Centroid Connector Vehicle Mix – Early Morning

6.5.3 Average Speed

Traditional planning models are rarely calibrated to produce accurate estimates of travel speed. Indeed, travel speed is often treated as a model input. Adjustments are made to free-flow speeds* as well as the underlying speed relationships to obtain reliable traffic volumes. However, no effort is made to ensure that the resulting speed estimates are reasonable.

The planning model for the National Capital Region uses speed-flow relationships based on standard equations developed by the U.S. Bureau of Public Roads (BPR). In these equations, travel speed is estimated as a function of the link volume to capacity ratio and free flow speed. To account for intersection delay, the standard BPR equations were modified during model development to include a coefficient for the free flow speed (RMOC 1999). This coefficient has the effect of reducing the free flow speed (as estimated by the posted speed limit) to better represent travel on signalized urban streets in the National Capital Region. The coefficient varies according to the road classification, reflecting the impact of different levels of signalization on free flow speeds.

However, recent research suggests that the standard BPR curves are out of date. In particular, concerns have been raised regarding the ability of the curves to predict travel speeds at traffic flows approaching capacity (SAI et al. 1998). In fact, the standard BPR curve has been shown to underestimate speeds at flows below capacity, and overestimate speeds at flows above capacity. Moreover, the curves are insensitive to signal control parameters that are known to have as great an impact on travel speed as the volume to capacity ratio (Dowling Associates 1997).

For this reason, an attempt was made to improve the speed relationships in the travel demand model for the National Capital Region through development of a speed post-processor with the ability to account for intersection delays, as well as queuing from congestion. However, it soon became apparent that any effort to implement a speed post-

* Free-flow speeds are the speeds observed when the traffic volume is virtually zero (i.e. interaction between vehicles in the traffic stream does not influence travel speed)

processor would be meaningless without local data to validate the speed relationships. Without such data, it is impossible to assess whether the speed post-processor represents an improvement over the existing speed relationships in EMME/2.

Due to the extensive work required to create a reliable speed post-processor, it was decided to use the existing speed relationships in the travel demand model to estimate vehicle emissions in the National Capital Region. However, a sensitivity test was conducted to determine the impact of using modified BPR curves to estimate travel speed on freeways and rural highways. These curves are based on recent data, and are believed to represent an improvement over previous versions of the BPR curve (Dowling Associates 1997; SAI et al. 1998). For freeways, these equations have the form:

Equation 6-1

$$\text{Travel Speed} = \frac{\text{Speed}_{\text{FreeFlow}}}{(1 + 0.20(v/c)^{10})}$$

In this equation, v/c represents the volume to capacity ratio, based on the actual road capacity. In contrast, the standard BPR equation is based on the “practical” road capacity, which is typically assumed to be 80% of the true capacity.

In addition to using modified BPR equations, an attempt was also made to adjust the free flow speed on freeways and rural highways using the relationship:

Equation 6-2

$$\text{Free flow speed (km/hr)} = 0.88 * \text{posted speed limit (km/hr)} + 22$$

The relationships described in Equation 6-1 and 6-2 are documented in a summary of speed post-processing techniques by Dowling Associates (1997) and are recommended for use in emission calculations involving MOBILE6 (SAI et al. 1998).

Although revised equations are also recommended for arterial roads, the equations require detailed traffic signalization data which was not readily available. Moreover, the speed relationships previously developed for the Ottawa-Hull model account for the level of signalization to some extent through the inclusion of a special coefficient as discussed

above. Consequently, no attempt was made to adjust the travel speeds on arterial roads as estimated by EMME/2.

Figure 6-32 illustrates the existing speed relationships used in the EMME/2 model for arterial roads of varying capacity*. As this figure shows, the curves are quite different from both the standard and modified BPR equations. In Figure 6-32, the modified BPR equation has not been adjusted to account for the level of traffic signalization. If such adjustments were made, the curve would shift downward, approaching the Ottawa-Hull equations used in the EMME/2 model.

Figure 6-33 presents similar information for freeways. In Figure 6-33, the modified BPR equation is plotted with and without adjustments to the free flow speed, calculated using Equation 6-2. However, even though the existing speed relationship within the EMME/2 model uses has the same value of free flow speed (equal to the posted speed limit), the co-efficient applied to the equation has the effect of lowering the free flow speed to 90 km/hr. Given the operating characteristics of freeways in the National Capital Region, this “effective” free flow speed appears unrealistic. When traffic volumes are low, freeways are typically characterized by average travel speeds between 100 and 120 km/hr. For comparison purposes, the standard BPR curve is plotted in Figure 6-34. Although the standard BPR curve also differs from the existing speed relationships in EMME/2, the shape of the curves is similar, since the Ottawa-Hull speed relationships were originally based on the standard BPR equations.

It should be noted that the modified BPR equation uses the actual road capacity to compute vehicle speeds, unlike the standard BPR equation which is based on “practical” capacity. Typically, practical capacity is defined as 80% of the actual road capacity. Although documentation is scarce, it appears that the capacity values in the current travel demand model for the National Capital Region represent the practical capacity of the

* The volume to capacity ratios in Figure 6-32 to Figure 6-35 are based on the “practical” capacity of the road, which is typically assumed to be 80% of the true capacity. While the standard BPR equations use the practical road capacity, the modified BPR equations use the actual road capacity. As a result, volume to capacity ratios based on practical capacity cannot be substituted directly into the modified BPR equations without appropriate adjustment.

road. As a result, application of the modified BPR equations requires adjustment of the capacity values. In the EMME/2 model, the lane capacity of a freeway segment is 1800 veh/hr. Increasing this value by 25% gives an actual lane capacity of 2250 veh/hr. Discussion with staff at the Region of Ottawa-Carleton confirmed that this capacity value is reasonable. However, data based on the *Highway Capacity Manual* suggest that a capacity of 2250 veh/hr may be high for urban freeways, depending on the proportion of heavy vehicles and peak hour factor (Dowling Associates 1997). For this reason, the sensitivity test was conducted using different capacity assumptions. Initially, the capacity values in the model were increased by 25%. The analysis was then repeated, increasing the capacity values by 10% and 0% respectively. The resulting BPR curves are shown in Figure 6-35. In addition, the tests were conducted for both peak and off-peak periods, since any change in the underlying speed relationships is likely to have a significant impact on congested and uncongested travel.

Figure 6-32 Comparison of Speed Estimation Techniques for Arterial Roads

Figure 6-33 Comparison of RMOC and Modified BPR Speed Equations - Freeways

Figure 6-34 Comparison of RMOC and Standard BPR Speed Equations - Freeways

Figure 6-35 Modified BPR Equations Used in Sensitivity Analysis

Figure 6-36 to Figure 6-39 present the results of the sensitivity tests. Given the difference between the original speed equations in the EMME/2 model and the modified BPR equations, it is not surprising that the impact on vehicle emissions would be substantial. In the PM peak hour, NO_x emissions increase by more than 20%, while CO emissions increase by 15%. In contrast, VOC emissions increase by only 1%. In the early morning period, NO_x emissions increase by 17%, CO emissions increase by 36%, and VOC emissions increase by 10%. In both the peak and off-peak hours, greenhouse gas emissions increase by approximately 5%.

Post-processing of travel speeds using the modified BPR equation has the effect of increasing the average travel speed on freeways and rural highways (refer to Table 6-7). Consequently, a greater proportion of travel occurs at speeds between 100 and 110 km/hr, as shown in Figure 6-40 for the PM peak hour. As a result, travel that originally occurred near the middle of the speed range (where emissions tend to be lowest) is shifted to the

high end of the speed range, increasing vehicle emissions. The magnitude of the increase depends on the nature of the individual pollutant and the range of travel affected.

Figure 6-41 and Figure 6-42 illustrate the impact of computing the level of congestion based on the actual road capacity, compared to the practical capacity. In the early morning, virtually all travel occurs at a volume to capacity ratio of less than 0.6, since travel demand is low. Consequently, travel speeds approach free flow conditions. Without speed-processing, the majority of freeway travel occurs at speeds between 85 and 90 km/hr. Application of the modified BPR curves increases the free flow speed on freeways by over 20%, causing most freeway travel to occur at speeds approaching 110 km/hr. The result is higher vehicle emissions.

However, it should not be concluded that post-processing of travel speeds will automatically lead to higher speed estimates. Indeed, Stopher and Fu (1996) found that speed post-processing tended to decrease travel speeds, which caused an increase in vehicle emissions due to higher levels of traffic congestion. While over 45% of the travel in the National Capital Region occurs on freeways and rural highways, a substantial amount of travel also occurs on arterial and collector roads. At present, it is unclear whether the EMME/2 model overestimates or underestimates travel speeds on such facilities. Consequently, it is impossible to predict the overall impact of speed post-processing on vehicle emissions.

Freeway Speed Post-Processing Sensitivity Analysis - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
No Speed Post-Processing	2,127,230	3,225	29,285	2,798
Mod. BPR Eq'n, EMM/2 Capacity	2,127,230	3,250	32,679	3,241
Mod. BPR Eq'n, EMM/2 Capacity * 1.1	2,127,230	3,255	33,320	3,320
Mod. BPR Eq'n, EMM/2 Capacity * 1.25	2,127,230	3,259	33,747	3,362
Passenger vehicles only				
No Speed Post-Processing	1,917,455	2,924	26,838	2,065
Mod. BPR Eq'n, EMM/2 Capacity	1,917,455	2,952	29,950	2,376
Mod. BPR Eq'n, EMM/2 Capacity * 1.1	1,917,455	2,957	30,537	2,428
Mod. BPR Eq'n, EMM/2 Capacity * 1.25	1,917,455	2,961	30,927	2,454

* no external travel

Figure 6-36 Sensitivity of Air Pollutants to Speed Post-processing (PM Peak Hr)

Freeway Speed Post-Processing Sensitivity Analysis - Early Morning (Off-Peak)

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
No Speed Post-Processing	443,357	615	5,574	774
Mod. BPR Eq'n, EMM/2 Capacity	443,357	677	7,570	907
Mod. BPR Eq'n, EMM/2 Capacity * 1.1	443,357	677	7,570	907
Mod. BPR Eq'n, EMM/2 Capacity * 1.25	443,357	677	7,570	907
Passenger vehicles only				
No Speed Post-Processing	389,276	545	5,046	501
Mod. BPR Eq'n, EMM/2 Capacity	389,276	602	6,868	588
Mod. BPR Eq'n, EMM/2 Capacity * 1.1	389,276	602	6,868	588
Mod. BPR Eq'n, EMM/2 Capacity * 1.25	389,276	602	6,868	588

* no external travel

Figure 6-37 Sensitivity of Criteria Pollutants to Speed Post-processing (Early AM)

Freeway Speed Post-Processing Sensitivity Analysis - PM Peak Hour

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
No Speed Post-Processing	2,126,661	529,426	194,571	17,500
Mod. BPR Eq'n, EMME/2 Capacity	2,126,661	553,685	202,674	19,027
Mod. BPR Eq'n, EMME/2 Capacity * 1.1	2,126,661	556,546	203,544	19,283
Mod. BPR Eq'n, EMME/2 Capacity * 1.25	2,126,661	558,624	204,217	19,433
Passenger vehicles only				
No Speed Post-Processing	1,917,455	445,237	180,239	0
Mod. BPR Eq'n, EMME/2 Capacity	1,917,455	463,197	187,509	0
Mod. BPR Eq'n, EMME/2 Capacity * 1.1	1,917,455	465,087	188,274	0
Mod. BPR Eq'n, EMME/2 Capacity * 1.25	1,917,455	466,587	188,881	0

* excludes external travel

Figure 6-38 Sensitivity of GHG Emissions to Speed Post-processing (PM Peak Hr)

Freeway Speed Post-Processing Sensitivity Analysis - Early Morning (Off-Peak)

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
No Speed Post-Processing	443,083	113,016	37,875	7,008
Mod. BPR Eq'n, EMME/2 Capacity	443,083	118,417	39,660	7,365
Mod. BPR Eq'n, EMME/2 Capacity * 1.1	443,083	118,417	39,660	7,365
Mod. BPR Eq'n, EMME/2 Capacity * 1.25	443,083	118,417	39,660	7,365
Passenger vehicles only				
No Speed Post-Processing	389,276	86,713	35,104	0
Mod. BPR Eq'n, EMME/2 Capacity	389,276	90,689	36,713	0
Mod. BPR Eq'n, EMME/2 Capacity * 1.1	389,276	90,689	36,713	0
Mod. BPR Eq'n, EMME/2 Capacity * 1.25	389,276	90,689	36,714	0

* excludes external travel

Figure 6-39 Sensitivity of GHG Emissions to Speed Post-processing (Early AM)

Table 6-7 Comparison of Travel Speeds Resulting from Speed Post-Processing

ALL LINKS IN MODEL	Early Morning Period			PM Peak Hour		
	Minimum Speed	Maximum Speed	Weighted Avg. Speed	Minimum Speed	Maximum Speed	Weighted Avg. Speed
No Speed Post-Processing	3	91	81	3	91	56
Modified BPR Eqn, EMM/2 Capacity	14	110	83	1	110	68
Modified BPR Eqn, EMM/2 Capacity * 1.1	14	110	83	2	110	69
Modified BPR Eqn, EMM/2 Capacity * 1.2	14	110	83	3	110	70

FREEWAYS AND RURAL HIGHWAYS	Early Morning Period			PM Peak Hour		
	Minimum Speed	Maximum Speed	Weighted Avg. Speed	Minimum Speed	Maximum Speed	Weighted Avg. Speed
No Speed Post-Processing	45	91	86	5	91	68
Modified BPR Eqn, EMM/2 Capacity	66	110	107	1	110	98
Modified BPR Eqn, EMM/2 Capacity * 1.1	66	110	107	2	110	102
Modified BPR Eqn, EMM/2 Capacity * 1.2	66	110	107	5	110	104

Figure 6-40 Impact of Speed Post-Processing of PM Peak Hour Travel Speeds

Figure 6-41 V/C Ratios Based on Actual and Practical Capacity- PM Peak Hour

Figure 6-42 V/C Ratios Based on Actual and Practical Capacity - Early Morning

6.5.4 Model Versus Survey

The majority of the sensitivity tests were conducted using trip tables derived from the 1995 Origin-Destination Survey. These same trip tables were used to compute daily vehicle emissions, as discussed in Sections 7.2.1 and 7.3.1. However, a travel demand model has been developed to predict travel behaviour in the future for the PM peak hour. This model was calibrated using data from the 1995 OD Survey, and can be used to model travel activity in 1995, as well as 2021. Figure 6-43 and Figure 6-44 illustrate the difference in vehicle emissions that can be attributed to modelling travel activity in EMME/2 compared to using trip tables based on survey data.

In general, the 1995 OD Survey predicts higher CO and VOC emissions than the travel demand model in EMME/2. However, estimates of NO_x emissions are slightly lower, reflecting differences between the two approaches.

Trip tables based on the 1995 OD Survey and the EMME/2 model predict similar amounts of travel. Indeed, the difference in vehicle-kilometers of travel between the two approaches is less than 0.4%. Consequently, the difference in vehicle emissions cannot be attributed solely to differences in the overall amount of travel. Rather, any difference in vehicle emissions must be explained by differences in travel characteristics. Use of the EMME/2 model requires look-up tables based on the road classification to compute operating mode fractions. As Section 6.3.3 describes, the look-up tables developed in this research tend to overpredict travel in the hot-start mode, which has the effect of reducing CO and VOC emissions and increasing NO_x emissions.

However, the difference in vehicle emissions can also be attributed to differences in travel speeds. The 1995 OD Survey predicts a higher level of congestion on the transportation network. Indeed, the average travel speed (45.4 km/hr) is 5% lower than the average speed predicted by the EMME/2 travel demand model (47.3 km/hr). As Figure 6-45 shows, the 1995 OD Survey predicts a lower proportion of travel at the high end of the speed spectrum. Since NO_x emissions increase rapidly at speeds above optimal, the lower the amount of high-speed travel, the lower the amount of NO_x

emissions. In contrast, CO and VOC emissions tend to increase as traffic congestion becomes more severe. Unlike NO_x emissions, CO and VOC's are less sensitive to changes in travel speed above optimal conditions. However, emissions increase rapidly as speeds approach zero. Since a high proportion of travel in the PM peak hour occurs at speeds below optimal, any increase in congestion is likely to result in increased CO and VOC emissions. As this discussion indicates, the speed distribution in Figure 6-45 is reflected in the vehicle emission trends in Figure 6-43.

Greenhouse gas emissions are also influenced by differences in travel speed. As Figure 6-44 illustrates, the travel demand model in EMME/2 predicts a lower amount of greenhouse gas emissions. During the PM peak hour, the majority of roads operate at travel speeds below the speed required for optimal fuel efficiency. As roads become less congested, travel speeds increase, reducing fuel consumption. Since the 1995 OD Survey predicts a higher degree of congestion on the transportation network, fuel consumption is greater, leading to higher greenhouse gas emissions.

Model vs OD Survey - PM Peak Hour

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
1995 OD Survey	2,127,230	3,225	29,285	2,798
Emme/2 Model	2,120,627	3,080	27,488	2,806
Percentage difference	-0.31	-4.50	-6.14	0.29
Passenger vehicles only				
1995 OD Survey	1,917,455	2,924	26,838	2,065
Emme/2 Model	1,910,795	2,789	25,161	2,070
Percentage difference	-0.35	-4.62	-6.25	0.24

* excludes external travel

Figure 6-43 Sensitivity to Data Origin – Criteria Pollutants, PM Peak Hour

Model vs OD Survey - PM Peak Hour

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
1995 OD Survey	2,126,661	529,426	194,571	17,500
Emme/2 Model	2,120,044	522,351	191,776	17,438
Percentage difference	-0.31	-1.34	-1.44	-0.36
Passenger vehicles only				
1995 OD Survey	1,917,455	445,237	180,239	0
Emme/2 Model	1,910,795	438,675	177,580	0
Percentage difference	-0.35	-1.47	-1.48	N/A

* excludes external travel

Figure 6-44 Sensitivity to Data Origin – Greenhouse Gases, PM Peak Hour

Figure 6-45 Speed Comparison: EMME/2 Model vs. 1995 OD Survey

7 VEHICLE EMISSIONS

7.1 INTRODUCTION

Once the input data were obtained and the necessary tools developed, the final step of the research was to predict vehicle emissions in the National Capital Region. This chapter describes the results of the modelling effort.

7.2 CRITERIA POLLUTANTS

7.2.1 Daily Emissions - 1995

Using the tools described in Chapter 5, vehicle emissions were computed for the National Capital Region. For each analysis period, trip tables from the 1995 OD Survey were assigned to the transportation network using the EMME/2 macro, travel.mac. Background traffic was taken into account during the assignment process in order to account for congestion from commercial vehicles. However, post-processing of travel speeds was not performed as explained in Section 6.5.3. During the assignment process, travel.mac was used to summarize key travel parameters, including the link classification, speed, and amount of travel by passenger vehicles and buses. The link classification scheme used in the analysis is discussed in Section 4.3. Section 4.2 describes the analysis periods, and outlines the justification for selecting representative hours to model travel activity. Since cold-start trip tables were available from the linked trip analysis, the amount of travel in different operating modes was computed on a link-by-link basis and stored in the travel output file (refer to Section 4.8). Vehicle emissions were analyzed on a link-by-link basis for several reasons. Of primary importance was the ability to import data into EMME/2 in order to create a graphical depiction of vehicle emissions in the National Capital Region.

The information from travel.mac was read into the Emission Calculator to compute daily vehicle emissions for a typical October day. Table 7-1 outlines the input data that were required by the Emission Calculator, along with the values assumed for fuel, temperature,

and vehicle fleet characteristics. Where applicable, the source of the data is also presented.

Table 7-1 Summary of Input Data Assumptions

Input Data	Assumed Value	Source	Comments
Type of Analysis	link-by-link	N/A	
Amount of Travel (vkt) by Passenger Vehicles and Buses	N/A	Calculated on a link-by-link basis using travel.mac	Output file = trvldat.out
Link Classification	N/A	Calculated on a link-by-link basis using travel.mac	Refer to Section 4.3
Speed	N/A	Calculated on a link-by-link basis using travel.mac	No speed post-processing was performed
Operating Mode Fractions	N/A	Calculated on a link-by-link basis using travel.mac	For each analysis period, a cold-start trip table was assigned to the transportation network (see Section 4.8)
Trip Length Distribution	N/A	Calculated during traffic assignment using travel.mac	Output file = e2trip.out Refer to Appendix J for trip length distributions used in analysis
Vehicle Mix	See Appendix D		Refer to Section 4.4 for additional detail
Fuel Volatility Class	C	Environment Canada (Philpott 1993)	
Fuel Vapour Pressure	14.4 psi	Environment Canada (Philpott 1993)	
Analysis Year	1995	N/A	
Season	July	N/A	
Maximum Daily Temperature	12.5 °C	Environment Canada (Environment Canada 1983-1999)	
Minimum Daily Temperature	3.7 °C	Environment Canada (Environment Canada 1983-1999)	

Ambient Temperature	See Table 4-23	Environment Canada (Environment Canada 1983-1999)	
Vehicle Age Distribution for Light- Duty Cars and Trucks*	Based on 1990 Ontario vehicle fleet	Environment Canada (Philpott 1993)	Refer to Section 4.10
Vehicle Age Distribution for Other Vehicle Categories*	MOBILE5 default values	N/A	
Mileage Accumulation Rates*	MOBILE5 default values	N/A	
Inspection and Maintenance Programs*	None	N/A	

* See Figure 5-5 for the MOBILE5 input file used in the Emission Calculator

After computing vehicle emissions for each representative hour, factors were applied to determine the amount of emissions produced during the analysis period as a whole. The factors accounted for the proportion of travel occurring throughout the hour compared to the longer analysis period. Additional detail can be found in Section 4.2. Since intra-zonal trips are excluded from the assignment process, the vehicle emissions associated with such trips were analyzed separately, using the process outlined in Section 6.2.1. Since intra-zonal trips represent only 3% of the travel in the National Capital Region, their contribution to overall emission levels is minor (less than 3% for each pollutant analyzed).

Combining the emissions from intra-zonal trips with the emissions produced during each analysis period, an estimate of total daily vehicle emissions was obtained. Figure 7-1 to Figure 7-3 illustrate the vehicle emissions produced in the National Capital Region for a typical October day in 1995. Additional detail can be found in Appendix M.

Figure 7-1 shows the relative contribution of each analysis period to total daily emissions. As this figure shows, the vehicle emissions produced during each analysis period are approximately the same, with the exception of the early morning period. However, the AM and PM peak periods are only 2.5 hours in length. In comparison, the midday period lasts six hours, while the evening period has a duration of 10 ten hours. Consequently, vehicle emissions are produced at a greater rate during the peak periods, when travel

activity is most intense. Not only does the amount of travel increase during the AM and PM peak period, but congestion is more severe, leading to higher vehicle emissions.

Figure 7-1 also shows the level of vehicle emissions associated with commercial vehicles in the National Capital Region. When commercial vehicles are included in the emission calculations, the increase in VOC and CO emissions is proportional to the increase in travel activity. However, NO_x emissions increase substantially, reflecting the emission characteristics of heavy duty trucks and buses.

In Figure 7-2, vehicle emissions are summarized by location in the study area. Not surprisingly, rural areas produce a low amount of vehicle emissions. Outside the urban area, travel activity is reduced. Moreover, travel speeds tend to be higher, since speed limits are greater and congestion is less severe. As a result, rural areas produce a disproportionately low amount of CO and VOC emissions compared to the overall amount of travel in rural zones. Vehicle emissions produced in the downtown core and urban areas show a different trend. Indeed, over 56% of the travel in Ottawa-Carleton occurs in downtown Ottawa and the surrounding urban environment. However, these areas produce over 65% of the VOC and CO emissions, due to slower travel speeds and the impact of traffic congestion. In contrast, NO_x emissions agree closely with the amount of travel occurring in rural, suburban, and urban areas; the impact of congestion has little influence on the relative contribution of NO_x emissions associated with different land use designations.

Figure 7-3 shows the distribution of vehicle emissions by facility classification. In Ottawa, 45% of travel occurs on freeways and rural highways. However, freeways are associated with only 33% of VOC emissions and 30% of CO emissions. On the other hand, 46% of NO_x emissions are produced on freeways, reflecting the primary function of such roads as high-speed travel facilities. Indeed, NO_x emissions increase rapidly at travel speeds above optimal, leading to high emission levels on facilities characterized by high travel speeds.

Local roads (including centroid connectors) and minor arterials contribute almost 50% of the VOC emissions and 53% of the CO emissions produced from mobile sources in Ottawa-Hull, yet represent only 36% of the total amount of travel. Clearly, the slower travel speeds associated with such facilities result in higher vehicle emissions of CO and VOC's. However, these slower travel speeds have less impact on NO_x emissions, of which local roads and minor arterials produce 35%.

While Figure 7-2 and Figure 7-3 contain emission estimates for all vehicle categories observed in the National Capital Region, additional figures are presented in Appendix M, summarizing emissions from passenger vehicles only. It should also be noted that all figures showing vehicle emissions by type of road or location do not include emissions from intra-zonal travel.

Figure 7-1 Daily Emissions By Time of Day

Figure 7-2 Daily Emissions By Surrounding Land-Use Environment

Figure 7-3 Daily Emissions By Road Classification

7.2.2 Growth in 2021

While the 1995 OD Survey can be used to obtain a base level of emissions in the National Capital Region, it is impossible to model changes in vehicle emissions resulting from modifications to the road network, changes in travel behaviour, or the introduction of different transportation and land-use policies. It is also impossible to predict future levels of vehicle emissions. For this reason, vehicle emissions were calculated using the travel demand model developed by TRANS. This model is used to forecast travel activity in the PM peak hour in 1995 and 2021. To develop emission estimates, the same procedure was followed as outlined in Section 7.2.1 for daily vehicle emissions, with the exception that trip tables were derived from the TRANS model, rather than the 1995 OD Survey.

Figure 7-4 compares the PM peak hour vehicle emissions in 1995 and 2021. As this figure shows, vehicle emissions increase by almost 50% in the year 2021. However, the amount of travel increases by almost the same amount, indicating that any increase in vehicle emissions can be attributed primarily to increases in travel activity. Vehicle congestion is controlled through the construction of new roads and the enhancement of existing roads; vehicle emissions are not unduly influenced by higher levels of congestion. Table 7-2 describes the travel activity during the PM peak hour in 1995 compared to 2021. The speed distribution for the two years is shown in Figure 7-5. In general, the 1995 model predicts a higher proportion of travel at both the high and low ends of the speed spectrum; the 2021 model dominates the middle portion, where vehicle emissions tend to be lower. From this analysis, it appears that bottlenecks exist in the 1995 transportation network which are addressed in 2021. However, since travel demand is lower in 1995, a greater amount of travel occurs at high speeds where sufficient capacity exists. In 2021, these high-speed routes suffer from increased travel demand. Since there is less high-speed travel in 2021, we would expect NO_x emissions to increase less rapidly than might be assumed by the increase in travel activity. This is reflected in Figure 7-4.

Table 7-2 PM Peak Hour Travel Activity - 2021 vs. 1995

Criteria	2021 PM Peak Hour	1995 PM Peak Hour	Percentage Change
Total trips (excluding intra-zonal)	210,221	143,944	46%
Total vehicle-kilometers travelled	3,262,984	2,158,553	51%
Total vehicle-hours travelled	71,513	45,617	57%
Average trip length (min)	20.4	19.0	7%
Average trip distance (km)	15.5	15.0	3%
Average travel speed ¹ (km/hr)	45.7	47.3	3%
Weighted avg. travel speed ² (km/hr)	54.7	57.4	4%

¹ speed = vkt/vht (or average trip distance/average trip duration)

² link speed weighted by amount of travel

PM Peak Hour Emissions - 1995 vs 2021

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
1995 Model	2,120,627	3,080	27,488	2,806
2021 Model	3,132,216	4,548	40,843	4,089
Percentage difference	47.70	47.67	48.58	45.70
Passenger vehicles only				
1995 Model	1,910,795	2,789	25,161	2,070
2021 Model	2,818,623	4,113	37,371	2,997
Percentage difference	47.51	47.48	48.53	44.73

* excludes external travel

Figure 7-4 PM Peak Hour Vehicle Emissions in 1995 Versus 2021 **Figure 7-5 Speed Distribution - 1995 Model vs. 2021 Model, PM Peak Hour**

To develop an estimate of daily emissions from emissions in the PM peak hour, factors were developed for each pollutant of interest describing the amount of pollutant produced in the PM peak hour compared to the entire day. Daily emissions were obtained by analyzing data from the 1995 OD Survey, which captures travel activity over a 24-hour period (refer to Section 7.2.1). Using this approach, the daily level of vehicle emissions in 2021 could be determined. Moreover, if changes in travel activity are modelled using data for the 1995 PM peak hour, the corresponding level of daily emissions can also be calculated. The factors developed in this analysis are presented in Table 7-3.

Table 7-3 Daily Emission Factors

	VKT	VOC's (kg)	CO (kg)	NO _x (kg)
Passenger Vehicles Only				
1995 Model, PM Peak Hour	2,818,623	4,113	37,371	2,997
1995 Daily Emissions*	18,041,910	25,962	236,158	21,399
Factor	9.44	9.31	9.39	10.34
All Vehicle Categories				
1995 Model, PM Peak Hour	3,132,216	4,548	40,843	4,089
1995 Daily Emissions*	20,294,312	28,969	259,657	30,888
Factor	9.57	9.41	9.45	11.01

* Includes emissions from intra-zonal trips

It should be noted that daily emission factors could be developed for each facility type. However, the additional complexity of this approach was not considered to be warranted. It is assumed that the relative proportion of travel on different road facilities will remain constant in the future. Where significant differences are anticipated, an effort should be made to produce unique emission factors for each facility classification. As Table 7-4 shows, the proportion of daily travel associated with different facility classifications is approximately the same as that predicted by the 1995 and 2021 PM peak hour models.

Table 7-4 Distribution of Travel in Ottawa-Carleton, Passenger Vehicles Only

Location / Facility Classification	Percentage of Overall Travel		
	Daily Travel - 1995 OD Survey	1995 PM Peak Hour Model	2021 PM Peak Hour Model
Core	10%	11%	9%
Urban	46%	44%	38%
Suburban	18%	17%	22%
Rural	26%	28%	31%
TOTAL	100%	100%	100%
Local Roads*	13%	14%	14%
Minor Arterials	23%	26%	24%
Major Arterials	19%	23%	29%
Freeways & Rural Highways	45%	37%	33%
TOTAL	100%	100%	100%

* Includes centroid connectors

Figure 7-6 shows the daily level of vehicle emissions predicted for 1995 and 2021. Since factors were applied to determine these emissions, the trends are identical to those presented for the PM peak hour. Figure 7-7 to Figure 7-10 show the distribution of daily emissions by road classification and surrounding land use. These figures are based on emissions from all vehicle categories. Additional figures describing emissions from passenger vehicles only are contained in Appendix N. In general, the trends described in Section 7.2.1 apply to Figure 7-7 to Figure 7-10 as well. Moreover, as these figures show, trends in 1995 are reflected in the 2021 emissions data.

It should be noted that emissions in 2021 were modelled using an analysis year of 1995 in MOBILE5. As a result, the vehicle technology is assumed to be constant over the planning horizon. Certainly, improvements will occur; it is likely that electric vehicles and other low-emission alternatives will be introduced over the next 20 years. However, without sufficient data to forecast changes in vehicle technology, a “worst case” scenario was investigated, in which technology does not contribute to improvements in vehicle emission levels. In addition, operating mode fractions derived from 1995 data were applied when modelling emissions in 2021. Again, fleet turnover during this period will result in a higher fraction of vehicles equipped with catalytic converters, influencing the proportion of travel in each of the three operating modes. At the same, manufacturers are

decreasing the length of time vehicles operate in the cold-start mode. Since it is unclear how these changes will impact vehicle emissions in the future, operating mode fractions were assumed to remain constant over the planning horizon.

It is certain that changes in vehicle technology will occur in the future, however, such changes are difficult to predict. Moreover, existing modelling tools are limited in their ability to account for many of the technological changes that are likely to occur. To model the future in a meaningful way, different “technology scenarios” must be developed and explored. Since an investigation of future vehicle technologies was beyond the scope of this investigation, it was decided to compute future emission levels ignoring changes in the vehicle fleet. Consequently, the resulting emission estimates should not be considered a realistic prediction of future emission levels, but rather an indication of what will happen if technological solutions are not developed and applied.

Daily Emissions - 1995 vs 2021

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
1995 Model	20,294,312	28,969	259,657	30,888
2021 Model	29,975,182	42,778	385,804	45,003
Percentage difference	47.70	47.67	48.58	45.70
Passenger vehicles only				
1995 Model	18,041,910	25,962	236,158	21,399
2021 Model	26,613,706	38,289	350,756	30,971
Percentage difference	47.51	47.48	48.53	44.73

* excludes external travel

Figure 7-6 Daily Emissions Estimated from PM Peak Hour - 1995 vs. 2021

Figure 7-7 Ontario Daily Emissions By Location - 1995 vs. 2021

Figure 7-8 Quebec Daily Emissions By Location - 1995 vs. 2021

Figure 7-9 Ontario Daily Emissions by Road Classification – 1995 vs. 2021

Figure 7-10 Quebec Daily Emissions by Road Classification - 1995 vs. 2021

7.3 GREENHOUSE GAS EMISSIONS

7.3.1 Daily Emissions - 1995

Greenhouse gas emissions were predicted in much the same way as NO_x, CO, and VOC emissions. Trip tables from the 1995 OD Survey were assigned to the transportation network in EMME/2 using the macro, travel.mac. The resulting travel activity was summarized on a link-by-link basis and read into the Emission Calculator to compute vehicle emissions. However, unlike criteria pollutants, greenhouse gases cannot be predicted using MOBILE5. Instead, fuel consumption equations and greenhouse gas emission factors must be supplied by the user.

To estimate fuel consumption as a function of average travel speed, equations were applied from a Montreal study (MTQ 1995). In the Montreal study, fuel consumption equations were developed from the micro-simulation model FREQ8PE. Since the fuel consumption rates in this model are based on data from 1980, adjustments were made in the Montreal Study to account for the fuel efficiency of the 1993 Quebec vehicle fleet. To predict fuel consumption in the National Capital Region, the equations used in the Montreal study were applied without further adjustment. Statistics from the Transportation Energy Databook (Davis 1999) suggest that the fuel economy of the passenger vehicle fleet has not changed substantially between 1990 and 1997. More importantly, data were not available to account for differences between the 1993 vehicle fleet in Quebec, and the 1995 Ottawa fleet. However, it is believed that the two vehicle fleets will exhibit similar fuel consumption characteristics.

In the Montreal study, fuel consumption equations were developed for light-duty gas vehicles, heavy-duty gas vehicles, heavy-duty diesel vehicles and buses. Separate equations were developed for arterial roads and freeways, due to the different operating characteristics associated with such facilities. Figure 7-11 shows the resulting fuel consumption rates for light-duty gas vehicles. At speeds below 30 km/hr, fuel consumption is higher on freeways compared to arterial roads due to the frequent accelerations and decelerations associated with freeway travel under severely congested

conditions. At speeds between 35 and 65 km/hr, fuel consumption is higher on arterial roads due to the effects of traffic signalization. At speeds above 65 km/hr, fuel consumption is independent of the road classification.

Figure 7-11 Fuel Consumption for Light Duty Gas Vehicles

It must be emphasized that the fuel consumption equations used in this study do not represent the most recent data available. As such, caution should be used when interpreting the results of the greenhouse gas analysis. Although a preliminary literature review was conducted, no research could be found concerning the relationship between fuel consumption and average travel speed. Researchers at the Oak Ridge National Laboratory (ORNL) were contacted for information, but were unable to provide relevant data. While the laboratory recently completed fuel consumption tests on a number of vehicles, the data were collected as a function of the vehicle's instantaneous speed and acceleration characteristics for use in micro-simulation models. Consequently, data from the ORNL study could not be used to predict fuel consumption as a function of average travel speed.

For comparison purposes, data from the ORNL study is plotted against the fuel consumption relationship for light-duty gas vehicles reported earlier (Figure 7-12).

Not surprisingly, fuel consumption is higher when based on average travel speed, since congestion and intersection delays result in reduced fuel efficiency. Results of the ORNL study can be found in the Transportation Energy Databook, along with data from previous fuel consumption tests (Davis 1999).

Figure 7-12 Fuel Consumption as a Function of Average Travel Speed and Instantaneous Speed

In addition to fuel consumption data, the user must also specify greenhouse gas emission factors. These factors express the amount of greenhouse gas emissions produced for every liter of fuel consumed, and are a function of both the type of fuel, as well as the emission control technology present on the vehicle. The primary greenhouse gases include CO₂, CH₄, and N₂O. Both CH₄ and N₂O are influenced by catalytic converters. However, CO₂

remains unaffected^{*}. Emission factors were developed based on the assumption that 94% of passenger vehicles were equipped with catalytic converters in 1995 (refer to Section 4.8). It was further assumed that each type of catalytic converter was equally represented in the vehicle fleet.

The amount of CO₂, N₂O and CH₄ produced per liter of fuel was obtained from an Environment Canada report entitled *Canada's Greenhouse Gas Inventory* (Neitzert et al. 1999). Equivalency factors expressing the relative contribution of each of these gases to the greenhouse effect were used to develop a composite emission factor for each vehicle category, taking into account the assumptions outlined above. For CO₂, the equivalency factor is 1. N₂O has an equivalency factor of 21, while CH₄ has an equivalency factor of 310. Table 7-5 presents the emission factors used to compute greenhouse gas emissions in the National Capital Region. A summary of the fuel consumption equations and greenhouse gas emission factors used in the analysis is presented in Appendix K.

Table 7-5 Greenhouse Gas Emission Factors (g/L)

Vehicle Category	Range of Values [*]			Composite Emission Factor Used in Analysis ^{**}
	CO ₂	CH ₄	N ₂ O	
Light Duty Gas Autos	2360	0.25-0.52	0.046-0.58	2457
Light Duty Gas Trucks	2360	0.19-0.56	0.046-1.0	2517
Heavy Duty Gas Vehicles	2360	0.17-0.49	0.046-1.0	2479
Heavy Duty Diesel Trucks	2730	0.12-0.15	0.1	2764

* Depends on emission control technology

** Assumes 94% of vehicles have catalytic converters;

Equivalency factors are 1 for CO₂, 21 for CH₄, and 310 for N₂O

^{*} For light duty gasoline automobiles, CH₄ emissions vary from 0.25 to 0.52 g/litre of fuel, depending on the type of catalytic converter. N₂O emissions vary from 0.046 to 0.21 g/litre, while CO₂ emissions remain constant at 2360 g/litre (Neitzert et al. 1999).

The vehicle categories used in the analysis were selected based on the available fuel consumption data, as well as the original vehicle categories defined in the Classification and Occupancy Counts. For additional detail on the vehicle mix used to compute greenhouse gases, refer to Section 4.4.

Results of the greenhouse gas analysis are presented in Figure 7-13 to Figure 7-15. Additional detail can also be found in Appendix M. Figure 7-13 shows the amount of greenhouse gases produced throughout the day. While each analysis period contributes a similar amount of greenhouse gas emissions (with the exception of the early morning period), the figure is misleading, since the AM and PM peak periods are much shorter than either the midday or evening periods. Indeed, the AM and PM peak periods have a combined duration of only five hours, yet are responsible for over 43% of the greenhouse gas emissions produced in the National Capital Region from mobile sources. Since 43% of the travel also occurs at this time, the impact of vehicle congestion appears to be minor.

Figure 7-13 also shows the greenhouse gas emissions produced from commercial vehicles. While the inclusion of commercial vehicle traffic causes travel activity to increase by 12%, greenhouse gas emissions increase by over 24%, reflecting the emission characteristics of heavy duty trucks and buses.

When broken down by facility classification and land-use environment, the amount of greenhouse gas emissions corresponds closely to the amount of travel. The downtown core has slightly higher greenhouse gas emissions than predicted by the amount of travel, while rural areas have slightly less. Likewise, the proportion of greenhouse gases produced on local roads and minor arterials is greater than the proportion of travel on such facilities, while the reverse is true for freeways. Such trends can be explained by differences in travel speeds. Rural areas and freeways are typically characterized by high-speed travel with minimal delays. In contrast, travel speeds tend to be lower on local roads and minor arterials, which have lower speed limits and frequent intersections. The same is true for travel in the downtown core, where congestion levels are often worse. As Figure 7-11 shows, fuel consumption is greatest when travel speeds are low. Although

fuel efficiency is also reduced at higher travel speeds, the effect is less severe. Consequently, greenhouse gas emissions increase substantially as vehicle speeds approach zero. However, at higher travel speeds, only a minor increase in greenhouse gas emissions is observed.

Figure 7-13 to Figure 7-15 include emissions from all vehicle categories. Additional figures can be found in Appendix M describing greenhouse gas emissions from passenger vehicles only.

Figure 7-13 Daily Greenhouse Gas Emissions and Fuel Use

Figure 7-14 Daily Greenhouse Gas Emissions and Fuel Use by Location

Figure 7-15 Daily Greenhouse Gas Emissions and Fuel Use by Facility Type

7.3.2 Growth in 2021

Trip tables derived from the 1995 OD Survey capture travel over a 24-hour period, and are thus required to compute daily vehicle emissions. However, survey data cannot be easily manipulated to investigate changes in travel activity resulting from new transportation policies or changes in the socio-economic environment. Rather, models are developed to forecast future travel behaviour. Such models also serve as important tools for predicting vehicle emissions. To determine the future level of greenhouse gas emissions that can be expected in the National Capital Region, the travel demand model in EMME/2 was used to model travel activity during the PM peak hour in 1995 and 2021.

Figure 7-16 illustrates the growth in greenhouse gas emissions that occurs between 1995 and 2021. Over this time, travel activity increases by 47%, resulting in a 47% increase in greenhouse gas emissions. From these results, it is apparent that sufficient infrastructure is available in 2021 to accommodate the increased travel demand. Otherwise, greenhouse gas emissions would increase by more than 47%, due to higher levels of traffic congestion. Since the growth in greenhouse gas emissions parallels the growth in travel activity, it can be concluded that the transportation network in 2021 exhibits operating characteristics similar to the 1995 network; existing levels of traffic congestion persist into the future. Figure 7-5 reinforces this conclusion. In 2021, less travel occurs at speeds lower than 20 km/hr. At the same time, the proportion of travel at speeds greater than 80 km/hr is reduced, indicating that capacity deficiencies in 1995 have been addressed, and that the entire network is being used more efficiently. As a result, high-speed facilities that were formerly under-utilized have lower travel speeds, which tends to reduce greenhouse gas emissions. With less travel at the very low end of the speed spectrum, greenhouse gas emissions are further reduced. Consequently, any increase in greenhouse gas emissions can be attributed solely to increases in the overall amount of travel.

It should be noted that the emission estimates for 2021 do not account for changes in vehicle technology which are likely to occur over the next 20 years. Although both fuel consumption and greenhouse gas emission rates will certainly be affected by advances in vehicle technology, an examination of future technology scenarios was beyond the scope

of this investigation. While the Emission Calculator allows the user to specify new technology vehicles, fuel consumption data for such vehicles is largely unavailable. As a result, the 2021 emission estimates should not be interpreted as an accurate prediction of future emission levels. Instead, the results indicate the magnitude of technology improvements that are required if greenhouse gas emissions are to be reduced.

PM Peak Hour Emissions - 1995 vs 2021

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
1995 Model	2,120,044	522,351	191,776	17,438
2021 Model	3,131,175	772,641	283,300	26,087
Percentage difference	47.69	47.92	47.72	49.60
Passenger vehicles only				
1995 Model	1,910,795	438,675	177,580	0
2021 Model	2,818,623	647,912	262,248	0
Percentage difference	47.51	47.70	47.68	N/A

* excludes external travel

Figure 7-16 PM Peak Hour Greenhouse Gas Emissions and Fuel Use - 1995 vs. 2021

Since the TRANS travel demand model is only capable of predicting travel activity for the PM peak hour, factors were developed to estimate daily greenhouse gas emissions from emissions in the PM peak hour. The factors used in the analysis are shown in Table 7-6. These factors are based on the proportion of greenhouse gas emissions occurring in the PM peak hour compared to the total amount of emissions produced each day, as estimated from the 1995 OD Survey.

Table 7-6 Daily Emission Factors for Greenhouse Gases

	VKT	Greenhouse Gas (kg)	Gasoline Use (litres)	Diesel Use (litres)
Passenger Vehicles Only				
1995 Model, PM Peak Hour	1,910,795	438,675	177,580	N/A
1995 Daily Emissions*	18,041,910	4,046,351	1,637,846	N/A
Factor	9.44	9.22	9.22	N/A
All Vehicle Categories				
1995 Model, PM Peak Hour	2,120,044	522,351	191,776	17,438
1995 Daily Emissions*	20,294,606	5,029,663	1,774,519	232,190
Factor	9.57	9.63	9.25	13.32

* Includes emissions from intra-zonal trips

Figure 7-17 illustrates daily greenhouse gas emissions for a typical October day in 1995 and 2021. Since these emissions were computed by factoring emissions in the PM peak hour, the trends in Figure 7-17 mirror those in Figure 7-13.

The distribution of daily emissions by facility class and location is shown in Figure 7-18 to Figure 7-21. These figures are based on emissions from all vehicle categories. Emissions corresponding to passenger vehicles only can be found in Appendix N. Since the proportion of travel on different facility types during the PM peak hour is similar to that observed over the entire day, the trends discussed in Section 7.3.1 apply to Figure 7-18 to Figure 7-21 as well. In general, the amount of greenhouse gas emissions is proportional to the amount of travel, with minor variations attributed to differences in operating characteristics. Moreover, trends in 1995 are also evident in 2021. Local roads and minor arterials produce a slightly higher amount of greenhouse gas emissions than predicted by the amount of travel on such facilities, while freeways and rural highways produce slightly less. Likewise, the proportion of greenhouse gases produced in the downtown core is slightly greater than the proportion of travel in this location, while the reverse is true for rural areas. These trends are a reflection of differences in travel speeds; at low travel speeds, fuel consumption increases substantially, increasing greenhouse gas emissions.

Daily Emissions - 1995 vs 2021

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
1995 Model	20,294,606	5,029,663	1,774,519	232,190
2021 Model	29,973,882	7,439,675	2,621,392	347,354
Percentage difference	47.69	47.92	47.72	49.60
Passenger vehicles only				
1995 Model	18,041,910	4,046,351	1,637,846	0
2021 Model	26,613,706	5,976,362	2,418,748	0
Percentage difference	47.51	47.70	47.68	N/A

* excludes external travel

Figure 7-17 Daily Greenhouse Gas Emissions and Fuel Use - 1995 vs. 2021

Figure 7-18 Daily GHG Emissions and Fuel Use By Location - Ontario

Figure 7-19 Daily GHG Emissions and Fuel Use by Location – Quebec

Figure 7-20 Daily GHG Emissions and Fuel Use By Road Type – Ontario

Figure 7-21 Daily GHG Emissions and Fuel Use By Road Type - Quebec

7.4 EMME/2 DIAGRAMS

When analyzing emissions on a link-by-link basis, output from the Emission Calculator can be summarized according to the link classification scheme or formatted into an output file suitable for importing into EMME/2. Once in EMME/2, the vehicle emissions can be displayed graphically. Moreover, calculations can be performed based on link characteristics stored within the model. For illustration purposes, a sample of EMME/2 diagrams is presented in Figure 7-22 to Figure 7-25, showing vehicle emission levels in the National Capital Region.

In these figures, the link colour identifies whether the link is located in downtown Ottawa (black), downtown Hull (blue), or the surrounding urban environment (red for Ottawa, violet for Hull). To account for differences in travel distance, the emissions on each link have been divided by the link length, giving emission estimates measured in kilograms per kilometer.

Figure 7-22 shows the level of NO_x emissions produced during the PM peak hour in 1995 from passenger vehicles only. This figure is contrasted with Figure 7-23, which shows the level of NO_x emissions produced in the early morning between 5:30 a.m. and 6:30 a.m. Not surprisingly, emissions are lower, reflecting reduced travel demand in the off-peak period. Figure 7-24 shows the daily level of NO_x emissions, with an expanded scale. Figure 7-25 illustrates the influence of congestion of VOC emissions. In this figure, VOC emissions per kilometer have been divided by the number of passenger vehicles assigned to the link. In essence, the figure shows the grams of VOC emissions produced for each vehicle-kilometer of travel. This value is equivalent to the emission factors estimated by MOBILE5. In areas where congestion is more severe, the emission factors will be greater, highlighting potential problem areas in the transportation network. However, as Figure 7-25 shows, the emission factors are relatively constant throughout the transportation network, suggesting that vehicle congestion, if any, is uniformly distributed throughout the study area.

Similar figures can also be produced for CO and greenhouse gas emissions, highlighting trends for different analysis periods or vehicle categories. Due to space limitations, these figures are omitted. However, in the case study described in Section 7.5, additional figures were created to illustrate the spatial distribution of vehicle emissions.

The ability to manipulate vehicle emission estimates within the EMME/2 environment is of considerable importance. Not only can results be shown graphically, but emission estimates can be aggregated according to the requirements of the user. Areas where vehicle emissions are greatest can be readily identified for further study and analysis. Consequently, any interface between vehicle emission models and travel demand models must allow a two-way flow of information to be truly valuable.

Figure 7-22 NO_x Emissions (kg/km) - PM Peak Hour

Figure 7-23 NO_x Emissions (kg/km) - Early Morning Period

Figure 7-24 Daily NO_x Emissions (kg/km)

Figure 7-25 VOC Emission Factors (kg/km/vehicle) - PM Peak Hour

7.5 CASE STUDY

Travel demand models provide important information for estimating the base level of vehicle emissions in an given area. However, such information can also be derived from traffic counts, spot speed studies, and roadside surveys. The true value of travel demand models lies in their ability to model changes in travel behaviour resulting from new transportation policies, modifications to the transportation network, and variations in travel demand. To illustrate how travel demand models and vehicle emission models can be used to evaluate the environmental impacts of transportation policies, a simple case study was developed based on the 2021 travel demand matrix for the PM peak hour. In this case study, two scenarios were examined. In the first scenario, it was assumed that all road modifications outlined in the Region of Ottawa-Carleton's Official Plan were constructed by the year 2021. In the second scenario, it was assumed that all future road modifications were abandoned in favour of other, non-transportation related projects. While this scenario is highly unrealistic, it serves to illustrate the value of using travel demand models to investigate vehicle emissions. Indeed, scenario 2 represents a worst-

case situation, in which travel demand continues to grow without the required infrastructure to support such growth.

Figure 7-26 and Figure 7-27 illustrate the impact on vehicle emissions that such a policy would entail. Without additional infrastructure to support regional growth, VOC emissions would increase by 17%, CO emissions would increase by 21%, NO_x emissions would increase by 3%, and greenhouse gases would increase by 11%. Of course, if travel demand could be reduced by encouraging drivers to use alternative modes of transportation such as public transit, the impact on air quality would be less severe.

The increase in vehicle emissions that results from inadequate funding of transportation infrastructure is primarily caused by increased congestion on the road network. As Figure 7-28 shows, travel speeds decrease significantly when travel demand for 2021 is assigned to the existing 1995 transportation network. The travel characteristics of each scenario are presented in Table 7-7.

Although travel speeds decrease between 1995 and 2021, it must be noted that the trip tables used in the analysis do not reflect changes in the trip distribution or modal split which may occur as congestion on the transportation network increases due to a lack of infrastructure development. To account for such changes in travel behaviour, new trip tables could be generated using the EMME/2 model for the National Capital Region. Since the modal split is sensitive to the trip duration, it is expected that the vehicle emissions computed using the revised trip tables would be slightly different than the values presented above.

Case Study: Impact of Road Network Improvements on Vehicle Emissions

	VKT	VOC's (kg)	CO (kg)	NOx (kg)
All vehicles				
2021 Demand, 2021 Network	3,132,216	4,548	40,843	4,089
2021 Demand, 1995 Network	3,248,061	5,338	49,377	4,202
Percentage difference	3.70	17.37	20.90	2.76
Passenger vehicles only				
2021 Demand, 2021 Network	2,818,623	4,113	37,371	2,997
2021 Demand, 1995 Network	2,928,781	4,838	45,209	3,109
Percentage difference	3.91	17.63	20.97	3.76

* excludes external travel

Figure 7-26 Case Study: Criteria Pollutants

Case Study: Impact of Road Network Improvements on Vehicle Emissions

	VKT	GHG's (kg)	Gas (litres)	Diesel (litres)
All vehicles				
2021 Demand, 2021 Network	3,131,175	772,641	283,300	26,087
2021 Demand, 1995 Network	3,247,045	861,082	317,626	27,381
Percentage difference	3.70	11.45	12.12	4.96
Passenger vehicles only				
2021 Demand, 2021 Network	2,818,623	647,912	262,248	0
2021 Demand, 1995 Network	2,928,781	726,411	294,028	0
Percentage difference	3.91	12.12	12.12	N/A

* excludes external travel

Figure 7-27 Case Study: GHG Emissions and Fuel Use

Table 7-7 Comparison of Case Study Scenarios

Criteria	2021 Demand, 2021 Transportation Network	2021 Demand, 1995 Transportation Network	Percentage Difference
Total trips*	210,221	210,221	0%
Total vehicle-km travelled	3,262,984	3,379,388	3.6%
Total vehicle-hours travelled	71,513	89,037	24.5%
Average trip length (min)	20.4	25.4	24.5%
Average trip distance (km)	15.5	16.1	3.6%
Average travel speed (km/hr)	45.7	38.0	16.8%

* excluding intra-zonal

Figure 7-28 Case Study Speed Distribution

Figure 7-29 and Figure 7-30 illustrate the difference in VOC emissions on a link-by-link basis. In these figures, the link colour corresponds to the type of land use:

- black = downtown core, Ontario
- red = urban, Ontario
- blue = downtown core, Quebec
- violet = urban, Quebec

A comparison of the two figures reveals deficiencies in the 1995 network which must be addressed in order to accommodate travel demand in 2021. In particular, VOC emissions on the Ottawa River Bridges decrease significantly when funding is available to construct additional infrastructure. Examination of Figure 7-31 and Figure 7-32 leads to a similar conclusion. In these figures, the amount of VOC emissions from passenger vehicles is divided by the number of vehicles assigned to the link. In this way, it is possible to determine the impact of congestion on automobile pollution. As congestion increases, each vehicle produces a greater amount of emissions. However, if the emissions per vehicle remain constant, the impact of congestion is minimal; any difference in vehicle emissions can be attributed solely to variations in the amount of travel. In Figure 7-31 and Figure 7-32, VOC emissions per vehicle are greatest on the Ottawa River Bridges as well as the downtown area of Hull, reflecting the need for additional infrastructure in these locations to address capacity deficiencies.

Similar figures can be produced for CO, NO_x, and greenhouse gas emissions. Since the purpose of the case study was merely to demonstrate how the Emission Calculator can be used to evaluate the environmental implications of transportation policies, these figures are not included in the report. However, the trends revealed in these figures are similar to those observed for VOC emissions.

Figure 7-29 to Figure 7-32 illustrate the value of computing emissions on a link-by-link basis. Emission results can be presented graphically, revealing “hot spots” in the transportation network where modifications to the road network may be warranted. Moreover, the emission data can be manipulated within the EMME/2 environment. The emissions associated with any geographic location or road classification can be determined, revealing trends that would otherwise be obscured. Clearly, the use of travel demand models to predict vehicle emissions has many advantages. By linking travel demand models to vehicle emission models, planners are able to investigate the environmental implications of transportation policies, which will ultimately lead to better decisions by policy-makers.

Figure 7-29 VOC Emissions (kg/km) - 2021 Demand Assigned to 2021 Network

Figure 7-30 VOC Emissions (kg/km) - 2021 Demand Assigned to 1995 Network

Figure 7-31 VOC Emissions (g/km/vehicle) - 2021 Demand, 2021 Road Network

Figure 7-32 VOC Emissions (g/km/vehicle) - 2021 Demand, 1995 Road Network

7.6 COMPARISON OF RESULTS

To assess the accuracy of the vehicle emission estimates for the National Capital Region, an attempt was made to obtain data for similar Canadian cities. Unfortunately, most emission inventories document emissions over an entire year; little information could be found describing daily or hourly vehicle emissions in Canadian communities.

A notable exception is Hamilton-Wentworth. As part of the Hamilton-Wentworth Air Quality Initiative, an effort was made to model vehicle emissions on an hourly basis using output from the integrated urban model, IMULATE, in conjunction with MOBILE5 (HAQI 1997). The goal of the study was to investigate the impact of future transportation and land use scenarios on vehicle emissions in the Hamilton area. As such, the study provides an excellent example of the types of transportation policy scenarios that can be investigated using vehicle emission models.

Anderson et al. (1996) outline the approach taken to model vehicle emissions using the IMULATE model. Essentially, emission factor look-up tables are used to describe the level of vehicle emissions at 0.1 mph intervals, allowing vehicle emissions to be calculated on a link-by-link basis and illustrated graphically. A comparison of the vehicle emission estimates for Hamilton and Ottawa-Hull is presented in Table 7-8.

Table 7-8 Comparison of Vehicle Emissions in Hamilton and Ottawa-Hull

	Hamilton, AM Peak Hour	Ottawa, 8:00 a.m. - 9:00 a.m.	Percentage Difference
Veh-km travelled	797,085	1,458,189	+83%
HC emissions (kg)	7,480	2246	-70%
NO _x emissions (kg)	6,577	1707	-74%
CO emissions (kg)	80,983	21,374	-74%

* includes emissions from passenger vehicles only

As Table 7-8 shows, the Hamilton-Wentworth analysis predicts a much higher level of vehicle emissions relative to the amount of travel. In the study described by Anderson et al. (1996), the emission factors used with the IMULATE model conform to winter-driving conditions. Unfortunately, it is not clear whether the same assumptions were

applied when developing the emission estimates in Table 7-8. However, if such assumptions are applicable, some of the variation between the Ottawa and Hamilton results can be explained. As shown in the temperature sensitivity tests in Section 6.3.5, CO and NO_x emissions increase significantly as the temperature drops. Miller et al. (1995) report similar findings. Since the Ottawa-Hull emission estimates were derived using typical October temperatures, the level of vehicle emissions is expected to be lower compared to emission estimates based on winter conditions.

The Ottawa and Hamilton transportation networks also show different levels of vehicle congestion. Indeed, the Hamilton emission estimates in Table 7-8 correspond to an average congested speed of 33 km/hr. In contrast, the average travel speed in the National Capital Region is 43 km/hr during the AM peak hour. As traffic congestion increases, vehicle emissions also increase. While hydrocarbon and CO emissions are particularly sensitive to reductions in travel speed, NO_x emissions are also affected to a lesser extent. (Anderson et. al 1996). Consequently, the difference in vehicle emissions observed in Table 7-8 may be a reflection of the operating characteristics of the Ottawa-Hull and Hamilton transportation networks.

Vehicle emissions have also been computed for Edmonton, Alberta using a traffic motion and vehicle emission model to track the second by second behaviour of vehicles on the road network (Checkel 1996). The model requires as input the average travel speed and link characteristics from the regional travel demand model implemented in EMME/2. Table 7-9 presents the results of the Edmonton study.

As Table 7-9 shows, the daily amount of travel in the National Capital Region is 9% lower than the amount of travel in Edmonton, despite the lower population of the Edmonton metropolitan area. As a result, the EMME/2 model for the National Capital Region may be underpredicting the amount of travel on minor roads and residential streets. In general, the Edmonton road network has a higher average speed than the network in Ottawa-Hull. As a result, we would expect vehicle emissions in Ottawa to be higher relative to the level of travel activity. Off-setting this trend, however, is differences

in the vehicle age distribution. Since the Edmonton vehicle fleet has a higher proportion of older vehicles, emission estimates will tend to increase.

Given the wide range of factors influencing mobile source emissions, and the sensitivity of emission estimates to changes in input parameters, the difference between the Edmonton and Ottawa-Hull results appears reasonable. Without additional information regarding the accuracy of the calculation procedures, it is impossible to make further conclusions.

Table 7-9 Comparison of Vehicle Emissions in Edmonton and Ottawa-Hull

	Edmonton, Total Day	Ottawa, Total Day	Percent Difference
Veh-km travelled	19,825,300	18,041,900	-9%
HC emissions (kg)	28,400	26,000	-8%
NO _x emissions (kg)	14,200	21,400	+51%
CO emissions (kg)	203,600	236,000	+16%
Fuel use (litres)	2,946,000	1,638,000	-44%
CO ₂ emissions (kg)	6,558,000	3,866,000	-41%

* includes emissions from passenger vehicles only

Annual emission summaries for selected Canadian cities were obtained from a CAA report (EEA 1999). In this study, provincial emission inventories were used to estimate vehicle emissions in six metropolitan areas. To disaggregate mobile source emissions to the metropolitan level, vehicle registration data was selected as an appropriate socioeconomic indicator. The results of the study are presented in Table 7-10. In this table, the annual amount of travel in Ottawa-Hull was estimated by multiplying the daily amount of travel in 1995 by 399 to account for fluctuations in travel activity throughout the year. Data from the Nationwide Personal Transportation Study in the United States suggests that, in October, 15.4% of weekly travel occurs on a typical weekday (U.S. DOT 1995). Moreover, 7.2% of annual travel occurs in the month of October. As a result, annual travel can be approximated by multiplying the amount of travel on a typical October weekday by 399.

As Table 7-10 shows, the annual amount of travel in Ottawa-Hull is much lower than either Calgary or Edmonton, suggesting that the EMME/2 model for the National Capital Region underestimates travel activity on minor and local roads. Indeed, since Ottawa is larger than both Calgary and Edmonton, it is expected that the annual amount of travel will also be greater. Despite this discrepancy, the ratio of passenger vehicle travel to total travel in all three urban areas is similar. As a result, the accuracy of the Ottawa-Hull commercial vehicle analysis appears to be acceptable.

While daily travel estimates can be factored to obtain annual activity levels, vehicle emissions are more difficult to factor due to the sensitivity of emission forecasts to changes in temperature. For this reason, no attempt was made to compute annual vehicle emissions in Ottawa-Hull based on output from the Emission Calculator.

Table 7-10 Comparison of Annual Vehicle Emission Estimates from CAA Study

	Ottawa-Hull ¹	Cities Analyzed in CAA Study					
		Calgary	Edmonton	Montreal	Toronto	St. John	Vancouver
1996 CMA Population ²	1,010,498	821,628	862,597	3,326,510	4,263,757	125,705	1,831,665
1995 VKT – Autos and Light Trucks (10 ⁹ kilometers/year)	7.2	10.43	10.48	27.64	47.42	1.93	13.56
1995 VKT – All Vehicle Categories (10 ⁹ kilometers/year)	8.1	11.65	11.94	30.21	51.41	2.12	15.05
1995 VOC Emissions from Autos and Light Trucks (10 ⁶ grams/year)	Not available	24,663	24,843	49,523	70,077	3,957	21,025
1995 VOC Emissions from all Mobile Sources (10 ⁶ grams/year)	Not available	33,894	35,453	68,796	99,881	4,987	25,385
1995 NO _x Emissions from Autos and Light Trucks (10 ⁶ grams/year)	Not available	18,006	18,108	39,905	57,713	3,026	19,151
1995 NO _x Emissions from all Mobile Sources (10 ⁶ grams/year)	Not available	58,461	64,867	126,110	138,176	7,347	39,238

¹ Ottawa-Hull data based on results presented in Section 7.2.1 and 7.3.1

Annual vehicle emissions not computed (annual vkt derived by multiplying daily vkt by 399)

Vehicle emissions for Ottawa-Hull not given in CAA study

² Population data from 1996 Census (Statistics Canada 2000)

A 1994 status report of transportation in Ottawa-Carleton estimates that private vehicles in the Ottawa region travelled a total of 6.420 billion kilometers in 1993 (RMOC 1994). Assuming an annual growth rate of 1%, this translates to 6.549 billion kilometers of travel in 1995. These estimates were derived by multiplying the number of privately owned vehicles in Ottawa-Carleton by the average annual mileage accumulation. As a result, visitor travel within the National Capital Region is excluded from the annual estimates, while travel by local residents outside the National Capital Region is included.

In comparison, the EMME/2 model for Ottawa-Hull predicts approximately 5.6 billion vehicle-kilometers of travel in Ottawa-Carleton in 1995. This value was obtained by multiplying the amount of daily passenger vehicle travel in Ottawa by 399 to account for the distribution of travel throughout the year. From these results, the EMME/2 model appears to underestimate travel activity. A similar conclusion was drawn from the CAA and Edmonton studies presented above.

Data from the Transportation Association of Canada's *Urban Indicator Series* also suggests that the EMME/2 model underpredicts travel activity in the National Capital Region (TAC 1999). As Table 7-11 shows, travel estimates from the EMME/2 model are between 15 and 20% lower than estimates from the TAC report. Although differences in the analysis year may account for some of this variation, travel growth alone is unlikely to account for the discrepancies observed. Indeed, the EMME/2 estimates include travel associated with rural zones and collector roads: travel which is omitted from the TAC summary.

Table 7-11 Comparison of Travel Activity from TAC Report and EMME/2 Model

TAC Urban Indicators Report – 1996 Data	
Travel on arterial roads and freeways, private vehicles only	18,380,000 vkt
Travel on arterial roads and freeways, private and commercial vehicles	20,268,000 vkt
Average vkt per capita, based on fuel sales	22.3
EMME/2 Model – 1995 OD Survey Data	
Travel on freeways and arterial/collector roads, private vehicles only	15,179,000 vkt
Travel on freeways and arterial/collector roads, all vehicle categories	17,133,000 vkt
Average vkt per capita, based on CMA population*	17.9

* Calculated as 18,042,000 vkt from passenger vehicles / 1,010,000 people
(population data from Statistics Canada 2000)

An effort was also made to evaluate the accuracy of fuel consumption and greenhouse gas emission estimates. Unlike criteria pollutants, fuel consumption and greenhouse gas emissions are often modelled ignoring ambient temperature. Since the Emission Calculator forecasts fuel consumption solely on the basis of travel activity and link operating speed, estimates of daily fuel consumption can be factored to obtain annual fuel consumption levels. In this case, factors were based on data from the U.S. Nationwide Personal Transportation Survey which describe the proportion of vehicle travel on a typical October day compared to annual travel activity (U.S. DOT 1995). Annual greenhouse gas emissions were computed in a similar manner.

In terms of fuel consumption, the 1994 status report of transportation in Ottawa-Carleton indicates that passenger vehicles in the region consumed 857 million litres of fuel in 1993 (RMOC 1994). If travel increases at 1% annually, it is estimated that 874 million litres of fuel were consumed in 1995. Using output from EMME/2, the Emission Calculator predicts an annual fuel consumption rate of approximately 504 million litres, reflecting the tendency of the EMME/2 model to underpredict travel activity. However, the results also indicate that the fuel consumption equations used in the analysis may be out of date.

The Transportation Association of Canada's *Urban Indicator Series* reports that vehicles in Ottawa-Hull consumed nearly 915 litres of fuel per capita in 1996, based on fuel sales in local municipalities (TAC 1999). In contrast, results from the Emission Calculator suggest that over 647 litres of fuel were consumed per capita in 1995. This value was

derived by dividing the annual fuel consumption in the National Capital Region (653.5 million litres) by the CMA population (1,010,000 individuals).

Unfortunately, fuel consumption estimates based on fuel sales generally include fuel purchased inside the urban area and consumed elsewhere, yet exclude fuel consumed within the urban area and purchased elsewhere. As a result, it is difficult to compare the results of fuel consumption models with fuel sales records. However, since the fuel consumption estimates all have a similar order of magnitude, it can be concluded that the Emission Calculator is functioning correctly, even if the fuel equations are out of date.

Any error in fuel consumption will also influence greenhouse gas emission estimates. Based on provincial data from *Canada's Greenhouse Gas inventory*, light-duty vehicles in Ontario produced 30,353 kilo-tonnes of greenhouse gases in 1995 (Neitzert et al. 1999). Using data from Statistics Canada (2000), the proportion of Ontario residents living in the Region of Ottawa-Carleton is approximately 7.1%. If Ottawa produces 7.1% of Ontario's greenhouse gas emissions, it is estimated that 2155 kilo-tonnes of greenhouse gases were produced in the region in 1995. In contrast, the Emission Calculator estimates a value of 1245 kilo-tonnes. This value was obtained by multiplying daily greenhouse gas emissions from passenger vehicles by 399, as discussed above. Although the method of proportioning Ontario's greenhouse gas emissions is crude at best, it verifies that the Ottawa-Hull emission forecasts are within the same order of magnitude as forecasts based on provincial data. Indeed, since the provincial estimates also include greenhouse gas emissions from light-duty commercial vehicles, it is expected that the amount of greenhouse gas emissions will be slightly higher than if passenger vehicles were analyzed separately.

Clearly, it is difficult to assess the accuracy of the modelling results. Emission estimates for other metropolitan areas are largely non-existent. Where estimates do exist, the values are often based on annual emission inventories which are difficult to compare with daily or hourly emission forecasts. From an investigation of the available data, it can be concluded that the vehicle emission estimates for Ottawa-Hull appear to be reasonable, although the EMME/2 model may be underestimating travel activity. As new information

becomes available, additional conclusions can be drawn regarding the accuracy of the emission calculation tools for the National Capital Region.

8 CONCLUSIONS

8.1 BENEFITS OF RESEARCH

Health care expenditures, lost productivity, damage to crops and forests--the cost of air pollution is indeed significant. Greenhouse gas emissions are predicted to shift global climate patterns, threatening ecosystems which sustain human life. Emissions from the transportation sector influence the health and welfare of individual Canadians, the quality of life in urban communities, and the well-being of the global environment. The need to understand and model vehicle emissions has never been greater.

The research work described in this report attempts to improve upon existing modelling practices by creating simple yet powerful tools that allow planners to investigate methods to reduce vehicle emissions and improve air quality. Indeed, the tools were designed to be as flexible as possible, and can be used to forecast vehicle emissions in any urban area that uses EMME/2 to model travel demand. The primary objectives of the research described in Chapter 1 were fully met. Specific outcomes of the research include:

- Development of tools to link EMME/2 with MOBILE5, improving the integration between vehicle emission models and transportation planning models
- Development of tools to estimate greenhouse gas emissions as a function of average travel speed
- Estimation of vehicle emissions in the National Capital Region for both 1995 and 2021
- Investigation of the sensitivity of vehicle emission estimates to changes in input parameters, including the trip length distribution, vehicle fleet characteristics, temperature, operating mode fractions, greenhouse gas emission factors, travel speed, and vehicle mix
- Illustration of a potential application of geographic information systems (GIS) in transportation planning

- Analysis of intra-zonal trips which are not assigned to the transportation network in EMME/2
- Calculation of travel time and distance values for each trip in the 1995 Origin-Destination Survey, taking into account variations in congestion levels throughout the day
- Inclusion of commercial vehicle traffic in the EMME/2 assignment process
- Analysis of vehicle operating mode characteristics in the National Capital Region by assigning cold-start trip tables to the transportation network in EMME/2

From collecting input data to developing the Emission Calculator to analyzing vehicle emissions in the National Capital Region, the scope of this research project was extensive. It is envisioned that the many valuable outcomes will support future research work in the field of vehicle emissions modelling, contributing to the overall understanding of the relationship between transportation, vehicle emissions, and air quality.

8.2 MAJOR CONCLUSIONS

From the results of this study, it is clear that the integration of vehicle emission models and travel demand models is both feasible and desirable. Indeed, analysis of vehicle emissions on a link-by-link basis allows results to be presented graphically, facilitating the determination of emission “hot spots” in the transportation network and permitting appropriate solutions to be devised. This kind of graphical analysis can be particularly powerful when presenting results to people who influence future transportation policy, yet are unfamiliar with the intricacies of vehicle emissions modelling.

However, the research work encompassed more than just the development of tools to compute vehicle emissions. Some of the key conclusions from this work are summarized below.

1. The inclusion of commercial vehicle traffic in the EMME/2 assignment process increases travel times by approximately 9% during the PM peak hour, but has only a

minor impact during off-periods when congestion levels are much lower. In both cases, the overall amount of travel remains virtually unchanged, indicating that the accuracy of the assignment results was not jeopardized by taking into account the congestion caused by heavy trucks, buses, and taxis.

2. Vehicle mix varies according to the road classification, as well as its geographic location (core, urban, suburban, rural).
3. Geographic information systems are ideally suited for analyzing trip data. However, transportation planning organizations must make the effort to integrate such systems into their everyday transportation planning activities.
4. Intra-zonal travel represents only a small fraction (approximately 3%) of the overall amount of travel in the National Capital Region. The average length of intra-zonal trips depends on the location within the study area. Intra-zonal trips in rural areas tend to be longer, since traffic zones cover a much larger geographic area. In contrast, the shortest intra-trips occur in the downtown core, where traffic zones are smallest.
5. The operating mode fractions for the National Capital Region are quite different from the MOBILE5 default values. While the overall amount of travel in the stabilized mode is similar, MOBILE5 predicts a much higher proportion of travel in the hot transient mode than is observed in Ottawa-Hull. Conversely, Ottawa-Hull has a much greater proportion of travel in the cold transient mode. From the linked trip analysis, it was found that 33% of the trips in the National Capital Region begin in the hot start mode, while 67% begin in the cold start mode. Overall, 46.5% of travel occurs in the stabilized mode, while 15.5% occurs in the hot transient mode and 38% occurs in the cold transient mode. Assignment of cold-start trip tables in EMME/2 shows that freeways and major highways typically have more travel in the stabilized mode, unlike local roads and centroid connectors which are characterized by a high degree of travel in the transient mode. In terms of daily trends, the number of cold start trips was found to be greatest in the morning period, and lowest during the midday. The

midday and evening periods also have the lowest fraction of travel in the stabilized mode, perhaps due to the shorter trip lengths observed at these times.

6. In the National Capital Region, vehicle emissions for a typical October day in 1995 were estimated to be:

- VOC's - 29,000 kg
- CO - 260,000 kg
- NO_x - 31,000 kg
- GHG's - 5,030,000 kg

These values are based on 20,290,000 vehicle-kilometers of travel, as estimated by EMME/2.

7. Almost one half of the travel in the National Capital Region occurs on freeways and rural highways. However, such roads produce only one third of the CO and VOC emissions attributed to mobile sources in Ottawa-Hull. In contrast, local roads and minor arterials produce approximately 50% of the CO and VOC emissions, despite accounting for only 36% of the overall amount of travel. The fraction of NO_x emissions associated with different road facilities mirrors the proportion of travel on such facilities. The same is true for greenhouse gas emissions. In terms of geographic location, the proportion of CO and VOC emissions produced in the downtown core is greater than the proportion of travel in this location. In rural zones, the reverse is true due to differences in travel speeds. However, variation in NO_x and greenhouse gas emissions can be attributed almost solely to variations in the amount of travel.
8. Assuming that characteristics of the vehicle fleet remain constant over time, vehicle emissions in Ottawa-Carleton will increase by approximately 50% between 1995 and 2021 if infrastructure improvements are implemented according to current plans. This change in vehicle emissions primarily reflects growth in travel activity, not increased congestion.
9. Estimates of vehicle emissions vary depending on the method used to aggregate travel data. In general, emissions are lowest when using a trip-based approach, and greatest

when emissions are computed using a link-by-link approach. The maximum difference between the two approaches was less than 10% for each pollutant analyzed.

10. Sensitivity tests show that vehicle emissions are very sensitive to changes in the age distribution of the vehicle fleet. Since economic fluctuations were observed to have a significant impact on the vehicle fleet, care must be taken in deriving fleet characteristics for estimation of vehicle emissions.
11. Vehicle emissions were also shown to be sensitive to changes in temperature and operating mode fractions. In general, accuracy is improved by assigning cold-start trip tables to the transportation network to obtain operating mode fractions on a link-by-link basis. Such cold-start trip tables can be derived by applying factors based on the proportion of trips beginning in the cold start mode. If operating mode fractions cannot be developed from assignment of cold start trip tables, use of operating mode look-up tables is recommended, rather than applying MOBILE5 default values. Indeed, the default values were shown to underestimate VOC and CO emissions, and overestimate NO_x emissions compared to values obtained using local data.
12. Vehicle emissions appear to be largely insensitive to changes in the trip length distribution.
13. The inclusion of commercial vehicle traffic in the EMME/2 assignment process increases VOC and CO emissions in the PM peak hour, while NO_x and greenhouse gas emissions are slightly lower. During the early morning period, the inclusion of commercial vehicle traffic has only a minor impact, since traffic congestion does not exist, and vehicle speeds are largely unaffected.
14. The use of GHG emission factors from 1995 to model greenhouse gas emissions in 2021 does not have a large effect on overall emission levels.
15. Post-processing of travel speeds on freeways and rural highways has a significant impact on vehicle emissions in both the peak and off-peak periods due to higher vehicle speeds.

16. In general, data from the travel demand model for the National Capital Region predicts lower levels of CO, VOC, and greenhouse gas emissions compared to travel data from the 1995 Origin-Destination Survey. However, the model estimates slightly higher amounts of NO_x emissions. These differences can be largely attributed to lower levels of vehicle congestion predicted by the travel model.

8.3 RESEARCH LIMITATIONS

The research work described in this report represents an initial attempt to model vehicle emissions in the National Capital Region. As such, deficiencies in input data were identified throughout the study. For obvious reasons, it is not possible to address every deficiency which currently exists. Rather, an effort was made to fulfill the objectives of the research project, recognizing the need for future refinement and enhancement.

Because the 1995 Origin-Destination Survey was conducted between September and December, the travel activity captured in the survey cannot be used to model vehicle emissions in the summer or winter without adjustments to account for changes in travel behaviour throughout the year. However, data concerning the seasonal variation in travel in the National Capital Region were not available. As a result, vehicle emissions were only modelled for a typical October day, even though smog is most critical in the summer, while CO emissions are a concern in the winter.

Due to missing or incomplete data, numerous assumptions were necessary throughout the research project. Wherever possible, sensitivity tests were conducted to determine the impact of the assumptions on the study results. In particular, assumptions were made regarding:

- The number of vehicles in Ottawa-Hull equipped with catalytic converters in 1995
- The break-down of heavy vehicles by weight classification
- The use of individual vehicles by members of the same household (to determine the vehicle start mode)
- The distribution of external trips throughout the day

- The vehicle age distribution in Ottawa-Hull (although local data was available for 1998, the impact of fluctuations in the economy made it impossible to apply the data to the 1995 vehicle fleet)

It is also recognized that the vehicle mix estimated from the 1996 Classification and Occupancy counts could be improved by analyzing additional traffic count data. Ideally, traffic counts from a number of years should be analyzed to account for variations in the vehicle mix over time.

In addition, the accuracy of the fuel consumption equations used to compute greenhouse gas emissions could not be verified. The equations are based on output from a micro-simulation model and are likely somewhat dated. Likewise, the greenhouse gas emission factors used in the analysis may be subject to error. The factors were calculated based on assumptions of the vehicle technology present in the 1995 fleet. However, the exact composition of the vehicle fleet was not known, and the greenhouse gas emission factors are somewhat lower than those assumed by the Transportation Table in its assessment of measures to reduce greenhouse gas emissions in Canada (Hagler Bailly 1999).

It must also be emphasized that estimates of vehicle emissions in 2021 should be viewed with caution. The estimates are based on the vehicle fleet present in 1995. Although this practice is endorsed by the U.S. Environmental Protection Agency (U.S. EPA 1994), it is likely that changes in vehicle technology will influence future emission levels. In particular, greenhouse gas emission factors, fuel consumption equations, and operating mode characteristics were not adjusted to account for changes in emission control systems or improvements in fuel economy that will occur over the next twenty years. To adequately model future vehicle emissions under different technology scenarios, a wide range of inter-related assumptions would need to be explored, which was beyond the scope of this investigation.

A final limitation involves the use of speed post-processors. The need to improve speed estimates from travel demand models has been well-documented (refer to Section 2.9.2). However, the application of speed post-processors is not a simple task. To achieve any meaningful improvement, traffic signalization data should be incorporated into the travel

demand model for the National Capital Region. Moreover, local speed data should be used to calibrate speed relationships, or at a minimum, verify the accuracy of speed relationships developed elsewhere. Lacking such data, it is impossible to conclude whether a particular speed post-processor represents an improvement over existing speed estimation techniques. Indeed, there is little merit to blindly applying speed relationships from the literature unless it can be proven that the relationships are relevant for the National Capital Region. For this reason, post-processing of travel speeds was not conducted as part of the emission estimation process. Consequently, the accuracy of the vehicle emission estimates for the National Capital Region must be viewed in light of the quality of the underlying travel speed data.

8.4 RECOMMENDATIONS FOR FUTURE RESEARCH

As research in the field of vehicle emissions modelling continues to progress, existing deficiencies will be addressed in a continual effort to improve the accuracy and ease with which vehicle emissions can be calculated. The following recommendations are based on deficiencies identified during the course of this research project. These recommendations provide direction for future research, and suggest actions which can be taken over the course of normal data collection exercises to improve the input data used to model vehicle emissions in the National Capital Region. Specifically, it is recommended that:

1. The seasonal variation in travel in the National Capital Region be determined in order to model vehicle emissions during the summer and winter months when air pollution is most severe;
2. The functionality of the Emission Calculator be enhanced by modifying the program to read in the characteristics of the EMME/2 assignment and display the information to the user;
3. The Emission Calculator be updated for use with MOBILE6 (MOBILE6 includes an enhanced treatment of evaporative emissions, fuel effects, and travel on different road facilities);

4. A study be conducted to determine the impact of using MOBILE6 to model vehicle emissions compared to MOBILE5;
5. Speed post-processors be developed to improve the accuracy of the speed estimates derived from EMME/2;
6. The vehicle age distribution for Ottawa-Hull be adjusted to account for fluctuations in the economy, as well as trends towards lower vehicle usage for older vehicles;
7. Local mileage accumulation rates be determined, perhaps by including vehicle ownership questions in the next origin-destination survey;
8. The fuel consumption equations used to model greenhouse gas emissions be verified and updated as necessary;
9. Fuel consumption equations and greenhouse gas emission factors be revised to account for changes in vehicle fleet technology over time;
10. The travel demand model for the National Capital Region be revised to include the road classification (local, collector, arterial, freeway), rather than distinguishing roads by the lane capacity and posted speed limit;
11. Questions be included in the next origin-destination survey concerning the household vehicle used to make a particular trip. Such information will allow the movement of individual vehicles to be tracked, so that the vehicle start mode can be determined more easily;
12. The results of vehicle emission forecasts be verified using emission inventories from other sources;
13. New methodologies be developed to assess the accuracy of emission models using existing or emerging technologies;
14. Estimates of air quality be computed for the National Capital Region, and compared with pollutant concentrations measured at local monitoring stations;

15. An attempt be made to model future vehicle emissions taking into account anticipated changes in vehicle technology; and
16. Estimates of the amount of travel in the National Capital Region be computed from local traffic counts in order to determine the accuracy of the results from EMME/2.

From the above list, two recommendations for future research are believed to be particularly important: post-processing of travel speeds, and determination of vehicle emissions using MOBILE6. Such research is deemed essential if estimates of vehicle emissions are to be improved.

It also recommended that efforts be made to co-ordinate research activity in the transportation and air quality fields so that new developments can be fully integrated and exploited. Moreover, the results of modelling exercises must be verified wherever possible, allowing researchers to identify deficiencies and pursue solutions. Lastly, the transportation profession must embrace changes in technology which will impact data collection techniques, as well as the models used to forecast vehicle emissions and travel demand.

To enhance air quality and avert global climate change, action must be taken today. However, the effectiveness of such action depends on the ability of modellers to understand the relationship between air quality, vehicle emissions, and travel activity. Research in this area must continue to progress if informed decisions are to be made regarding the most cost-effective and socially-acceptable policies to pursue. Enhancements in vehicle emission models must be accompanied by improvements in travel demand models. However, perhaps more importantly, the environmental implications of alternative transportation policies must be at the forefront of the decision process. Understanding is meaningless without the political will to act.

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APPENDIX A

TRAVEL DEMAND MODELLING

TRAVEL DEMAND MODELLING

Models such as MOBILE5 and MOBILE6 require accurate estimates of travel activity to forecast vehicle emissions. Although traffic counts and surveys can be used to determine the amount of travel in an urban area, it is difficult to assess the change in vehicle activity that will occur due to changes in the socio-economic environment or the introduction of new transportation policies. For this reason, travel demand models are frequently used to predict travel activity when modelling vehicle emissions.

Transportation is a derived demand. People travel in order to participate in various activities essential to human existence. To ensure the transportation system provides adequate mobility, transportation planning is essential. In this way, resources can be allocated to meet a community's goals and objectives. However, transportation planning cannot proceed without a reliable estimate of future travel demand. Transportation demand forecasting is thus central to the process of urban transportation planning.

Travel demand models attempt to predict the number of people or vehicles using a particular transportation facility in the future. These estimates are derived based on the socio-economic characteristics of the region as well as known patterns of human behaviour which are incorporated into models. These models are developed using data from origin-destination surveys as well as census and regional employment statistics. After calibrating the models to account for local conditions, the models are used to forecast future travel behaviour. By comparing the demand for various facilities with the existing capacity, deficiencies in the transportation system can be identified. Transportation modelling is thus an important tool for evaluating policy scenarios and developing appropriate strategies for satisfying future mobility needs.

Conventional urban transportation models consist of four steps: trip generation, trip distribution, modal split, and traffic assignment. These steps are described in the following sections.

Trip Generation

The demand for travel manifests itself in the form of trips. These trips can be characterized by their origin and destination, mode of travel, route, purpose, time of day, and frequency. Each trip has a single origin and a single destination and can be classified as either home-based or non home-based. Home-based trips begin or end at the traveller's place of residence, while non home-based trips do not. For example, the trip from home to work is defined as a home-based work trip. However, if an individual travels from work to the grocery store, the trip is defined as a non home-based trip since the trip neither starts nor ends at the individual's home.

Wright and Ashford (1998) describe trip generation models: "Trip generation is the analytical process that provides the relationship between urban activity and travel. The number of trips to and from activities in an area is related to land use and socio-economic characteristics" (265). Based on these characteristics, the number of trips that are produced by each zone in the study area can be predicted, as well as the number of trips that are attracted to each zone. In general, trip productions are associated with the residential land use in a given zone while trip attractions are associated with the non-residential land use. For example, each time a commuter travels to work in the morning and returns at the end of the day, two home-based work trips have occurred. The zone where the commuter lives is the origin for the morning trip and the destination for the afternoon trip. However, the zone is said to have produced two trips since two trip ends are associated with the residential land use in the zone. Likewise, the zone containing the place of employment has attracted two trips. In the case of non-home based trips, the origin zone is attributed with the trip production while the destination zone is attributed with the trip attraction.

This distinction between productions/attractions and origins/destinations has been made in order to facilitate trip generation procedures. Trip productions are based primarily on the socio-demographic characteristics of the population within a zone, such household size, auto ownership, gender, income, age, and occupation. On the other hand, trip attractions can be predicted using such data as zonal employment, retail floor space, or school enrolment. The most appropriate variables to use depend on the trip purpose being modelled. Once trips have been distributed between zones, factors are applied to account for the number of trips occurring during the peak period as well as the directional distribution. The result is an origin-destination matrix for the peak period.

In general, trip attraction and production models are developed for each trip purpose. In cross-classification methods, the population in an urban area is divided into homogenous groups, and average trip production rates are estimated for each classification. While cross-classification methods can be used to predict trip attractions, they are rarely used for this purpose due to the difficulty in obtaining a statistically valid sample. Regression models establish a statistical relationship between the number or frequency of trips and the various explanatory variables. These models are used to predict both productions and attractions, typically using data aggregated to the zonal level. On the other hand, discrete choice models use disaggregate data to estimate the probability that an individual or household will make a certain number of trips. Like the cross-classification method, discrete choice models are generally limited to estimating trip productions. Since separate models are used to predict the trip productions and attractions, the number of trips produced in the study area will rarely equal the number of trip attractions. Balancing techniques are thus applied to ensure that the number of trips is conserved.

Once the number of trip productions and attractions has been determined for each zone in the study area, the number of trips that occur between each pair of zones must be computed in order to develop an origin-destination matrix. This step constitutes the trip distribution stage of the transportation modelling process.

Trip Distribution

According to Meyer and Miller (1984), “the task of trip distribution is to ‘distribute’ or ‘link up’ the ... productions and attractions for each zone as predicted by the trip generation model in order to predict the flow of trips T_{ij} from each production zone i to each attraction zone j ” (250). In other words, trip distribution models connect the trip ends associated with production and attraction to form “trip interchanges” between particular pairs of zones.

Many trip distribution models exist, including growth factor techniques such as the Fratar model, intervening opportunities models, and disaggregate destination choice models. However, the most widely used model for distributing trips is the gravity model, originally named after Newton’s law of gravitational attraction from which it derives its form. The gravity model attempts to describe patterns of human interaction. The model was developed over 100 years ago based on the observation that interaction between cities is dependent on the population of the cities as well as the distance between them. Since that time, the gravity model has evolved considerably, and has been used in a wide range of applications. Today, the model is commonly used in transportation planning applications, and is based on the hypothesis that the number of trips between a particular origin and destination zone is proportional to:

- total trip productions at the origin
- total trip attractions at the destination
- the “friction” between zones, which is a function of the travel impedance
- a socio-economic adjustment factor

The form of the gravity model used in transportation planning is thus:

$$T_{ij} = \frac{P_i A_j F(c_{ij}) K_{ij}}{\sum_{j=1}^n (A_j F(c_{ij}) K_{ij})}$$

where T_{ij} is the number of trips between the origin zone i and the destination zone j
 A_j is the number of trip attractions at zone j
 P_i is the number of trip productions at zone i
 c_{ij} is the travel impedance
 F is the friction factor
 K_{ij} is a socio-economic adjustment factor
 n is the total number of zones

This model must be applied iteratively in order to ensure that the total productions and attractions for each zone are maintained. The model is calibrated by adjusting the friction factor until the observed and predicted trip length distributions correspond. The friction factor is a function of the impedance or cost of travelling between zones. This cost can be measured in terms of distance, travel time, or out-of pocket expenses. Generally, an

inverse power or exponential function is used to estimate the friction factor. However, the parameters of the function will vary depending on the trip purpose, since an individual's willingness to travel depends on the nature of the trip. As a result, the gravity model is usually applied once for each trip purpose.

Modal Split

The purpose of applying modal split models is to determine the percentage of trips that are made using each of the different modes of transportation available. Up until this point, all flows are measured in terms of person trips. However, to estimate the level of congestion on a particular roadway, it is important to know the number of vehicle trips, which requires information on the modal split, as well as the average vehicle occupancy.

Modal split can be performed either before or after the trip distribution stage. When performed after trip distribution, the service characteristics of the alternative modes can be incorporated into the model, as well as any relevant socio-economic characteristics such as income or auto-ownership. In general, modal split models should include explanatory variables which describe the characteristics of the trip maker, the destination, and the route (Shallal 1999). Diversion curves are typically used for this purpose, as well as disaggregate modal choice models, such as the multinomial logit model. These models are based on the concept of utility maximization. According to this concept, individuals will always choose the travel alternative with the maximum benefit, such as the lowest travel time and cost, or the greatest comfort and convenience.

Once the number of vehicle trips between each zone has been determined, the remaining step is to assign the trips to the transportation network.

Traffic Assignment

As Wright and Ashford (1998) state: "the final step in the simulation of travel patterns ... is the assignment of zonal trip interchanges to the individual transportation facilities" (281). This process produces an estimate of the traffic volume using each link in the transportation network. During calibration, this volume is compared with known traffic volumes to assess the overall accuracy of the modelling process. In general, this comparison is accomplished using screenlines, which are strategically placed imaginary lines that cross the study area. The total volume of traffic crossing these lines is measured in the field and compared with model estimates. If the comparison is favourable, the model is assumed to be sufficiently accurate, and can be used for forecasting future travel demand.

Trips are loaded onto the transportation network via centroid connectors. These imaginary roads represent the local street network which has been excluded from the model. Trips are assumed to begin and end at the zone centroid, the centre of activity of the zone.

There are several techniques for assigning trips to the transportation network. The simplest is known as “all or nothing” traffic assignment. In this method, all the trips between a particular origin and destination are assigned to the shortest path between that origin and destination, regardless of the volume of traffic already using the route. Since the capacity of the links is ignored, the effect of congestion is also ignored.

To overcome this limitation, more sophisticated traffic assignment techniques have been developed which account for capacity restraints and the increase in travel time that can occur due to congestion. In user-equilibrium models, it is assumed that each traveller seeks to optimize his or her own travel time. Thus, when the system reaches equilibrium, no-one can improve their travel time by unilaterally changing routes. In contrast, system-optimization models attempt to minimize the system-wide travel time. In this method, an individual traveller cannot change routes without increasing the total travel time on the network, even though the traveller may be able to improve his or her own travel time. Other traffic assignment techniques include stochastic assignment, diversion techniques, and capacity restraint models. To apply these techniques, the capacity of each link in the transportation network must be known, as well as the link performance function. This function indicates how the travel time along a particular link changes as the traffic volume increases.

After assigning trips to the transportation network, volume to capacity ratios can be determined. These ratios indicate the level of service of a particular facility, and can be used to identify potential deficiencies in the transportation network.

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APPENDIX B

TRAVEL IN THE NATIONAL CAPITAL REGION

Daily Distribution of Trips in the National Capital Region by Mode

Time	Bicycle	Motor-cycle	School Bus	Transit	Walk	Taxi	Other	Not Stated	Auto Pass'r	Auto Driver	Total Trips	Hourly Trips	
												Total	Auto Driver
4:00 - 4:15	60		110	390	577	45	41	611	387	2,477	4,698		
4:15 - 4:30	18			25	107			12		311	473		
4:30 - 4:45				43	43				97	791	974		
4:45 - 5:00	69			64		21			49	210	344	6,489	3,789
5:00 - 5:15				112	112	44	74		298	1,873	2,582	4,373	3,185
5:15 - 5:30				46	41	22	14		72	718	912	4,812	3,591
5:30 - 5:45	20			289	222		6		602	3,746	4,885	8,723	6,546
5:45 - 6:00	21			394	136		26		338	1,897	2,812	11,191	8,233
6:00 - 6:15	169	6		2,782	423	29	85		1,502	9,486	14,482	23,091	15,847
6:15 - 6:30	63		23	1,858	391	21	5		972	5,652	8,986	31,165	20,780
6:30 - 6:45	180	66	122	4,666	861	54	105		3,978	18,269	28,302	54,582	35,304
6:45 - 7:00	179		236	3,718	499		48	22	3,025	11,420	19,148	70,917	44,827
7:00 - 7:15	728	72	2,773	12,425	2,166	69	140		8,268	34,476	61,117	117,552	69,816
7:15 - 7:30	236	60	3,613	6,067	1,258		59	6	4,726	17,436	33,461	142,028	81,600
7:30 - 7:45	1,047	67	4,890	13,756	5,399	136	62	111	11,336	44,307	81,110	194,836	107,639
7:45 - 8:00	644	25	4,722	6,783	4,022	68	89		5,482	22,772	44,606	220,295	118,991
8:00 - 8:15	2,191	64	11,105	16,670	13,905	366	213	25	12,327	50,678	107,542	266,720	135,194
8:15 - 8:30	751		3,869	4,688	6,708	94	89	28	5,107	20,167	41,500	274,759	137,924
8:30 - 8:45	1,613	50	3,697	7,996	12,443	178	280	80	7,962	35,032	69,329	262,978	128,649
8:45 - 9:00	336	43	1,395	1,674	4,125	66	61		2,576	14,100	24,376	242,748	119,976
9:00 - 9:15	505	21	404	5,149	5,747	173	189	6	4,548	27,763	44,507	179,712	97,061
9:15 - 9:30	105	4	94	635	1,120	86	26		839	6,393	9,302	147,514	83,287
9:30 - 9:45	254	42	13	2,680	2,625	85	43		3,521	17,529	26,792	104,977	65,784
9:45 - 10:00	43			528	1,018	40			910	4,861	7,400	88,000	56,545
10:00 - 10:15	650	44	60	4,392	5,972	208	89	19	5,956	28,668	46,058	89,552	57,451
10:15 - 10:30	122			495	1,283	21			1,054	6,253	9,230	89,479	57,311
10:30 - 10:45	345	42	34	2,257	3,223	92	128		4,086	18,550	28,755	91,442	58,333
10:45 - 11:00	69		19	417	1,370	64			1,286	5,793	9,017	93,060	59,264
11:00 - 11:15	320		39	4,823	4,550	269	151	43	5,721	26,763	42,678	89,680	57,358
11:15 - 11:30	205	20		697	1,856	64			1,430	7,128	11,401	91,851	58,233
11:30 - 11:45	704	45	85	2,674	8,092	41	80		4,077	19,949	35,747	98,844	59,632
11:45 - 12:00	156		49	688	3,150	116	44		1,892	8,443	14,538	104,365	62,283

Daily Distribution of Trips in the National Capital Region by Mode

Time	Bicycle	Motor-cycle	School Bus	Transit	Walk	Taxi	Other	Not Stated	Auto Pass'r	Auto Driver	Total Trips	Hourly Trips	
												Total	Auto Driver
12:00 - 12:15	815	62	156	6,075	11,462	301	188	59	6,939	34,897	60,954	122,641	70,417
12:15 - 12:30	135		32	831	4,046	89	44		1,746	7,593	14,515	125,755	70,882
12:30 - 12:45	747	40	102	2,299	8,607	128	56		4,242	20,004	36,225	126,233	70,937
12:45 - 13:00	161			586	3,253	84	44	22	2,156	10,051	16,356	128,051	72,544
13:00 - 13:15	872	39	49	4,724	10,042	467	89	19	7,241	30,575	54,117	121,214	68,223
13:15 - 13:30	170	19	5	832	2,231		22		1,862	6,765	11,906	118,604	67,394
13:30 - 13:45	91	42	58	2,955	4,346	220	112		4,079	18,693	30,595	112,974	66,083
13:45 - 14:00	78	21	25	409	1,313	55	4		1,246	5,823	8,974	105,591	61,856
14:00 - 14:15	620	20	386	4,808	7,081	243	67	20	6,802	28,404	48,450	99,925	59,684
14:15 - 14:30	75		1,109	832	1,534	108	11	20	1,279	5,552	10,519	98,538	58,471
14:30 - 14:45	418	19	3,081	4,475	4,870	244	165	21	5,211	21,381	39,885	107,829	61,160
14:45 - 15:00	243		1,599	1,011	2,287	50	24		1,800	7,299	14,312	113,166	62,636
15:00 - 15:15	1,485	83	7,339	11,798	13,235	328	301	21	8,656	36,690	79,935	144,651	70,922
15:15 - 15:30	683	19	5,581	4,586	6,657	117	96	64	3,882	11,418	33,103	167,235	76,788
15:30 - 15:45	1,395	108	9,347	12,708	15,055	306	289	134	10,810	37,836	87,988	215,337	93,242
15:45 - 16:00	363	20	1,967	2,688	3,681	134	19		3,862	13,000	25,735	226,761	98,943
16:00 - 16:15	2,189	115	3,472	15,634	11,411	294	334	64	14,215	58,099	105,826	252,652	120,353
16:15 - 16:30	507		834	3,140	2,237	46	38	20	4,397	17,642	28,860	248,409	126,577
16:30 - 16:45	1,233	89	442	11,588	7,084	74	122	114	12,440	50,040	83,225	243,646	138,781
16:45 - 17:00	422		119	2,244	2,511	84	30		4,348	18,146	27,904	245,816	143,927
17:00 - 17:15	1,666	107	172	14,555	9,971	218	247	5	15,851	64,171	106,965	246,955	149,999
17:15 - 17:30	325		59	2,325	2,135	28	33	21	5,111	17,172	21,207	245,302	149,529
17:30 - 17:45	1,118	149	71	7,738	6,772	180	267	26	12,220	42,815	71,357	233,434	142,304
17:45 - 18:00	344	24	27	1,080	2,019	25	25		4,963	14,401	22,909	228,439	138,560
18:00 - 18:15	1,103	64	50	6,606	7,071	257	221	43	14,895	44,995	75,304	196,778	119,384
18:15 - 18:30	359	46	6	635	1,686	68	25		5,501	12,778	21,104	190,675	114,989
18:30 - 18:45	586	68		3,275	4,089	245	164		13,130	33,213	54,770	174,089	105,387
18:45 - 19:00	208	25		420	1,515	57		58	5,758	13,090	21,132	172,311	104,076
19:00 - 19:15	668	24	19	3,289	6,781	268	65	79	17,201	40,337	68,730	165,737	99,418
19:15 - 19:30	93	23	6	589	1,579	21	51		4,711	10,940	18,006	162,638	97,579
19:30 - 19:45	754	43		1,656	4,535	21	68	45	12,056	27,483	46,667	154,535	91,849
19:45 - 20:00	129	23		237	1,196	86		22	3,383	8,325	13,401	146,804	87,084
20:00 - 20:15	594	21		2,181	4,351	197	88	49	11,221	27,441	46,143	124,217	74,188

Daily Distribution of Trips in the National Capital Region by Mode

Time	Bicycle	Motor-cycle	School Bus	Transit	Walk	Taxi	Other	Not Stated	Auto Pass'r	Auto Driver	Total Trips	Hourly Trips	
												Total	Auto Driver
20:15 - 20:30	109			153	814	20			2,959	7,284	11,339	117,550	70,533
20:30 - 20:45	126	25		1,347	2,714	58	41	20	9,458	18,993	32,781	103,665	62,043
20:45 - 21:00	74			221	921			38	2,680	6,232	10,166	100,430	59,950
21:00 - 21:15	322		19	2,470	4,099	381	69	72	11,103	24,286	42,821	97,108	56,795
21:15 - 21:30	23			473	601			5	3,337	7,063	11,502	97,271	56,574
21:30 - 21:45	107	72		1,421	2,049	255	28		6,962	16,698	27,592	92,081	54,279
21:45 - 22:00	25			351	512	21			2,103	4,943	7,956	89,871	52,990
22:00 - 22:15	255	44		1,590	2,739	145	26	19	7,915	18,113	30,846	77,895	46,817
22:15 - 22:30	173			198	495	40			1,958	4,671	7,362	73,755	44,425
22:30 - 22:45	66	20		793	1,479	146		19	4,694	10,367	17,672	63,836	38,093
22:45 - 23:00	185	27	23	136	279	126			959	3,033	4,493	60,373	36,183
23:00 - 23:15	24			901	1,555	41	21		4,906	11,255	18,999	48,527	29,325
23:15 - 23:30	43			153	323	21			733	2,432	3,706	44,870	27,086
23:30 - 23:45				490	686	124	43		2,989	6,768	11,143	38,341	23,488
23:45 - 0:00	122		5	49	225	40			1,121	1,868	3,304	37,152	22,323
0:00 - 0:15				375	1,349	116			2,814	6,781	11,561	29,714	17,849
0:15 - 0:30	65	23		88	70				346	1,192	1,631	27,639	16,609
0:30 - 0:45					200	41	21		1,015	2,849	4,279	20,775	12,690
0:45 - 1:00	90	23		91	67	40			270	585	985	18,456	11,406
1:00 - 1:15		61			630	397	21	20	1,560	2,713	5,581	12,476	7,339
1:15 - 1:30	21				93	21			166	473	752	11,597	6,620
1:30 - 1:45	44				353	143			848	1,877	3,242	10,560	5,648
1:45 - 2:00		4			216	162		17	174	415	589	10,165	5,478
2:00 - 2:15				40	21				860	1,766	3,108	7,692	4,531
2:15 - 2:30					87	68			116	259	396	7,336	4,317
2:30 - 2:45					65				287	675	1,117	5,210	3,116
2:45 - 3:00	21	21		23	90	151			28	154	246	4,868	2,854
3:00 - 3:15					65				421	571	1,299	3,059	1,660
3:15 - 3:30					65				87	49	201	2,863	1,450
3:30 - 3:45	21				103	59			116	397	674	2,421	1,172
3:45 - 4:00					99	42			21	339	522	2,696	1,357
4:00 - 4:15									22		22	1,419	
TOTAL	34,369	2,301	73,512	260,054	293,086	10,150	5,723	2,102	410,664	1,436,074	2,528,035

Summary of Travel in Each Analysis Period

Time Period	Number of Hours	Vehicle-Kilometers Travelled	% of Daily Travel
Early Morning	3.0	879,400	6.4
AM Peak Period	2.5	2,955,306	21.3
Midday	6.0	3,170,481	22.9
PM Peak Period	2.5	3,382,783	24.4
Evening	10.0	3,457,001	25.0
Total	24.0	13,844,971	100.0

* excludes external trips

Daily Distribution of Travel - Auto Drivers

Time	Veh-Km Travelled	Veh-Min Travelled	No. of Trips	Sample Size	Time	Veh-Km Travelled	Veh-Min Travelled	No. of Trips	Sample Size
0:00 - 0:15	70,253	72,653	6,405	366	12:15 - 12:30	54,259	60,336	7,459	444
0:15 - 0:30	10,958	11,433	1,103	66	12:30 - 12:45	158,613	175,409	19,493	1164
0:30 - 0:45	29,228	30,752	2,677	151	12:45 - 13:00	65,676	74,458	9,794	558
0:45 - 1:00	5,324	5,754	562	29	13:00 - 13:15	246,334	269,739	29,333	1758
1:00 - 1:15	28,977	29,841	2,547	162	13:15 - 13:30	45,287	52,100	6,564	380
1:15 - 1:30	3,596	3,858	401	24	13:30 - 13:45	151,704	166,920	17,877	1051
1:30 - 1:45	19,968	20,974	1,856	101	13:45 - 14:00	44,898	49,808	5,779	337
1:45 - 2:00	4,979	5,077	415	21	14:00 - 14:15	246,942	264,965	27,111	1600
2:00 - 2:15	18,054	19,111	1,671	89	14:15 - 14:30	43,489	48,769	5,428	326
2:15 - 2:30	1,815	1,926	175	11	14:30 - 14:45	189,544	204,326	20,516	1231
2:30 - 2:45	7,455	7,425	594	32	14:45 - 15:00	58,039	63,168	7,095	415
2:45 - 3:00	1,669	1,556	154	7	15:00 - 15:15	336,522	358,818	35,388	2102
3:00 - 3:15	8,811	8,560	520	29	15:15 - 15:30	93,178	99,676	11,289	661
3:15 - 3:30	339	380	49	3	15:30 - 15:45	386,203	519,060	36,624	2199
3:30 - 3:45	4,147	4,267	375	25	15:45 - 16:00	106,768	148,153	12,839	761
3:45 - 4:00	4,278	4,135	334	23	16:00 - 16:15	625,472	849,374	56,306	3494
4:00 - 4:15	26,425	26,987	2,157	138	16:15 - 16:30	163,241	222,812	17,424	1050
4:15 - 4:30	2,635	2,848	247	16	16:30 - 16:45	548,608	751,590	48,626	3013
4:30 - 4:45	13,571	12,579	691	48	16:45 - 17:00	152,099	209,795	17,871	1066
4:45 - 5:00	3,167	2,972	210	13	17:00 - 17:15	697,460	946,003	62,259	3789
5:00 - 5:15	28,351	27,826	1,729	129	17:15 - 17:30	149,338	202,219	16,875	1024
5:15 - 5:30	11,409	11,470	708	51	17:30 - 17:45	436,739	591,358	41,583	2532
5:30 - 5:45	55,546	55,163	3,570	244	17:45 - 18:00	116,855	157,705	14,059	842
5:45 - 6:00	34,437	31,830	1,762	128	18:00 - 18:15	458,021	472,070	43,271	2579
6:00 - 6:15	158,705	152,919	8,968	617	18:15 - 18:30	107,774	112,794	12,472	725
6:15 - 6:30	91,079	89,973	5,519	359	18:30 - 18:45	316,546	329,543	32,148	1899
6:30 - 6:45	289,174	281,404	17,545	1193	18:45 - 19:00	102,311	111,351	12,867	746
6:45 - 7:00	164,900	164,598	11,117	704	19:00 - 19:15	339,231	360,404	38,641	2200
7:00 - 7:15	497,992	617,947	33,306	2199	19:15 - 19:30	76,216	82,958	10,790	612
7:15 - 7:30	217,168	276,406	17,024	1101	19:30 - 19:45	227,279	240,000	26,802	1530
7:30 - 7:45	551,766	704,870	43,147	2642	19:45 - 20:00	56,324	61,246	8,178	475
7:45 - 8:00	230,209	304,447	22,483	1311	20:00 - 20:15	228,838	242,491	26,076	1510
8:00 - 8:15	532,835	695,199	49,456	2962	20:15 - 20:30	52,386	56,505	7,092	415
8:15 - 8:30	168,241	224,828	19,968	1149	20:30 - 20:45	166,308	176,629	18,441	1076
8:30 - 8:45	335,743	441,393	34,330	1990	20:45 - 21:00	45,110	49,552	6,091	340
8:45 - 9:00	100,178	136,266	13,862	763	21:00 - 21:15	219,722	230,614	23,433	1355
9:00 - 9:15	266,940	338,236	26,856	1581	21:15 - 21:30	61,607	65,139	6,865	392
9:15 - 9:30	54,233	69,734	6,239	352	21:30 - 21:45	159,531	165,256	15,966	927
9:30 - 9:45	161,999	172,839	16,999	995	21:45 - 22:00	46,458	47,774	4,816	274
9:45 - 10:00	35,960	40,706	4,811	273	22:00 - 22:15	181,028	189,406	17,376	997
10:00 - 10:15	253,552	272,991	27,504	1653	22:15 - 22:30	43,360	46,274	4,534	247
10:15 - 10:30	40,417	46,072	6,140	351	22:30 - 22:45	104,767	107,949	9,823	570
10:30 - 10:45	147,548	161,881	17,919	1061	22:45 - 23:00	26,930	28,748	3,006	169
10:45 - 11:00	36,759	42,531	5,730	314	23:00 - 23:15	109,364	114,791	10,636	599
11:00 - 11:15	220,147	238,484	25,834	1524	23:15 - 23:30	19,417	21,024	2,391	127
11:15 - 11:30	47,345	54,094	7,086	404	23:30 - 23:45	72,218	74,835	6,423	378
11:30 - 11:45	150,786	167,331	19,379	1148	23:45 - 0:00	16,406	17,106	1,812	102
11:45 - 12:00	55,757	64,449	8,197	468					
12:00 - 12:15	285,726	312,606	33,804	2011					
					TOTAL	13,844,971	16,362,602	1,391,676	83072

* excludes external trips; trips with no origin/destination zone

Travel Summary Based on Trips in 1995 OD Survey

Time Period	Description	Trips Included in Summary			Intra-zonal Trips Only No External Trips*
		All Trips	No External Trips*	No Intra-zonal Trips	
Early Morning Period	Fraction of travel in rep. hour:	0.39	0.39	0.39	0.31
	VKT in analysis period:	1,008,418	879400	866617	12783
	VKT in representative hour:	391,377	339767	335805	3962
AM Peak Period	Fraction of travel in rep. hour:	0.38	0.38	0.38	0.48
	VKT in analysis period:	3260424	2955306	2879284	76022
	VKT in representative hour:	1247938	1136998	1100253	36745
Midday Period	Fraction of travel in rep. hour:	0.16	0.16	0.16	0.15
	VKT in analysis period:	3732290	3170481	3030487	139993
	VKT in representative hour:	615119	515909	495157	20753
PM Peak Period	Fraction of travel in rep. hour:	0.42	0.42	0.42	0.43
	VKT in analysis period:	3786238	3382783	3280917	101866
	VKT in representative hour:	1606032	1435636	1391457	44179
Evening Period	Fraction of travel in rep. hour:	0.14	0.14	0.14	0.18
	VKT in analysis period:	3929258	3457001	3308037	148964
	VKT in representative hour:	565718	492640	466374	26267

* Also excludes trips with incomplete origin/destination data

Number of Trips in the National Capital Region by Trip Duration

Duration (min.)	AM Peak Period	PM Peak Period	AM Peak Hour	PM Peak Hour	Early Morning	Midday Period	Evening Period	Total Trips
0	4,346	5,936	2,396	2,829	717	9,425	9,400	29,824
1	9,789	13,578	4,930	5,980	698	22,708	21,218	67,990
2	13,659	18,353	6,181	7,779	2,041	34,161	27,490	95,704
3	11,812	15,326	5,790	6,383	1,593	31,248	30,075	90,052
4	12,328	19,987	5,963	8,332	1,727	33,225	31,676	98,943
5	12,274	17,032	5,538	6,576	1,724	25,637	22,657	79,323
6	11,914	15,813	6,148	7,252	2,020	24,718	22,494	76,959
7	11,302	14,701	5,576	6,818	2,698	23,806	23,250	75,757
8	12,087	13,728	6,471	6,102	2,167	22,524	21,615	72,121
9	11,297	12,826	6,000	5,897	2,089	17,635	18,308	62,155
10	9,915	12,406	5,431	5,207	2,577	16,965	15,576	57,439
11	11,100	11,713	5,516	5,715	2,406	14,683	15,449	55,352
12	10,533	10,942	5,507	5,334	2,302	14,978	14,660	53,415
13	9,818	11,012	5,373	5,431	2,623	10,840	12,966	47,259
14	8,841	10,331	4,739	4,905	2,443	10,572	10,161	42,349
15	9,266	9,974	4,874	4,225	2,174	8,613	10,184	40,210
16	8,251	8,697	4,279	4,013	1,839	7,148	7,670	33,605
17	8,286	8,303	4,105	3,740	1,475	6,492	6,122	30,677
18	7,864	7,849	4,042	3,831	1,199	4,631	5,726	27,268
19	6,128	7,068	3,158	3,480	1,523	4,509	4,678	23,906
20	6,616	6,651	3,737	2,876	1,607	4,484	4,923	24,281
21	4,951	5,137	2,639	2,384	1,117	2,758	3,751	17,714
22	4,990	4,866	2,584	2,128	1,205	3,505	3,477	18,043
23	5,238	5,964	2,598	3,081	1,223	2,869	3,210	18,505
24	4,482	4,104	2,290	2,094	1,095	2,030	2,946	14,657
25	3,459	4,645	1,865	2,211	1,176	1,893	2,588	13,761
26	3,894	3,937	1,711	1,657	958	1,890	2,199	12,877
27	3,218	3,479	1,530	1,460	876	1,186	1,899	10,657
28	2,767	3,488	1,423	1,567	431	1,527	1,758	9,971
29	2,975	3,285	1,332	1,649	726	1,345	1,586	9,917
30	2,378	3,106	1,134	1,305	658	1,173	1,483	8,799
31	2,602	2,429	1,255	1,139	570	971	1,227	7,799
32	1,724	2,545	814	1,395	610	1,128	1,106	7,113
33	2,044	2,384	1,049	1,052	481	702	1,090	6,701
34	1,812	2,614	817	1,259	443	847	978	6,693
35	1,585	2,168	783	979	460	522	726	5,461
36	1,617	1,667	798	815	292	523	532	4,631
37	942	1,838	426	842	311	302	475	3,869
38	1,126	1,787	675	790	433	397	270	4,013
39	789	1,326	400	647	318	252	304	2,989
40	909	1,231	373	535	263	326	359	3,088
41	767	1,348	410	577	148	191	147	2,601
42	617	1,211	281	518	79	101	166	2,174
43	981	775	513	301	120	327	233	2,437
44	602	926	326	414	94	152	111	1,886
45	287	910	145	377	55	92	220	1,564
46	316	620	144	317	85	82	169	1,273
47	219	544	110	194	93	15	55	926
48	264	446	103	289	74	118	60	963
49	252	336	132	220	42	45	56	731
50	91	245	39	127	13	51	42	441
51	158	424	144	193	35	4	28	650
52	88	231	40	102	0	4	42	366
53	200	127	60	69	8	19	16	369
54	208	85	89	31	21	31	27	372
55	96	227	35	151	8	66	50	446
56	170	171	90	91	15	27	23	406
57	100	188	58	69	21	0	15	325
58	36	139	15	99	8	12	20	214
59	20	78	5	35	4	21	0	123
>60	276	1,212	87	586	13	17	45	1,563
TOTAL	266,676	324,466	135,078	146,459	54,223	376,523	369,788	1,391,676

* Based on data from the 1995 OD Survey

* Excludes external trips and trips with incorrect origin/destination data

Number of Trips in the National Capital Region By Trip Length

Distance (km)	AM Peak Period	PM Peak Period	AM Peak Hour	PM Peak Hour	Early Morning	Midday Period	Evening Period	Total Trips
0	7,853	10,693	4,125	5,123	853	14,997	14,065	48,460
1	20,643	29,868	9,838	12,388	2,213	47,784	40,200	140,709
2	22,625	32,042	10,770	13,323	2,540	48,671	46,219	152,097
3	17,950	25,172	9,033	10,821	2,039	35,305	29,889	110,355
4	16,283	21,337	8,180	9,268	2,095	28,887	27,068	95,670
5	16,239	20,125	8,517	9,247	2,560	24,815	24,304	88,043
6	13,511	16,145	7,000	7,738	1,832	20,718	17,873	70,079
7	13,326	15,265	7,128	6,999	1,986	14,190	14,499	59,266
8	12,358	14,457	6,621	7,129	2,262	17,500	16,549	63,126
9	11,635	13,759	6,064	6,249	2,348	12,696	13,615	54,053
10	11,909	13,484	6,404	6,069	2,348	14,971	13,809	56,520
11	10,955	11,526	6,053	5,547	2,579	12,207	13,697	50,964
12	9,905	11,988	4,863	5,593	1,952	10,962	10,502	45,308
13	8,363	9,362	4,418	4,406	1,739	7,977	9,333	36,773
14	7,417	7,028	3,812	3,529	1,298	7,297	7,969	31,010
15	7,016	7,399	3,595	3,190	1,664	5,502	6,443	28,023
16	6,621	6,461	3,465	3,086	1,707	6,243	7,697	28,728
17	4,672	5,339	2,439	2,403	1,165	4,901	4,590	20,667
18	4,245	4,097	2,009	1,922	1,488	4,411	5,188	19,429
19	3,990	4,038	1,713	1,828	1,018	3,416	4,460	16,922
20	3,140	3,952	1,657	1,699	1,182	3,105	3,746	15,125
21	2,880	3,478	1,520	1,471	949	1,855	3,004	12,165
22	4,026	3,458	1,915	1,739	1,128	2,864	3,325	14,801
23	2,388	3,059	1,214	1,542	1,004	2,159	2,477	11,087
24	2,336	1,973	1,006	1,075	933	2,092	2,782	10,116
25	1,256	1,593	550	731	558	1,137	2,017	6,562
26	1,701	2,122	828	959	716	1,602	1,947	8,088
27	1,706	1,595	774	751	605	1,225	1,447	6,579
28	1,339	2,080	626	843	582	1,550	1,648	7,200
29	1,482	1,956	619	892	639	1,812	2,131	8,020
30	1,723	1,926	785	802	745	1,311	1,921	7,627
31	1,477	1,864	744	874	709	1,470	2,121	7,641
32	1,536	2,219	792	1,048	672	1,165	1,757	7,350
33	1,481	1,773	773	691	527	1,396	1,271	6,447
34	770	833	387	360	393	419	808	3,222
35	956	1,036	485	447	493	698	874	4,057
36	674	870	349	451	364	425	674	3,008
37	1,408	1,289	679	590	459	933	958	5,047
38	789	841	416	359	201	751	761	3,344
39	578	598	319	256	323	539	688	2,727
40	386	601	255	312	259	375	462	2,084
41	406	350	209	144	389	547	560	2,253
42	652	525	274	242	205	554	621	2,557
43	649	730	328	331	192	445	508	2,525
44	336	485	153	213	412	291	322	1,846
45	297	485	129	200	205	280	365	1,632
46	418	358	165	180	178	404	526	1,884
47	365	499	212	274	264	216	199	1,543
48	247	262	112	71	172	168	138	986
49	192	261	67	106	51	133	205	842
50	410	264	183	103	235	122	311	1,341
51	134	138	59	55	102	149	164	687
52	145	321	65	149	108	132	179	886
53	204	191	111	135	116	116	198	825
54	136	233	55	136	90	122	121	702
55	48	143	10	96	23	99	66	380
56	99	111	47	50	91	13	66	380
57	133	132	53	64	45	115	51	476
58	31	37	0	21	44	30	83	224
59	36	14	26	5	21	0	45	116
>60	190	225	77	134	152	253	271	1,091
TOTAL	266,676	324,466	135,078	146,459	54,223	376,523	369,788	1,391,676

* Based on data from the 1995 OD Survey

* Excludes external trips and trips with incorrect origin/destination data

APPENDIX C

TRAFFIC ZONES

Traffic Zones in the National Capital Region

Traffic Zone	Land Classification	Province	Description	Traffic Zone	Land Classification	Province	Description
1	Core	ON	Ottawa Inner Area	130	Suburban	ON	Kanata
2	Core	ON	Ottawa Inner Area	131	Suburban	ON	Kanata
3	Core	ON	Ottawa Inner Area	132	Rural	ON	Rural Ontario (West)
4	Core	ON	Ottawa Inner Area	133	Rural	ON	Rural Ontario (West)
5	Core	ON	Ottawa Inner Area	134	Rural	ON	Rural Ontario (West)
6	Core	ON	Ottawa Inner Area	135	Rural	ON	Rural Ontario (West)
7	Core	ON	Ottawa Inner Area	136	Suburban	ON	SUC - Nepean
8	Core	ON	Ottawa Inner Area	137	Rural	ON	Rural Ontario (West)
9	Core	ON	Ottawa Inner Area	138	Rural	ON	Rural Ontario (West)
10	Core	ON	Ottawa Inner Area	139	Rural	ON	Rural Ontario (East)
11	Core	ON	Ottawa Inner Area	140	Suburban	ON	SUC - Gloucester
12	Core	ON	Ottawa Inner Area	141	Rural	ON	Rural Ontario (East)
13	Core	ON	Ottawa Inner Area	142	Suburban	ON	Orleans
14	Core	ON	Ottawa Inner Area	143	Suburban	ON	Orleans
15	Core	ON	Ottawa Inner Area	144	Suburban	ON	Orleans
16	Core	ON	Ottawa Inner Area	145	Rural	ON	Rural Ontario (East)
17	Core	ON	Ottawa Inner Area	146	Rural	QU	Rural Quebec (West)
18	Core	ON	Ottawa Inner Area	147	Rural	QU	Rural Quebec (West)
19	Core	ON	Ottawa Inner Area	148	Urban	QU	Aylmer
20	Core	ON	Ottawa Inner Area	149	Urban	QU	Aylmer
21	Core	ON	Ottawa Inner Area	150	Urban	QU	Aylmer
22	Core	ON	Ottawa Inner Area	151	Urban	QU	Aylmer
23	Core	ON	Ottawa Inner Area	152	Urban	QU	Aylmer
24	Core	ON	Ottawa Inner Area	153	Core	QU	Hull Inner Area
25	Core	ON	Ottawa Inner Area	154	Core	QU	Hull Inner Area
26	Urban	ON	Ottawa West - South	155	Core	QU	Hull Inner Area
27	Urban	ON	Ottawa West - South	156	Urban	QU	Hull
28	Urban	ON	Ottawa West - South	157	Urban	QU	Hull
29	Urban	ON	Ottawa West - South	158	Urban	QU	Hull
30	Urban	ON	Ottawa West - South	159	Urban	QU	Hull
31	Urban	ON	Ottawa West - South	160	Urban	QU	Hull
32	Urban	ON	Ottawa West - South	161	Urban	QU	Hull
33	Urban	ON	Ottawa West - North	162	Urban	QU	Hull
34	Urban	ON	Ottawa West - North	163	Urban	QU	Aylmer
35	Urban	ON	Ottawa West - North	164	Urban	QU	Hull
36	Urban	ON	Ottawa West - North	165	Urban	QU	West Gatineau
37	Urban	ON	Ottawa West - North	166	Urban	QU	West Gatineau
38	Urban	ON	Ottawa West - North	167	Urban	QU	West Gatineau
39	Urban	ON	Ottawa West - North	168	Urban	QU	West Gatineau
40	Urban	ON	Ottawa West - North	169	Urban	QU	West Gatineau
41	Urban	ON	Ottawa West - North	170	Urban	QU	West Gatineau
42	Urban	ON	Ottawa West - North	171	Suburban	QU	East Gatineau
43	Urban	ON	Ottawa West - North	172	Suburban	QU	East Gatineau
44	Urban	ON	Ottawa West - North	173	Suburban	QU	East Gatineau
45	Urban	ON	Ottawa West - North	174	Suburban	QU	East Gatineau
46	Urban	ON	Ottawa West - North	175	Suburban	QU	East Gatineau
47	Urban	ON	Ottawa West - North	176	Suburban	QU	East Gatineau
48	Urban	ON	Ottawa West - North	177	Rural	QU	Rural Quebec (East)
49	Urban	ON	Ottawa West - North	178	Suburban	QU	East Gatineau
50	Urban	ON	Ottawa West - North	179	Rural	QU	Rural Quebec (East)
51	Urban	ON	Ottawa West - South	180	Rural	QU	Rural Quebec (East)
52	Urban	ON	Ottawa West - South	181	Rural	QU	Rural Quebec (East)
53	Urban	ON	Ottawa West - South	182	Rural	QU	Rural Quebec (West)
54	Urban	ON	Ottawa West - South	183	Rural	QU	Rural Quebec (West)
55	Urban	ON	Ottawa West - South	184	Rural	QU	Rural Quebec (West)
56	Urban	ON	Ottawa West - North	185	Rural	QU	Rural Quebec (East)
57	Urban	ON	Ottawa West - South	186	Rural	QU	External Zone
58	Urban	ON	Ottawa West - South	187	Rural	QU	External Zone
59	Urban	ON	Ottawa West - South	188	Rural	QU	External Zone
60	Urban	ON	Ottawa West - South	189	Rural	QU	External Zone
61	Urban	ON	Ottawa West - South	190	Rural	ON	External Zone
62	Urban	ON	Ottawa West - South	191	Rural	ON	External Zone
63	Urban	ON	Ottawa West - South	192	Rural	ON	External Zone
64	Urban	ON	Ottawa West - South	193	Rural	ON	External Zone
65	Urban	ON	Ottawa West - South	194	Rural	ON	External Zone
66	Urban	ON	Ottawa West - South	195	Rural	ON	External Zone
67	Urban	ON	Ottawa West - South	196	Rural	ON	External Zone
68	Urban	ON	Ottawa South	197	Rural	ON	External Zone
69	Urban	ON	Ottawa South	198	Rural	ON	External Zone

Traffic Zone	Land Classification	Province	Description
70	Urban	ON	Ottawa South
71	Urban	ON	Ottawa South
72	Urban	ON	Ottawa South
73	Urban	ON	Ottawa South
74	Urban	ON	Ottawa South
75	Urban	ON	Ottawa South
76	Urban	ON	Ottawa South
77	Urban	ON	Ottawa South
78	Urban	ON	Ottawa South
79	Urban	ON	Ottawa South
80	Urban	ON	Ottawa South
81	Urban	ON	Ottawa South
82	Urban	ON	Ottawa South
83	Urban	ON	Ottawa South
84	Urban	ON	Ottawa South
85	Urban	ON	Ottawa South
86	Urban	ON	Ottawa South
87	Urban	ON	Ottawa South
88	Urban	ON	Ottawa South
89	Urban	ON	Ottawa South
90	Urban	ON	Ottawa East
91	Urban	ON	Ottawa East
92	Urban	ON	Ottawa East
93	Urban	ON	Ottawa East
94	Urban	ON	Ottawa East
95	Urban	ON	Ottawa East
96	Urban	ON	Ottawa East
97	Urban	ON	Ottawa East
98	Urban	ON	Ottawa East
99	Urban	ON	Ottawa East
100	Urban	ON	Ottawa East
101	Urban	ON	Ottawa East
102	Urban	ON	Ottawa East
103	Urban	ON	Ottawa East
104	Urban	ON	Ottawa East
105	Urban	ON	Ottawa East
106	Urban	ON	Ottawa East
107	Urban	ON	Ottawa East
108	Urban	ON	Ottawa East
109	Urban	ON	Ottawa East
110	Urban	ON	Ottawa East
111	Urban	ON	Ottawa South
112	Urban	ON	Ottawa South
113	Urban	ON	Ottawa South
114	Urban	ON	Ottawa South
115	Urban	ON	Ottawa South
116	Urban	ON	Ottawa South
117	Urban	ON	Ottawa South
118	Urban	ON	Ottawa South
119	Suburban	ON	Ottawa South
120	Urban	ON	Ottawa West - South
121	Urban	ON	Ottawa West - South
122	Urban	ON	Ottawa West - South
123	Urban	ON	Ottawa West - South
124	Urban	ON	Ottawa West - South
125	Urban	ON	Ottawa West - South
126	Urban	ON	Ottawa West - North
127	Urban	ON	Ottawa West - North
128	Urban	ON	Ottawa West - South
129	Suburban	ON	Kanata

Traffic Zone	Land Classification	Province	Description
199	Rural	ON	External Zone
200	Rural	ON	External Zone
201	Core	ON	Ottawa Inner Area
202	Suburban	ON	Orleans
203	Suburban	ON	Orleans
204	Suburban	ON	Orleans
205	Suburban	ON	Ottawa South
206	Suburban	ON	Kanata
207	Suburban	ON	Kanata
208	Suburban	ON	Kanata
209	Suburban	ON	Kanata
210	Suburban	ON	Kanata
211	Suburban	ON	Kanata
212	Suburban	ON	Kanata
213	Suburban	ON	Kanata
214	Suburban	ON	Kanata
215	Suburban	ON	Kanata
216	Suburban	ON	Stitsville
217	Suburban	ON	Stitsville
218	Suburban	ON	Stitsville
219	Suburban	ON	Stitsville
220	Suburban	ON	Kanata
221	Suburban	ON	SUC - Nepean
222	Suburban	ON	SUC - Nepean
223	Suburban	ON	SUC - Nepean
224	Suburban	ON	SUC - Nepean
225	Suburban	ON	SUC - Nepean
226	Suburban	ON	SUC - Nepean
227	Rural	ON	SUC - Gloucester
228	Rural	ON	SUC - Gloucester
229	Suburban	ON	SUC - Gloucester
230	Rural	ON	SUC - Gloucester
231	Suburban	ON	SUC - Gloucester
232	Urban	ON	Ottawa South
233	Urban	ON	Ottawa South
234	Urban	ON	Ottawa East
235	Suburban	ON	Orleans
236	Suburban	ON	Orleans
237	Suburban	ON	Orleans
238	Suburban	ON	Orleans
239	Suburban	ON	Orleans
240	Suburban	ON	Orleans
241	Suburban	ON	Orleans
242	Suburban	ON	Orleans
243	Suburban	ON	Orleans
244	Suburban	ON	Orleans
245	Suburban	ON	Orleans
246	Suburban	ON	Orleans
247	Suburban	ON	Orleans
248	Suburban	QU	East Gatineau
249	Suburban	QU	East Gatineau
250	Suburban	QU	East Gatineau
251	Suburban	QU	East Gatineau
252	Urban	QU	West Gatineau
253	Urban	QU	West Gatineau
254	Core	QU	Hull Inner Area
255	Core	QU	Hull Inner Area
256	Urban	QU	Aylmer
257	Urban	QU	Aylmer
258	Urban	QU	Aylmer

SUC = South Urban Community

APPENDIX D

VEHICLE MIX

Ratio of Taxis to Passenger Vehicles (x100)
AM Peak Period (7:00 am - 9:30 am)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	4.7	0.45	4.4	3.8	5.6	0.4	15.1	3.11	4.5	47
Urban	Arterials, Collectors	1.4	0.21	1.1	1.0	1.8	0.0	14.5	1.91	1.1	83
Suburban	Arterials, Collectors	0.3	0.05	0.3	0.2	0.4	0.0	1.1	0.30	0.2	36
Rural	Arterials, Collectors	0.1	0.02	0.0	0.0	0.1	0.0	0.4	0.09	0.0	26
N/A	Freeways and Rural Highways	0.3	0.07	0.3	0.1	0.4	0.0	0.9	0.28	0.2	15

Ratio of Taxis to Passenger Vehicles (x100)
PM Peak Period (3:30 pm - 6:00 pm)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	4.2	0.39	4.0	3.4	5.0	0.5	13.0	2.66	3.6	47
Urban	Arterials, Collectors	1.3	0.27	1.9	0.8	1.9	0.0	20.3	2.48	0.9	83
Suburban	Arterials, Collectors	0.3	0.05	0.3	0.2	0.4	0.0	1.2	0.29	0.2	36
Rural	Arterials, Collectors	0.4	0.32	0.1	0.0	1.1	0.0	8.3	1.62	0.0	26
N/A	Freeways and Rural Highways	0.3	0.07	0.3	0.2	0.4	0.0	1.0	0.26	0.2	15

Ratio of Taxis to Passenger Vehicles (x100)
Midday Period

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	5.7	0.52	5.5	4.7	6.8	0.7	15.8	3.57	4.7	47
Urban	Arterials, Collectors	1.7	0.27	1.2	1.1	2.2	0.0	19.7	2.50	1.2	83
Suburban	Arterials, Collectors	0.3	0.04	0.3	0.2	0.4	0.0	0.8	0.22	0.3	36
Rural	Arterials, Collectors	0.1	0.03	0.1	0.0	0.1	0.0	0.4	0.14	0.0	26
N/A	Freeways and Rural Highways	0.4	0.08	0.4	0.2	0.6	0.1	1.2	0.32	0.3	15

Ratio of School, Tourist, and Intercity Buses to Passenger Vehicles (x100)
AM Peak Period (7:00 am - 9:30 am)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	1.7	0.41	1.2	0.8	2.5	0.0	15.1	2.83	0.7	47
Urban	Arterials, Collectors	0.8	0.09	0.7	0.6	1.0	0.0	4.1	0.83	0.5	83
Suburban	Arterials, Collectors	1.2	0.18	1.1	0.8	1.6	0.0	4.3	1.11	0.9	36
Rural	Arterials, Collectors	2.0	0.74	1.4	0.5	3.5	0.0	16.7	3.78	0.8	26
N/A	Freeways and Rural Highways	0.6	0.10	0.6	0.4	0.8	0.2	1.7	0.38	0.6	15

Ratio of School, Tourist, and Intercity Buses to Passenger Vehicles (x100)
PM Peak Period (3:30 pm - 6:00 pm)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	1.1	0.20	0.9	0.7	1.5	0.0	7.1	1.35	0.7	47
Urban	Arterials, Collectors	0.5	0.06	0.5	0.4	0.6	0.0	2.6	0.53	0.4	83
Suburban	Arterials, Collectors	0.5	0.08	0.5	0.4	0.7	0.0	1.6	0.47	0.5	36
Rural	Arterials, Collectors	1.2	0.45	0.9	0.3	2.1	0.0	9.0	2.30	0.4	26
N/A	Freeways and Rural Highways	0.6	0.07	0.5	0.4	0.7	0.2	1.2	0.27	0.5	15

Ratio of School, Tourist, and Intercity Buses to Passenger Vehicles (x100)
Midday Period

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	0.9	0.15	0.8	0.6	1.2	0.0	4.6	1.02	0.7	47
Urban	Arterials, Collectors	0.6	0.07	0.5	0.4	0.7	0.0	3.9	0.67	0.4	83
Suburban	Arterials, Collectors	0.7	0.11	0.6	0.5	0.9	0.0	2.7	0.65	0.5	36
Rural	Arterials, Collectors	1.1	0.33	0.9	0.4	1.8	0.0	6.9	1.68	0.5	26
N/A	Freeways and Rural Highways	0.5	0.08	0.5	0.4	0.7	0.2	1.2	0.31	0.5	15

Ratio of Light Trucks to Passenger Vehicles (x100)
AM Peak Period (7:00 am - 9:30 am)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	24.3	0.56	24.2	23.2	25.4	17.8	34.4	3.81	24.3	47
Urban	Arterials, Collectors	26.0	0.64	25.6	24.8	27.3	14.9	51.6	5.83	24.9	83
Suburban	Arterials, Collectors	31.6	1.07	31.3	29.4	33.8	22.5	46.8	6.44	31.3	36
Rural	Arterials, Collectors	37.7	1.14	37.6	35.4	40.1	28.3	48.7	5.80	36.6	26
N/A	Freeways and Rural Highways	28.8	1.88	28.6	25.9	31.6	21.2	38.3	5.16	28.4	15

Ratio of Light Trucks to Passenger Vehicles (x100)
PM Peak Period (3:30 pm - 6:00 pm)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	22.0	0.49	21.8	21.0	23.0	15.7	33.7	3.35	21.7	47
Urban	Arterials, Collectors	24.0	0.45	23.6	23.1	24.8	17.6	39.7	4.08	23.3	83
Suburban	Arterials, Collectors	30.5	0.94	30.4	28.6	32.4	21.1	42.6	5.64	29.3	36
Rural	Arterials, Collectors	38.9	1.18	38.9	36.5	41.3	28.6	50.0	6.00	38.6	26
N/A	Freeways and Rural Highways	27.9	1.34	27.7	25.0	30.8	22.0	37.8	5.17	27.1	15

Ratio of Light Trucks to Passenger Vehicles (x100)
Midday Period

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	23.7	0.72	23.7	22.2	25.1	15.2	31.4	4.91	24.1	47
Urban	Arterials, Collectors	27.4	0.64	26.9	26.1	28.7	17.2	52.4	5.85	26.4	83
Suburban	Arterials, Collectors	33.3	0.99	33.1	31.3	35.4	23.6	47.7	5.94	32.3	36
Rural	Arterials, Collectors	42.3	1.85	41.8	38.5	46.1	29.9	62.1	9.41	39.7	26
N/A	Freeways and Rural Highways	32.4	1.40	32.2	29.4	35.4	26.2	43.0	5.41	30.9	15

Ratio of Heavy Trucks to Passenger Vehicles (x100)
AM Peak Period (7:00 am - 9:30 am)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	3.1	0.44	2.8	2.3	4.0	0.1	14.2	2.98	2.4	47
Urban	Arterials, Collectors	3.3	0.47	2.7	2.4	4.3	0.0	31.7	4.30	2.4	83
Suburban	Arterials, Collectors	4.9	0.70	4.4	3.4	6.3	0.4	18.7	4.18	3.3	36
Rural	Arterials, Collectors	10.8	2.43	9.5	5.7	15.8	0.0	46.9	12.41	6.3	26
N/A	Freeways and Rural Highways	5.7	0.56	5.6	4.5	6.9	3.2	9.9	2.16	5.5	15

Ratio of Heavy Trucks to Passenger Vehicles (x100)
PM Peak Period (3:30 pm - 6:00 pm)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	1.5	0.26	1.3	1.0	2.0	0.0	11.1	1.79	1.1	47
Urban	Arterials, Collectors	1.8	0.36	1.3	1.1	2.5	0.0	27.5	3.31	1.1	83
Suburban	Arterials, Collectors	2.4	0.33	2.2	1.7	3.1	0.3	9.2	2.00	1.8	36
Rural	Arterials, Collectors	7.5	1.35	7.0	4.7	10.2	1.5	22.4	6.87	5.1	26
N/A	Freeways and Rural Highways	3.9	0.43	3.9	3.0	4.9	1.5	6.6	1.65	3.5	15

Ratio of Heavy Trucks to Passenger Vehicles (x100)
Midday Period

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	2.5	0.34	2.3	1.9	3.2	0.0	10.5	2.36	1.9	47
Urban	Arterials, Collectors	3.5	0.44	3.0	2.6	4.4	0.0	31.0	4.05	3.0	83
Suburban	Arterials, Collectors	6.3	0.87	5.7	4.6	8.1	1.1	24.4	5.19	5.2	36
Rural	Arterials, Collectors	16.1	3.64	14.1	8.6	23.5	1.3	70.4	18.56	9.2	26
N/A	Freeways and Rural Highways	7.7	0.77	7.6	6.0	9.3	3.8	13.2	3.00	7.0	15

Ratio of "Other" Vehicles to Passenger Vehicles (x100)
AM Peak Period (7:00 am - 9:30 am)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	0.5	0.08	0.5	0.4	0.7	0.0	3.8	0.54	0.5	47
Urban	Arterials, Collectors	0.4	0.03	0.4	0.3	0.5	0.0	1.4	0.27	0.3	83
Suburban	Arterials, Collectors	0.5	0.04	0.5	0.4	0.6	0.0	1.1	0.26	0.4	36
Rural	Arterials, Collectors	0.8	0.25	0.6	0.3	1.4	0.0	6.7	1.28	0.5	26
N/A	Freeways and Rural Highways	0.3	0.02	0.3	0.2	0.3	0.2	0.4	0.08	0.3	15

Ratio of "Other" Vehicles to Passenger Vehicles (x100)
PM Peak Period (3:30 pm - 6:00 pm)

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	0.6	0.06	0.5	0.4	0.7	0.0	2.7	0.44	0.5	47
Urban	Arterials, Collectors	0.4	0.03	0.3	0.3	0.4	0.0	1.1	0.25	0.3	83
Suburban	Arterials, Collectors	0.5	0.07	0.5	0.4	0.7	0.0	2.0	0.42	0.5	36
Rural	Arterials, Collectors	0.6	0.08	0.5	0.4	0.7	0.0	1.7	0.42	0.5	26
N/A	Freeways and Rural Highways	0.3	0.05	0.3	0.2	0.4	0.1	0.7	0.19	0.2	15

Ratio of "Other" Vehicles to Passenger Vehicles (x100)
Midday Period

Area	Facility	Mean	Standard Error	5% Trimmed Mean	95% Confidence Interval		Minimum Value	Maximum Value	Standard Deviation	Median	Sample Size
					Lower	Upper					
Core	Arterials, Collectors	0.5	0.04	0.5	0.5	0.6	0.0	1.1	0.24	0.5	47
Urban	Arterials, Collectors	0.4	0.03	0.3	0.3	0.4	0.0	1.3	0.29	0.3	83
Suburban	Arterials, Collectors	0.4	0.05	0.4	0.3	0.5	0.0	1.2	0.30	0.4	36
Rural	Arterials, Collectors	1.0	0.32	0.7	0.3	1.7	0.0	7.5	1.65	0.5	26
N/A	Freeways and Rural Highways	0.4	0.06	0.4	0.3	0.5	0.1	0.8	0.22	0.3	15

Impact of Including "Background Traffic" in EMME/2 PM Peak Hour Traffic Assignment

Screenline	Observed Count	Model Without Background (1)		Model With Background (2)		Model With Background (3) (except on centroid connectors)		Comparison of Modelling Approaches				
		Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	(1) - (2)	(2) - (3)	(1) / (2)	(1) / (3)	(3) / (2)
Ottawa River (LN2,3,4)	10,180	10,824	1.06	10,823	1.06	10,824	1.06	1	1	1.000	1.000	1.000
Rideau River (LN19,20,32,33)	16,509	16,923	1.03	16,924	1.03	16,949	1.03	1	25	1.000	1.000	1.001
CPR (LN27, 28, 29)	11,236	11,152	0.99	11,152	0.99	11,154	0.99	0	2	1.000	1.000	1.000
Ottawa Central Area (LN35-38)	13,523	13,839	1.02	13,840	1.02	13,851	1.02	1	11	1.000	1.000	1.001
Rideau Canal (LN34, 39)	15,301	14,376	0.94	14,374	0.94	14,411	0.94	2	37	1.000	1.000	1.003
Fallowfield (LN9, 43)	5,551	6,221	1.12	6,225	1.12	6,207	1.12	4	18	0.999	0.999	0.997
Eagleson (LN10)	6,049	6,601	1.09	6,596	1.09	6,598	1.09	5	2	1.001	1.000	1.000
Green Creek (LN16)	6,607	7,445	1.13	7,443	1.13	7,474	1.13	2	31	1.000	1.000	1.004
CNR West / Acres (LN11,12)	12,678	13,493	1.06	13,506	1.07	13,481	1.06	13	25	0.999	0.999	0.998
CNR East (LN13,14,15)	10,595	9,961	0.94	9,955	0.94	9,911	0.94	6	44	1.001	0.996	0.996
Western Parkway (LN24,25)	12,339	13,459	1.09	13,457	1.09	13,425	1.09	2	32	1.000	0.999	0.998
Lelitim / Ramsayville (LN7,8)	4,669	5,133	1.10	5,136	1.10	5,117	1.10	3	19	0.999	0.999	0.996
Ile de Hull (LN60)	12,896	13,846	1.07	13,860	1.07	13,894	1.08	14	34	0.999	1.002	1.002
Boul. Gamelin (LN 61)	9,853	7,530	0.76	7,551	0.77	7,526	0.76	21	25	0.997	0.997	0.997
Ch. de la Montagne (LN62)	2,805	2,263	0.81	2,267	0.81	2,259	0.81	4	8	0.998	0.996	0.996
Deschenes (LN63)	2,959	2,423	0.82	2,420	0.82	2,377	0.80	3	43	1.001	0.982	0.982
Q64	2,425	2,324	0.96	2,318	0.96	2,315	0.95	6	3	1.003	0.999	0.999
Q65	8,370	9,455	1.13	9,454	1.13	9,455	1.13	1	1	1.000	1.000	1.000
Q66	1,953	1,738	0.89	1,738	0.89	1,733	0.89	0	5	1.000	0.997	0.997
Montee Palemont (LN67)	5,953	5,759	0.97	5,765	0.97	5,785	0.97	6	20	0.999	1.003	1.003
Q68	3,371	3,042	0.90	3,042	0.90	3,033	0.90	9	9	1.000	0.997	0.997
		Average		4.52		21		18.81				
		Maximum		44								

Screenline	Observed Count	Model Without Background (1)		Model With Background (2)		Model With Background (3) (except on centroid connectors)		Comparison of Modelling Approaches				
		Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	(1) - (2)	(2) - (3)	(1) / (2)	(1) / (3)	(3) / (2)
Ottawa River (LN2,3,4)	5,596	4,335	0.77	4,350	0.78	4,349	0.78	15	1	0.997	1.000	1.000
Rideau River (LN19,20,32,33)	14,774	14,464	0.98	14,469	0.98	14,474	0.98	5	5	1.000	1.000	1.000
CPR (LN27, 28, 29)	8,294	8,853	1.07	8,670	1.05	8,684	1.05	183	14	1.021	1.002	1.002
Ottawa Central Area (LN35-38)	10,338	7,292	0.71	6,944	0.67	6,962	0.67	348	18	1.050	1.003	1.003
Rideau Canal (LN34, 39)	11,893	11,486	0.97	11,221	0.94	11,244	0.95	265	23	1.024	1.002	1.002
Fallowfield (LN9, 43)	2,448	1,743	0.71	1,728	0.71	1,737	0.71	15	9	1.009	1.005	1.005
Eagleson (LN10)	3,834	4,277	1.12	4,138	1.08	4,139	1.08	139	1	1.034	1.000	1.000
Green Creek (LN16)	2,609	2,536	0.97	2,501	0.96	2,502	0.96	35	1	1.014	1.000	1.000
CNR West / Acres (LN11,12)	9,830	8,891	0.90	8,739	0.89	8,725	0.89	152	14	1.017	0.996	0.996
CNR East (LN13,14,15)	6,570	4,622	0.70	4,657	0.71	4,646	0.71	35	11	0.992	0.998	0.998
Western Parkway (LN24,25)	8,246	8,259	1.00	8,186	0.99	8,184	0.99	73	2	1.009	1.000	1.000
Lelitim / Ramsayville (LN7,8)	2,180	1,504	0.69	1,608	0.74	1,595	0.73	104	13	0.935	0.992	0.992
Ile de Hull (LN60)	5,166	4,714	0.91	4,666	0.90	4,678	0.91	48	12	1.010	1.003	1.003
Boul. Gamelin (LN 61)	5,310	3,055	0.58	3,078	0.58	3,085	0.58	23	8	0.993	1.003	1.003
Ch. de la Montagne (LN62)	1,537	820	0.53	866	0.56	865	0.56	46	1	0.947	0.999	0.999
Deschenes (LN63)	1,343	882	0.66	881	0.66	882	0.66	1	1	1.001	1.001	1.001
Q64	742	530	0.71	535	0.72	535	0.72	5	0	0.991	1.000	1.000
Q65	3,456	2,554	0.74	2,550	0.74	2,550	0.74	4	0	1.002	1.000	1.000
Q66	870	744	0.86	703	0.81	700	0.80	41	3	1.058	0.996	0.996
Montee Palemont (LN67)	3,777	1,912	0.51	1,869	0.49	1,870	0.50	43	1	1.023	1.001	1.001
Q68	1,657	1,421	0.86	1,421	0.86	1,415	0.85	0	6	1.000	0.996	0.996
		Average		75.24		348		6.86				
		Maximum		23								

Vehicle Mix Used in MOBILES Analysis - All Vehicle Categories

Area	Facility	Early AM						AM Peak						Midday					
		LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT	LDGT	HDGV	LDGT	LDGT	HDGV	MC	LDGV	LDGT1	LDGT2	HDGV	LDGT	MC
Core	Collector/Arterial	83.3	22.3	0.5	0.1	0.5	0.8	2.1	0.5	84.5	23.4	0.6	0.1	0.5	86.0	23.0	0.5	0.1	0.5
	Local	83.3	20.1	0.2	0.0	0.5	0.7	0.9	0.5	84.5	21.1	0.3	0.1	0.5	86.0	20.7	0.3	0.0	0.5
Urban	Collector/Arterial	80.7	23.5	0.5	0.1	0.5	0.8	1.8	0.4	80.1	24.8	0.6	0.1	0.5	79.2	26.1	0.7	0.1	0.5
	Local	80.7	21.2	0.2	0.0	0.5	0.7	0.9	0.4	80.1	22.3	0.3	0.1	0.5	79.2	23.5	0.3	0.1	0.5
Suburban	Collector/Arterial	76.0	28.8	0.7	0.1	0.5	1.0	2.4	0.5	74.8	30.3	1.0	0.2	0.5	73.4	32.1	1.3	0.2	0.4
	Local	76.0	25.9	0.4	0.1	0.5	0.9	1.2	0.5	74.8	27.3	0.5	0.1	0.5	73.4	28.9	0.5	0.1	0.4
Rural	Collector/Arterial	71.0	34.6	1.6	0.3	0.4	1.3	5.1	0.6	69.5	36.4	2.1	0.4	0.4	68.3	40.5	3.2	0.5	0.4
	Local	71.0	31.1	0.8	0.1	0.4	1.1	2.5	0.6	69.5	32.8	1.1	0.2	0.4	68.2	36.5	1.6	0.3	0.4
Freeways and Rural Highways		78.0	26.4	0.9	0.2	0.5	0.9	3.3	0.3	77.0	27.7	1.3	0.2	0.5	74.2	31.2	1.7	0.3	0.4

Area	Facility	PM Peak						Evening									
		LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT	MC	LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT	MC		
Core	Collector/Arterial	86.0	21.1	0.3	0.0	0.5	0.7	1.8	0.5	87.8	19.0	0.2	0.0	0.5	0.6	1.0	0.5
	Local	86.0	19.0	0.1	0.0	0.5	0.6	0.7	0.5	87.8	17.1	0.1	0.0	0.5	0.6	0.4	0.5
Urban	Collector/Arterial	82.5	22.9	0.3	0.0	0.5	0.8	1.4	0.3	84.4	20.5	0.2	0.0	0.5	0.7	0.8	0.3
	Local	82.5	20.6	0.1	0.0	0.5	0.7	0.7	0.3	84.4	18.5	0.1	0.0	0.5	0.6	0.4	0.3
Suburban	Collector/Arterial	75.5	29.5	0.5	0.1	0.5	1.0	2.1	0.5	77.9	26.6	0.2	0.0	0.5	0.8	0.8	0.5
	Local	75.5	26.5	0.2	0.0	0.5	0.9	1.3	0.5	77.9	23.9	0.1	0.0	0.5	0.8	0.4	0.5
Rural	Collector/Arterial	68.6	37.7	1.6	0.3	0.4	1.4	5.9	0.5	71.7	33.9	0.8	0.1	0.4	1.2	2.5	0.5
	Local	68.5	33.9	0.8	0.1	0.4	1.2	3.4	0.5	71.6	30.5	0.4	0.1	0.4	1.0	1.2	0.5
Freeways and Rural Highways		77.7	26.8	0.9	0.1	0.5	1.0	3.3	0.3	79.9	24.1	0.5	0.1	0.5	0.8	1.7	0.3

Vehicle Mix Used in MOBILES Analysis - Passenger Vehicles Only*

Area	Facility	Early AM						AM Peak						Midday					
		LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT	LDGT	HDGV	LDGT	LDGT	HDGV	MC	LDGV	LDGT1	LDGT2	HDGV	LDGT	MC
Core	Collector/Arterial	81.1	17.8	0.0	0.0	0.5	0.6	0.0	0.0	80.2	18.8	0.0	0.0	0.5	80.6	18.4	0.0	0.0	0.0
	Local	81.1	17.8	0.0	0.0	0.5	0.6	0.0	0.0	80.2	18.8	0.0	0.0	0.5	80.6	18.4	0.0	0.0	0.0
Urban	Collector/Arterial	80.1	18.8	0.0	0.0	0.5	0.6	0.0	0.0	79.0	19.8	0.0	0.0	0.5	78.0	20.0	0.0	0.0	0.0
	Local	80.1	18.8	0.0	0.0	0.5	0.6	0.0	0.0	79.0	19.8	0.0	0.0	0.5	78.0	20.0	0.0	0.0	0.0
Suburban	Collector/Arterial	75.8	23.0	0.0	0.0	0.5	0.7	0.0	0.0	74.5	24.3	0.0	0.0	0.4	73.1	25.7	0.0	0.0	0.0
	Local	75.8	23.0	0.0	0.0	0.5	0.7	0.0	0.0	74.5	24.3	0.0	0.0	0.4	73.1	25.7	0.0	0.0	0.0
Rural	Collector/Arterial	71.0	27.7	0.0	0.0	0.4	0.9	0.0	0.0	69.5	29.1	0.0	0.0	0.4	68.2	32.4	0.0	0.0	0.0
	Local	71.0	27.7	0.0	0.0	0.4	0.9	0.0	0.0	69.5	29.1	0.0	0.0	0.4	68.2	32.4	0.0	0.0	0.0
Freeways and Rural Highways		77.8	21.1	0.0	0.0	0.5	0.7	0.0	0.0	76.7	22.2	0.0	0.0	0.5	73.8	25.0	0.0	0.0	0.0

Area	Facility	PM Peak						Evening								
		LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT	LDGV	LDGT1	LDGT2	HDGV	LDGV	LDGT			
Core	Collector/Arterial	82.1	16.9	0.0	0.0	0.5	0.5	0.0	0.0	83.8	15.2	0.0	0.0	0.5	0.0	0.0
	Local	82.1	16.9	0.0	0.0	0.5	0.5	0.0	0.0	83.8	15.2	0.0	0.0	0.5	0.0	0.0
Urban	Collector/Arterial	80.6	18.3	0.0	0.0	0.5	0.6	0.0	0.0	82.5	16.4	0.0	0.0	0.5	0.0	0.0
	Local	80.6	18.3	0.0	0.0	0.5	0.6	0.0	0.0	82.5	16.4	0.0	0.0	0.5	0.0	0.0
Suburban	Collector/Arterial	75.2	23.6	0.0	0.0	0.5	0.8	0.0	0.0	77.6	21.2	0.0	0.0	0.5	0.7	0.0
	Local	75.2	23.6	0.0	0.0	0.5	0.8	0.0	0.0	77.6	21.2	0.0	0.0	0.5	0.7	0.0
Rural	Collector/Arterial	68.5	30.2	0.0	0.0	0.4	1.0	0.0	0.0	71.6	27.1	0.0	0.0	0.4	0.9	0.0
	Local	68.5	30.2	0.0	0.0	0.4	1.0	0.0	0.0	71.6	27.1	0.0	0.0	0.4	0.9	0.0
Freeways and Rural Highways		77.4	21.5	0.0	0.0	0.5	0.7	0.0	0.0	79.6	19.3	0.0	0.0	0.5	0.6	0.0

* Total of all 8 categories should add to 100% since passenger vehicles represent 100% of the EMME/2 output

Vehicle Mix Data Used in Greenhouse Gas Calculations

Area	Facility	Autos*					Non-Commercial Light Trucks*					Commercial Light Trucks				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	81.6	80.6	81.0	82.6	84.3	18.4	19.4	19.0	17.4	15.7	4.6	4.8	4.7	4.4	3.9
	Local	81.6	80.6	81.0	82.6	84.3	18.4	19.4	19.0	17.4	15.7	2.3	2.4	2.4	2.2	2.0
Urban	Collector/Arterial	80.6	79.5	78.5	81.1	83.0	19.4	20.5	21.5	18.9	17.0	4.9	5.1	5.4	4.7	4.2
	Local	80.6	79.5	78.5	81.1	83.0	19.4	20.5	21.5	18.9	17.0	2.4	2.6	2.7	2.4	2.1
Suburban	Collector/Arterial	76.2	75.0	73.5	75.7	78.1	23.8	25.0	26.5	24.3	21.9	5.9	6.3	6.6	6.1	5.5
	Local	76.2	75.0	73.5	75.7	78.1	23.8	25.0	26.5	24.3	21.9	3.0	3.1	3.3	3.0	2.7
Rural	Collector/Arterial	71.4	69.9	66.6	68.9	72.0	28.6	30.1	33.4	31.1	28.0	7.1	7.5	8.4	7.8	7.0
	Local	71.4	69.9	66.6	68.9	72.0	28.6	30.1	33.4	31.1	28.0	3.6	3.8	4.2	3.9	3.5
Freeways and Rural Highways		78.2	77.1	74.2	77.8	80.1	21.8	22.9	25.8	22.2	19.9	5.4	5.7	6.4	5.5	5.0

Area	Facility	Heavy Trucks - Gas (HDGV + LDGT2)					Heavy Trucks - Diesel (HDDV + LDDT)					School and Intercity Buses - HDDV				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	0.6	0.7	0.6	0.3	0.2	1.5	2.1	1.7	1.0	0.5	0.6	1.2	0.8	0.9	0.5
	Local	0.3	0.4	0.3	0.2	0.1	0.8	1.0	0.8	0.5	0.3	0.2	0.3	0.2	0.2	0.1
Urban	Collector/Arterial	0.5	0.7	0.8	0.3	0.2	1.5	2.0	2.2	1.0	0.5	0.4	0.7	0.5	0.5	0.3
	Local	0.3	0.4	0.4	0.2	0.1	0.7	1.0	1.1	0.5	0.3	0.2	0.4	0.3	0.3	0.2
Suburban	Collector/Arterial	0.9	1.2	1.5	0.6	0.3	2.4	3.2	4.2	1.6	0.8	0.0	1.1	0.6	0.5	0.0
	Local	0.4	0.6	0.7	0.3	0.1	1.2	1.6	2.1	0.8	0.4	0.0	1.1	0.6	0.5	0.0
Rural	Collector/Arterial	1.9	2.5	3.7	1.8	0.9	5.2	7.0	10.4	5.2	2.6	0.0	1.4	0.9	0.9	0.0
	Local	0.9	1.2	1.9	0.9	0.5	2.6	3.5	5.2	2.6	1.3	0.0	1.4	0.9	0.9	0.0
Freeways and Rural Highways		1.1	1.5	2.0	1.0	0.5	3.1	4.1	5.6	2.9	1.5	0.3	0.6	0.5	0.5	0.3

Area	Facility	Taxis					Other Vehicles				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	2.2	4.4	5.5	4.0	4.0	0.5	0.5	0.5	0.5	0.5
	Local	2.2	4.4	5.5	4.0	4.0	0.5	0.5	0.5	0.5	0.5
Urban	Collector/Arterial	0.6	1.1	1.2	1.9	1.9	0.4	0.4	0.3	0.3	0.3
	Local	0.6	1.1	1.2	1.9	1.9	0.4	0.4	0.3	0.3	0.3
Suburban	Collector/Arterial	0.2	0.3	0.3	0.3	0.3	0.5	0.5	0.4	0.5	0.5
	Local	0.2	0.3	0.3	0.3	0.3	0.5	0.5	0.4	0.5	0.5
Rural	Collector/Arterial	0.0	0.0	0.1	0.1	0.1	0.6	0.6	0.7	0.5	0.5
	Local	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.7	0.5	0.5
Freeways and Rural Highways		0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.3

* Categories included in passenger vehicle calculations (should add to 100%)

Note that all passenger vehicles, light trucks, and taxis are assumed to be gas-fueled due to a lack of fuel consumption equations for light duty diesel vehicles

Calculation of Auto Vehicle Ratios

Area	Facility	Non-Commercial Light Trucks						Autos						Taxis					
		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night	
Core	Collector/Arterial	18.4	19.4	19.0	17.4	15.7		81.6	80.6	81.0	82.6	84.3		2.2	4.4	5.5	4.0	4.0	
	Local	18.4	19.4	19.0	17.4	15.7		81.6	80.6	81.0	82.6	84.3		2.2	4.4	5.5	4.0	4.0	
Urban	Collector/Arterial	19.4	20.5	21.5	18.9	17.0		80.6	79.5	78.5	81.1	83.0		0.6	1.1	1.2	1.9	1.9	
	Local	19.4	20.5	21.5	18.9	17.0		80.6	79.5	78.5	81.1	83.0		0.6	1.1	1.2	1.9	1.9	
Suburban	Collector/Arterial	23.8	25.0	26.5	24.3	21.9		76.2	75.0	73.5	75.7	78.1		0.2	0.3	0.3	0.3	0.3	
	Local	23.8	25.0	26.5	24.3	21.9		76.2	75.0	73.5	75.7	78.1		0.2	0.3	0.3	0.3	0.3	
Rural	Collector/Arterial	28.6	30.1	33.4	31.1	28.0		71.4	69.9	66.6	68.9	72.0		0.0	0.0	0.1	0.1	0.1	
	Local	28.6	30.1	33.4	31.1	28.0		71.4	69.9	66.6	68.9	72.0		0.0	0.0	0.0	0.0	0.0	
Freeways and Rural Highways		21.8	22.9	25.8	22.2	19.9		78.2	77.1	74.2	77.8	80.1		0.2	0.3	0.4	0.3	0.3	

* Ratio of auto passenger vehicles to total passenger vehicles = 100% passenger vehicles - % light truck passenger vehicles

* 0.6% of autos are assumed to be diesel-fueled (based on NRCan data)

Area	Facility	Autos+Taxis						Autos + Taxis - Gas (LDGV)						Autos + Taxis - Diesel (LDDV)					
		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night	
Core	Collector/Arterial	83.8	85.0	86.5	86.6	88.3		83.3	84.5	86.0	86.0	87.8		0.5	0.5	0.5	0.5	0.5	
	Local	83.8	85.0	86.5	86.6	88.3		83.3	84.5	86.0	86.0	87.8		0.5	0.5	0.5	0.5	0.5	
Urban	Collector/Arterial	81.2	80.6	79.7	83.0	84.9		80.7	80.1	79.2	82.5	84.4		0.5	0.5	0.5	0.5	0.5	
	Local	81.2	80.6	79.7	83.0	84.9		80.7	80.1	79.2	82.5	84.4		0.5	0.5	0.5	0.5	0.5	
Suburban	Collector/Arterial	76.4	75.3	73.8	76.0	78.4		76.0	74.8	73.4	75.5	77.9		0.5	0.5	0.4	0.5	0.5	
	Local	76.4	75.3	73.8	76.0	78.4		76.0	74.8	73.4	75.5	77.9		0.5	0.5	0.4	0.5	0.5	
Rural	Collector/Arterial	71.4	69.9	66.7	69.0	72.1		71.0	69.5	66.3	68.6	71.7		0.4	0.4	0.4	0.4	0.4	
	Local	71.4	69.9	66.6	68.9	72.0		71.0	69.5	66.2	68.5	71.6		0.4	0.4	0.4	0.4	0.4	
Freeways and Rural Highways		78.4	77.4	74.6	78.1	80.4		78.0	77.0	74.2	77.7	79.9		0.5	0.5	0.4	0.5	0.5	

Calculation of Auto Vehicle Ratios (excluding taxis)

Area	Facility	Autos						Autos - Gas						Autos - Diesel					
		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night	
Core	Collector/Arterial	81.6	80.6	81.0	82.6	84.3		81.1	80.2	80.6	82.1	83.8		0.5	0.5	0.5	0.5	0.5	
	Local	81.6	80.6	81.0	82.6	84.3		81.1	80.2	80.6	82.1	83.8		0.5	0.5	0.5	0.5	0.5	
Urban	Collector/Arterial	80.6	79.5	78.5	81.1	83.0		80.1	79.0	78.0	80.6	82.5		0.5	0.5	0.5	0.5	0.5	
	Local	80.6	79.5	78.5	81.1	83.0		80.1	79.0	78.0	80.6	82.5		0.5	0.5	0.5	0.5	0.5	
Suburban	Collector/Arterial	76.2	75.0	73.5	75.7	78.1		75.8	74.5	73.1	75.2	77.6		0.5	0.4	0.4	0.5	0.5	
	Local	76.2	75.0	73.5	75.7	78.1		75.8	74.5	73.1	75.2	77.6		0.5	0.4	0.4	0.5	0.5	
Rural	Collector/Arterial	71.4	69.9	66.6	68.9	72.0		71.0	69.5	66.2	68.5	71.6		0.4	0.4	0.4	0.4	0.4	
	Local	71.4	69.9	66.6	68.9	72.0		71.0	69.5	66.2	68.5	71.6		0.4	0.4	0.4	0.4	0.4	
Freeways and Rural Highways		78.2	77.1	74.2	77.8	80.1		77.8	76.7	73.8	77.4	79.6		0.5	0.5	0.4	0.5	0.5	

Calculation of Light Truck Ratios

Area	Facility	Commercial Light Trucks						Commercial Light Trucks-Gas						Commercial Light Trucks-Diesel					
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night			
Core	Collector/Arterial	4.6	4.8	4.7	4.4	3.9	4.5	4.7	4.6	4.2	3.8	0.1	0.2	0.1	0.1	0.1			
	Local	2.3	2.4	2.4	2.2	2.0	2.2	2.3	2.3	2.1	1.9	0.1	0.1	0.1	0.1	0.1			
Urban	Collector/Arterial	4.9	5.1	5.4	4.7	4.2	4.7	5.0	5.2	4.6	4.1	0.2	0.2	0.2	0.1	0.1			
	Local	2.4	2.6	2.7	2.4	2.1	2.4	2.5	2.6	2.3	2.1	0.1	0.1	0.1	0.1	0.1			
Suburban	Collector/Arterial	5.9	6.3	6.6	6.1	5.5	5.8	6.1	6.4	5.9	5.3	0.2	0.2	0.2	0.2	0.2			
	Local	3.0	3.1	3.3	3.0	2.7	2.9	3.0	3.2	2.9	2.7	0.1	0.1	0.1	0.1	0.1			
Rural	Collector/Arterial	7.1	7.5	8.4	7.8	7.0	6.9	7.3	8.1	7.5	6.8	0.2	0.2	0.3	0.2	0.2			
	Local	3.6	3.8	4.2	3.9	3.5	3.5	3.6	4.1	3.8	3.4	0.1	0.1	0.1	0.1	0.1			
Freeways and Rural Highways		5.4	5.7	6.4	5.5	5.0	5.3	5.5	6.2	5.4	4.8	0.2	0.2	0.2	0.2	0.2			

Area	Facility	Non-Commercial Light Trucks					Non-Commercial Light Trucks - Gas					Non-Commercial Light Trucks - Diesel				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	18.4	19.4	19.0	17.4	15.7	17.8	18.8	18.4	16.9	15.2	0.6	0.6	0.6	0.5	0.5
	Local	18.4	19.4	19.0	17.4	15.7	17.8	18.8	18.4	16.9	15.2	0.6	0.6	0.6	0.5	0.5
Urban	Collector/Arterial	19.4	20.5	21.5	18.9	17.0	18.8	19.8	20.9	18.3	16.4	0.6	0.6	0.7	0.6	0.5
	Local	19.4	20.5	21.5	18.9	17.0	18.8	19.8	20.9	18.3	16.4	0.6	0.6	0.7	0.6	0.5
Suburban	Collector/Arterial	23.8	25.0	26.5	24.3	21.9	23.0	24.3	25.7	23.6	21.2	0.7	0.8	0.8	0.8	0.7
	Local	23.8	25.0	26.5	24.3	21.9	23.0	24.3	25.7	23.6	21.2	0.7	0.8	0.8	0.8	0.7
Rural	Collector/Arterial	28.6	30.1	33.4	31.1	28.0	27.7	29.1	32.4	30.2	27.1	0.9	0.9	1.0	1.0	0.9
	Local	28.6	30.1	33.4	31.1	28.0	27.7	29.1	32.4	30.2	27.1	0.9	0.9	1.0	1.0	0.9
Freeways and Rural Highways		21.8	22.9	25.8	22.2	19.9	21.1	22.2	25.0	21.5	19.3	0.7	0.7	0.8	0.7	0.6

Area	Facility	All Light Trucks						All Light Trucks - Gas (LDGT1)						All Light Trucks - Diesel (LDDV)					
		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night	
Core	Collector/Arterial	23.0	24.2	23.7	21.8	19.6		22.3	23.4	23.0	21.1	19.0		0.7	0.8	0.7	0.7	0.6	
	Local	20.7	21.8	21.3	19.6	17.6		20.1	21.1	20.7	19.0	17.1		0.6	0.7	0.7	0.6	0.5	
Urban	Collector/Arterial	24.3	25.6	26.9	23.6	21.2		23.5	24.8	26.1	22.9	20.5		0.8	0.8	0.8	0.7	0.7	
	Local	21.9	23.0	24.2	21.2	19.1		21.2	22.3	23.5	20.6	18.5		0.7	0.7	0.8	0.7	0.6	
Suburban	Collector/Arterial	29.7	31.3	33.1	30.4	27.4		28.8	30.3	32.1	29.5	26.6		0.9	1.0	1.0	0.9	0.8	
	Local	26.7	28.2	29.8	27.4	24.7		25.9	27.3	28.9	26.5	23.9		0.8	0.9	0.9	0.8	0.8	
Rural	Collector/Arterial	35.7	37.6	41.8	38.9	35.0		34.6	36.4	40.5	37.7	33.9		1.1	1.2	1.3	1.2	1.1	
	Local	32.1	33.8	37.6	35.0	31.5		31.1	32.8	36.5	33.9	30.5		1.0	1.0	1.2	1.1	1.0	
Freeways and Rural Highways		27.2	28.6	32.2	27.7	24.9		26.4	27.7	31.2	26.8	24.1		0.8	0.9	1.0	0.9	0.8	

* 3.1% of light trucks are assumed to be diesel fuelled (based on data from NRCan)

* On arterial/collector roads, 20% of light trucks can be classified as commercial vehicles

* On local roads, the fraction of commercial light trucks equals 50% of the fraction observed on arterial/collector roads

Calculation of Heavy Vehicle Ratios

Area	Facility	Heavy Trucks					Heavy Vehicles - Gas (HDGV)					Heavy Vehicles - Diesel (HDDV)				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	2.1	2.8	2.3	1.3	0.7	0.1	0.1	0.1	0.0	0.0	1.5	2.0	1.6	0.9	0.5
	Local	1.1	1.4	1.2	0.7	0.4	0.0	0.1	0.0	0.0	0.0	0.7	1.0	0.8	0.5	0.2
Urban	Collector/Arterial	2.0	2.7	3.0	1.3	0.7	0.1	0.1	0.1	0.0	0.0	1.4	1.9	2.1	0.9	0.5
	Local	1.0	1.4	1.5	0.7	0.4	0.0	0.1	0.1	0.0	0.0	0.7	1.0	1.1	0.5	0.2
Suburban	Collector/Arterial	3.3	4.4	5.7	2.2	1.1	0.1	0.2	0.2	0.1	0.0	2.4	3.1	4.1	1.6	0.8
	Local	1.7	2.2	2.9	1.1	0.6	0.1	0.1	0.1	0.0	0.0	1.2	1.6	2.0	0.8	0.4
Rural	Collector/Arterial	7.1	9.5	14.1	7.0	3.5	0.3	0.4	0.5	0.3	0.1	5.1	6.8	10.0	5.0	2.5
	Local	3.6	4.8	7.1	3.5	1.8	0.1	0.2	0.3	0.1	0.1	2.5	3.4	5.0	2.5	1.2
Freeways and Rural Highways		4.2	5.6	7.8	3.9	2.0	0.2	0.2	0.3	0.1	0.1	3.0	4.0	5.4	2.8	1.4

Area	Facility	Heavy Trucks						Medium Trucks - Diesel (LDDT)						Medium Trucks - Gas (LDGV2)					
		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night		Early AM	AM Peak	Midday	PM Peak	Night	
Core	Collector/Arterial	2.1	2.8	2.3	1.3	0.7		0.1	0.1	0.1	0.0		0.0	0.5	0.6	0.5	0.3	0.2	
	Local	1.1	1.4	1.2	0.7	0.4		0.0	0.0	0.0	0.0		0.0	0.2	0.3	0.3	0.1	0.1	
Urban	Collector/Arterial	2.0	2.7	3.0	1.3	0.7		0.1	0.1	0.1	0.0		0.0	0.5	0.6	0.7	0.3	0.2	
	Local	1.0	1.4	1.5	0.7	0.4		0.0	0.0	0.0	0.0		0.0	0.2	0.3	0.3	0.1	0.1	
Suburban	Collector/Arterial	3.3	4.4	5.7	2.2	1.1		0.1	0.1	0.1	0.1		0.0	0.7	1.0	1.3	0.5	0.2	
	Local	1.7	2.2	2.9	1.1	0.6		0.0	0.1	0.1	0.0		0.0	0.4	0.5	0.6	0.2	0.1	
Rural	Collector/Arterial	7.1	9.5	14.1	7.0	3.5		0.2	0.2	0.4	0.2		0.1	1.6	2.1	3.2	1.6	0.8	
	Local	3.6	4.8	7.1	3.5	1.8		0.1	0.1	0.2	0.1		0.0	0.8	1.1	1.6	0.8	0.4	
Freeways and Rural Highways		4.2	5.6	7.6	3.9	2.0		0.1	0.1	0.2	0.1		0.1	0.9	1.3	1.7	0.9	0.5	

* Assumes that 75% of heavy vehicles are HDGV (5%) or HDDV (95%)
 * Of the 25% LDDT2 / LDDT vehicles, 10% are assumed to be diesel (LDDT)

Area	Facility	Intercity / School Buses - HDDV					Total HDDV (Heavy Vehicles + Buses)				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	0.6	1.2	0.8	0.9	0.5	2.1	3.2	2.4	1.8	1.0
	Local	0.2	0.3	0.2	0.2	0.1	0.9	1.3	1.0	0.7	0.4
Urban	Collector/Arterial	0.4	0.7	0.5	0.5	0.3	1.8	2.6	2.6	1.4	0.8
	Local	0.2	0.4	0.3	0.3	0.2	0.9	1.3	1.3	0.7	0.4
Suburban	Collector/Arterial	0.0	1.1	0.6	0.5	0.0	2.4	4.2	4.7	2.1	0.8
	Local	0.0	1.1	0.6	0.5	0.0	1.2	2.7	2.6	1.3	0.4
Rural	Collector/Arterial	0.0	1.4	0.9	0.9	0.0	5.1	8.2	10.9	5.9	2.5
	Local	0.0	1.4	0.9	0.9	0.0	2.5	4.8	5.9	3.4	1.2
Freeways and Rural Highways		0.3	0.6	0.5	0.5	0.3	3.3	4.6	5.9	3.3	1.7

Area	Facility	Light Trucks - Diesel					Total LDDT - (Light + Medium Trucks)				
		Early AM	AM Peak	Midday	PM Peak	Night	Early AM	AM Peak	Midday	PM Peak	Night
Core	Collector/Arterial	0.7	0.8	0.7	0.7	0.6	1.2	1.4	1.3	1.0	0.8
	Local	0.6	0.7	0.7	0.6	0.5	0.9	1.0	0.9	0.8	0.6
Urban	Collector/Arterial	0.8	0.8	0.8	0.7	0.7	1.2	1.4	1.5	1.0	0.8
	Local	0.7	0.7	0.8	0.7	0.6	0.9	1.0	1.1	0.8	0.7
Suburban	Collector/Arterial	0.9	1.0	1.0	0.9	0.8	1.7	2.0	2.3	1.4	1.1
	Local	0.8	0.9	0.9	0.8	0.8	1.2	1.4	1.6	1.1	0.9
Rural	Collector/Arterial	1.1	1.2	1.3	1.2	1.1	2.7	3.3	4.5	2.8	1.9
	Local	1.0	1.0	1.2	1.1	1.0	1.8	2.1	2.8	1.9	1.4
Freeways and Rural Highways		0.8	0.9	1.0	0.9	0.8	1.8	2.1	2.7	1.7	1.2

APPENDIX E

EXTERNAL TRIPS

Planning and Development Approvals Department - RMOC

Screenlines Used In Determining External Trip Patterns

Screenline 43 - Stonehaven, Hope Side Road, Richmond Road

Screenline 44 - Richmond Side Road, Highway 417, Palladium Drive, Maple Grove Road, Hazledean Road, Fernbank Road

Screenline 46 - Regional Road 34, Regional Road 30, Regional Road 28, Highway 17, Wall Road

Screenline 49 - Eagleson Road, Twin Elm Road, Moodie Drive, Highway 416, Cedarview Road, Greenband Road, Jockvale Road, Highway 16

Screenline 50 - River Road, Precott Road, Dozois Road, Manotick Station Road, Old Prescott Road, Highway 31

Screenline 51 - 6th Line Road, 7th Line Road, 8th Line Road, 9th Line Road, 10th Line Road, 11th Line Road, Boundary Road

Screenline Traffic Counts Used to Establish Inbound External Trips

Time	TOTAL VOLUME OF PASSENGER VEHICLES						
	Line 43	Line 49	Line 46	Line 44	Line 50	Line 51	Total
7:00 - 7:15	229	361	380	566	381	761	2678
7:15 - 7:30	250	436	396	677	489	885	3133
7:30 - 7:45	256	479	357	800	439	796	3127
7:45 - 8:00	256	491	329	750	435	764	3025
8:00 - 8:15	241	414	296	651	362	658	2622
8:15 - 8:30	225	363	273	650	306	579	2396
8:30 - 8:45	189	323	235	537	240	475	1999
8:45 - 9:00	176	299	218	492	217	435	1837
9:00 - 9:15	129	230	176	388	167	343	1433
9:15 - 9:30	107	225	197	395	180	377	1481
9:30 - 9:45	94	218	174	375	169	343	1373
9:45 - 10:00	83	200	171	368	146	317	1285
11:30 - 11:45	57	194	186	405	140	326	1308
11:45 - 12:00	90	195	151	433	124	275	1268
12:00 - 12:15	72	205	197	382	135	332	1323
12:15 - 12:30	74	178	159	375	138	297	1221
12:30 - 12:45	64	216	176	401	155	331	1343
12:45 - 13:00	87	230	156	445	132	288	1338
13:00 - 13:15	67	154	174	437	159	333	1324
13:15 - 13:30	70	212	181	416	141	322	1342
15:00 - 15:15	75	223	154	438	164	318	1372
15:15 - 15:30	70	278	161	422	139	300	1370
15:30 - 15:45	81	237	181	438	157	338	1432
15:45 - 16:00	75	240	178	444	125	303	1365
16:00 - 16:15	86	219	155	460	145	300	1365
16:15 - 16:30	81	245	169	396	172	341	1404
16:30 - 16:45	84	295	144	491	154	298	1466
16:45 - 17:00	91	261	204	461	127	331	1475
17:00 - 17:15	76	259	174	512	146	320	1487
17:15 - 17:30	98	253	175	482	171	346	1525
17:30 - 17:45	105	277	156	501	154	310	1503
17:45 - 18:00	95	245	183	463	139	322	1447
TOTAL	3833	8655	6616	15451	6448	13064	54067
PM PEAK HR	332	1060	691	1860	599	1290	5832

* Passenger vehicles computed as autos + 80% light trucks

Screenline Traffic Counts Used to Establish Outbound External Trips

Time	TOTAL VOLUME OF PASSENGER VEHICLES						
	Line 43	Line 49	Line 46	Line 44	Line 50	Line 51	Total
7:00 - 7:15	43	140	88	193	51	24	539
7:15 - 7:30	56	136	115	244	64	36	651
7:30 - 7:45	48	166	113	291	67	38	723
7:45 - 8:00	68	199	113	351	83	72	886
8:00 - 8:15	64	185	118	316	81	64	828
8:15 - 8:30	74	175	144	300	84	71	848
8:30 - 8:45	63	181	131	343	88	39	845
8:45 - 9:00	58	175	139	329	89	36	826
9:00 - 9:15	63	188	159	320	88	55	873
9:15 - 9:30	52	168	141	278	89	43	771
9:30 - 9:45	34	189	145	295	107	36	806
9:45 - 10:00	57	210	150	303	100	33	853
11:30 - 11:45	68	203	148	410	151	36	1016
11:45 - 12:00	90	202	184	419	139	69	1103
12:00 - 12:15	75	175	197	385	147	37	1016
12:15 - 12:30	82	231	195	360	166	64	1098
12:30 - 12:45	62	178	179	385	136	56	996
12:45 - 13:00	67	207	203	372	146	62	1057
13:00 - 13:15	74	204	185	379	159	40	1041
13:15 - 13:30	70	202	213	367	124	38	1014
15:00 - 15:15	96	279	255	460	166	1	1257
15:15 - 15:30	125	263	288	445	193	67	1381
15:30 - 15:45	132	321	313	499	231	85	1581
15:45 - 16:00	145	268	344	579	270	147	1753
16:00 - 16:15	153	377	373	579	302	147	1931
16:15 - 16:30	223	403	471	664	335	194	2290
16:30 - 16:45	209	443	418	703	366	212	2351
16:45 - 17:00	214	456	405	650	383	226	2334
17:00 - 17:15	237	460	418	724	431	189	2459
17:15 - 17:30	266	474	442	590	372	197	2341
17:30 - 17:45	217	481	338	622	397	187	2242
17:45 - 18:00	218	407	373	527	284	140	1949
TOTAL	3503	8346	7498	13682	5889	2741	41659
PM PEAK HR	883	1762	1712	2741	1515	821	9434

* Passenger vehicles computed as autos + 80% light trucks

Calculation of Growth Factors Used to Adjust 1993 AM Peak Hour External Trip Matrix to 1995 Conditions

Trips from any origin zone to..		Trips to any destination zone from..		Trips to any external destination zone from..		Trips from any external origin zone to..		Trips from any non-external zone to..	
External Destination Zone	Growth Factor	External Origin Zone	Growth Factor	External Origin Zone	Growth Factor	External Destination Zone	Growth Factor	External Origin Zone	Growth Factor
186	1.04	186	1.05	186	1.05	186	1.04	186	1.05
187	1.05	187	1.05	187	1.05	187	1.05	187	1.05
188	1.05	188	1.05	188	1.05	188	1.05	188	1.05
189	1.05	189	1.05	189	1.05	189	1.05	189	1.05
190	1.05	190	1.05	190	1.05	190	1.05	190	1.05
191	1.04	191	1.04	191	1.05	191	1.04	191	1.04
192	1.08	192	1.08	192	1.05	192	1.08	192	1.08
193	1.09	193	1.09	193	1.05	193	1.09	193	1.09
194	1.12	194	1.12	194	1.05	194	1.12	194	1.12
195	1.09	195	1.09	195	1.05	195	1.09	195	1.09
196	1.08	196	1.08	196	1.05	196	1.08	196	1.08
197	1.04	197	1.04	197	1.05	197	1.04	197	1.04
198	1.05	198	1.05	198	1.05	198	1.05	198	1.05
199	1.05	199	1.05	199	1.05	199	1.05	199	1.05
200	1.05	200	1.05	200	1.05	200	1.05	200	1.05

* Growth factor = 1995 volume/1993 volume

Based on the above data, the following conclusions were made:

- * external-external trips: growth factor = 1.05
- * for each external zone, the growth factor for external-internal trips and internal-external trips is similar
- * therefore, the growth factors in Table A were applied

Table A

External Zone	Growth Factor
186	1.05
187	1.05
188	1.05
189	1.05
190	1.05
191	1.04
192	1.08
193	1.09
194	1.12
195	1.09
196	1.08
197	1.04
198	1.05
199	1.05
200	1.05

Impact of External Trip Matrix on AM Peak Hour Auto Assignment in EMME/2

Outbound Auto Vehicle Volumes

Screenline	Observed Count*	1995 Ext Matrix (1)		1993 Ext Matrix (2)		Factor Method (3)		Comparison of Modelling Approaches			
		Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	(1) - (2)	(2) - (3)	(1) / (2)	(3) / (2)
Ottawa River (LN2,3,4)	5,083	4,712	0.93	4,695	0.92	4,872	1.04	17	177	1.004	1.038
Rideau River (LN19,20,32,33)	12,047	13,859	1.15	13,804	1.15	14,103	1.17	55	299	1.004	1.022
CPR (LN27, 28, 29)	7,650	7,959	1.04	7,930	1.04	7,950	1.04	29	20	1.004	1.003
Ottawa Central Area (LN35-38)		6,990		6,997		7,139		7	142	0.999	1.020
Rideau Canal (LN34, 39)		11,203		11,175		11,506		28	331	1.003	1.030
Fallowfield (LN9, 43)		1,277		1,244		1,194		33	50	1.027	0.960
Eagleson (LN10)		3,965		3,925		3,758		40	167	1.010	0.957
Green Creek (LN16)		1,926		1,909		1,963		17	54	1.009	1.028
CNR West / Acres (LN11,12)		8,350		8,315		8,203		35	112	1.004	0.987
CNR East (LN13, 14, 15)		3,266		3,257		3,571		9	314	1.003	1.066
Western Parkway (LN24,25)	5,905	6,874	1.16	6,832	1.16	6,705	1.14	42	127	1.006	0.981
Lelirim / Ramsayville (LN7,8)		1,289		1,259		1,468		30	207	1.024	1.164
Ile de Hull (LN60)		4,292		4,273		4,515		19	242	1.004	1.057
Boul. Gamelin (LN 61)		2,928		2,917		2,998		11	81	1.004	1.028
Ch. de la Montagne (LN62)		712		706		683		6	23	1.008	0.967
Deschenes (LN63)		682		677		705		5	28	1.007	1.041
Q64		456		456		468		0	12	1.000	1.026
Q65		2,288		2,277		2,401		11	124	1.005	1.054
Q66		372		367		365		5	2	1.014	0.995
Montee Palment (LN67)		1,704		1,697		1,774		7	77	1.004	1.045
Q68		964		954		902		10	52	1.010	0.945
				Average		19.81		55		125.76	
				Maximum						331	

Inbound Auto Vehicle Volumes

Screenline	Observed Count*	1995 Ext Matrix (1)		1993 Ext Matrix (2)		Factor Method (3)		Comparison of Modelling Approaches			
		Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	Est. Volume	Est./Obs.	(1) - (2)	(2) - (3)	(1) / (2)	(3) / (2)
Ottawa River (LN2,3,4)	9,691	11,206.00	1.16	11,189	1.15	11,247.00	1.16	17	58	1.002	1.005
Rideau River (LN19,20,32,33)	15,224	18,285.00	1.20	18,235	1.20	18,066.00	1.19	50	169	1.003	0.991
CPR (LN27, 28, 29)	9,735	11,863.00	1.22	11,819	1.21	11,951.00	1.23	44	132	1.004	1.011
Ottawa Central Area (LN35-38)		15,528.00		15,516		15,249.00		12	267	1.001	0.983
Rideau Canal (LN34, 39)		15,155.00		15,139		14,906.00		16	233	1.001	0.985
Fallowfield (LN9, 43)		6,929.00		6,863		7,020.00		68	157	1.010	1.023
Eagleson (LN10)		6,262.00		6,191		6,542.00		71	351	1.011	1.057
Green Creek (LN16)		8,022.00		8,015		7,876.00		7	139	1.001	0.983
CNR West / Acres (LN11,12)		13,808.00		13,711		14,105.00		97	394	1.007	1.029
CNR East (LN13, 14, 15)		9,999.00		9,880		9,875.00		119	5	1.012	0.999
Western Parkway (LN24,25)	10,898	13,055.00	1.20	12,968	1.19	13,241.00	1.21	87	273	1.007	1.021
Lelirim / Ramsayville (LN7,8)		4,604.00		4,498		4,505.00		106	7	1.024	1.002
Ile de Hull (LN60)		14,132.00		14,101		14,178.00		31	77	1.002	1.005
Boul. Gamelin (LN 61)		8,474.00		8,438		8,513.00		36	75	1.004	1.009
Ch. de la Montagne (LN62)		2,407.00		2,399		2,444.00		8	45	1.003	1.019
Deschenes (LN63)		2,180.00		2,176		2,251.00		4	75	1.002	1.034
Q64		2,246.00		2,243		2,311.00		3	68	1.001	1.030
Q65		8,773.00		8,760		8,780.00		13	20	1.001	1.002
Q66		1,360.00		1,359		1,402.00		1	43	1.001	1.032
Montee Palment (LN67)		2,972.00		2,955		3,004.00		17	49	1.006	1.017
Q68		2,716.00		2,702		2,904.00		14	202	1.005	1.075
				Average		39.00		119		135.19	
				Maximum						394	

* Note that the AM Peak Hour varies depending on the screenline

Therefore, the volumes may be slightly higher than the volumes that would be observed between 8:00 a.m. and 9:00 a.m.

Also, observed traffic counts were not readily available for all screenlines

APPENDIX F

INTRA-ZONAL TRIP ANALYSIS

```

/////////////////////////////////////////////////////////////////
// This macro computes the shortest path between trip origins and destinations for
// intra-zonal trips in Ottawa-Carleton
//
// To run macro:
// 1. Using intra-zonal trip table, geocode origins and destinations to create two
//    separate layers
// 2. Paste latitude and longitude information from geocoding process into original
//    trip table using the following field headings: ORIG_LAT, ORIG_LONG,
//    DEST_LAT, DEST_LONG
// 2. Connect origins and destinations to line layer (Corresponding node layer should
//    be called "Endpoints")
// 3. Create network (g:\thesis\net1.net)
// 4. In original trip table (g:\thesis\iz_trip.dbf), add a field called BestPath"
//    to store distance results. This field should be real, with at least 2
//    decimal places.
// 5. In the "Endpoints" node layer, define a new formula field called "LongLat",
//    where LatLong = String(Longitude)+String(Latitude)
// 6. Using GISDK add-in, run macro. Results are stored in original trip table for
//    exporting back into MS Access
//
// Jennifer Armstrong, Carleton University
// October, 1999
/////////////////////////////////////////////////////////////////

Macro "Shortest Path" (Origins, Destinations)

// No need to declare variables

// Initialize variables
Counter = 1
Distance = 0

// Make the network active
NetFileName = "g:\thesis\net1.net"
Net_Handle = ReadNetwork(NetFileName)
Shared d_NetInfo

// Open the dbase table with origin and destination information
Results = OpenTable("ResultTable", "DBASE", {"g:\thesis\iz_trip.dbf", null})

// Get first O-D pair

SetView(Results)
Record = GetFirstRecord(Results + "|", {"ID", "Ascending"})

// Begin Looping
While Record<> null do

OrigLat = Results.ORIG_LAT
OrigLong = Results.ORIG_LONG
OrigData = String(OrigLong)+String(OrigLat)
DestLat = Results.DEST_LAT
DestLong = Results.DEST_LONG
DestData = String(DestLong)+String(DestLat)

// OutOrigLat=string(OrigData)
// OutDestLat=string(DestData)
// ShowMessage(OutOrigLat)
// ShowMessage(OutDestLat)

AnalysisLayer = "Endpoints"
SetView(AnalysisLayer)

AnalRec = LocateRecord("Endpoints|", "LongLat", {OrigData}, {"True"})
If AnalRec = null Then Do
// ShowMessage("Cannot find origin. An error code of 79 will be used.")
Distance = 79
Goto StoreResults

End

```

```

Origin_id = AnalysisLayer. ID

AnalRec = LocateRecord("Endpoints|", "LongLat", {DestData}, {"True"})
If AnalRec = null Then Do
//      ShowMessage("Cannot find destination. An error code of 79 will be used.")
      Distance = 79
      Goto StoreResults
End

Destin_id = AnalysisLayer. ID

// OutOrigID=string(Origin_id)
// OutDestID=string(Destin_id)
// ShowMessage(OutOrigID)
// ShowMessage(OutDestID)

Nodes = {Origin_id, Destin_id}

// ShowMessage(d_NetInfo[1])
// ShowMessage(d_NetInfo[2][1])

// Compute the shortest path
If Origin_id = Destin_id Then Do
      Distance = 0
      Goto StoreResults
End

On error do
//      ShowMessage("There is no shortest path. An error code of 99 will be used.")
      Distance = 99
      Goto StoreResults
End

ShortPath = ShortestPath(d_NetInfo, Nodes, 1, null)
Distance = ShortPath[1]

On error default

// Store the shortest path
StoreResults:

SetView(Results)
Results.BestPath = Distance

// Increment counter and re-initialize variables
Counter = Counter + 1
Distance = 0

// Continue with the next O-D pair until all trips analyzed
SetView(Results)
Record = GetNextRecord(Results + "|", null, {"ID", "Ascending"})

End

ShowMessage("All Done!")

EndMacro

```


GIS-Based Approach for Computing Intra-zonal Trip Lengths Compared to Factor Approach
(analysis of Ontario and Quebec zones, excluding trips with inaccurate co-ordinate information)

District	Zone	Prov.	GIS-Based Distance		Factor-Based Distance		Difference		Sample Size	Total Trips	Veh-Km Travelled	
			Average	W. Avg	Average	W. Avg	Average	Maximum			GIS	Factor
Core	1	ON	1.49	1.47	0.68	0.70	0.82	1.81	9	142	209	100
Core	2	ON	0.57	0.58	0.58	0.62	0.18	0.27	5	124	72	77
Core	3	ON	0.54	0.53	0.57	0.57	0.19	0.31	10	208	111	119
Core	4	ON	0.45	0.45	0.29	0.29	0.16	0.16	1	4	2	1
Core	5	ON	0.33	0.33	0.27	0.27	0.06	0.06	2	9	3	2
Core	6	ON	1.04	1.04	0.87	0.87	0.17	0.17	1	22	23	19
Core	7	ON	0.94	0.94	0.95	0.95	0.12	0.34	11	235	220	223
Core	8	ON	0.73	0.71	0.78	0.77	0.10	0.24	15	277	196	212
Core	9	ON	3.18	3.18	1.34	1.34	1.89	3.23	5	95	302	127
Core	10	ON	0.82	0.82	0.84	0.84	0.02	0.02	2	40	33	34
Core	11	ON	0.80	0.80	0.78	0.77	0.20	0.38	19	410	327	317
Core	12	ON	0.50	0.48	0.59	0.57	0.10	0.34	9	178	86	102
Core	13	ON	0.62	0.65	0.62	0.65	0.10	0.17	10	196	127	127
Core	17	ON	0.64	0.67	0.73	0.76	0.11	0.55	9	221	149	168
Core	19	ON	0.94	0.94	1.07	1.08	0.20	0.41	9	182	171	196
Core	20	ON	0.88	0.89	1.02	1.02	0.18	0.35	63	1276	1,131	1,305
Core	21	ON	1.25	1.25	1.17	1.17	0.08	0.08	1	22	28	26
Core	22	ON	1.18	1.34	0.58	0.63	0.61	3.32	9	166	223	105
Core	23	ON	1.44	1.40	1.39	1.30	0.39	1.29	14	250	349	324
Core	24	ON	0.73	0.73	0.79	0.79	0.15	0.34	19	394	288	312
Core	153	QU	0.59	0.58	0.62	0.60	0.06	0.15	15	327	188	197
Core	154	QU	0.49	0.48	0.49	0.48	0.03	0.08	6	93	45	45
Core	155	QU	1.10	1.10	0.99	0.99	0.12	0.22	9	191	210	190
Core	201	ON	0.37	0.41	0.37	0.40	0.05	0.09	6	78	32	31
Core	255	QU	0.35	0.41	0.32	0.38	0.03	0.03	2	26	11	10
Rural	132	ON	6.28	7.28	6.39	7.49	0.15	0.26	4	55	399	410
Rural	133	ON	10.44	10.61	9.00	9.15	1.68	7.19	991	5132	54,469	46,971
Rural	134	ON	4.74	4.91	4.35	4.52	0.59	4.54	398	2358	11,580	10,662
Rural	135	ON	2.94	2.94	3.17	3.17	0.50	0.73	4	27	81	87
Rural	138	ON	5.71	5.66	5.50	5.45	0.51	4.56	802	5588	31,642	30,473
Rural	139	ON	9.69	9.88	9.41	9.59	0.74	7.54	647	3925	38,786	37,657
Rural	141	ON	4.82	5.81	4.05	4.80	1.08	3.72	38	218	1,269	1,047
Rural	145	ON	8.13	8.14	7.46	7.47	0.90	4.44	245	1575	12,812	11,765
Rural	146	QU	4.30	4.30	2.51	2.51	1.79	2.38	4	92	395	231
Rural	147	QU	3.12	3.12	3.02	3.02	0.13	0.28	7	161	502	486
Rural	177	QU	4.40	4.26	3.68	3.53	0.89	11.85	53	1,060	4,516	3,745
Rural	179	QU	2.04	2.05	1.61	1.62	0.53	1.59	59	1,144	2,343	1,857
Rural	180	QU	1.94	1.95	1.80	1.80	0.27	1.70	446	8,565	16,662	15,422
Rural	182	QU	12.44	13.11	13.48	14.23	1.31	2.61	77	327	4,293	4,659
Rural	183	QU	12.72	12.60	12.11	12.00	0.93	3.43	296	1,326	16,707	15,900
Rural	184	QU	5.24	5.31	5.17	5.23	0.61	4.39	318	1,491	7,922	7,795
Rural	185	QU	19.06	18.64	14.26	13.91	4.81	5.00	218	1,326	24,714	18,437
Rural	230	ON	1.92	1.92	2.22	2.22	0.29	0.47	5	99	191	220
Suburban	119	ON	0.74	0.74	0.78	0.78	0.14	0.26	6	126	93	98
Suburban	129	ON	1.85	1.85	1.73	1.73	0.26	1.73	54	1317	2,430	2,278
Suburban	130	ON	1.95	1.94	1.89	1.89	0.22	1.56	206	3771	7,333	7,117
Suburban	131	ON	1.36	1.37	1.32	1.32	0.31	1.30	85	1772	2,431	2,342
Suburban	136	ON	2.14	2.14	1.84	1.85	0.45	2.60	314	6748	14,461	12,498
Suburban	142	ON	1.42	1.37	1.36	1.33	0.24	2.33	110	2515	3,447	3,341
Suburban	143	ON	1.34	1.33	1.23	1.23	0.26	1.25	21	463	618	568
Suburban	144	ON	1.52	1.52	1.42	1.42	0.24	0.83	29	685	1,040	970
Suburban	171	QU	1.39	1.81	1.19	1.55	0.20	0.44	3	46	83	71
Suburban	172	QU	0.85	0.86	0.79	0.81	0.15	0.48	24	493	422	397
Suburban	173	QU	1.11	1.11	1.00	1.00	0.18	0.87	60	1,338	1,491	1,335
Suburban	174	QU	1.72	1.72	1.17	1.17	0.64	1.37	26	612	1,053	714
Suburban	175	QU	1.45	1.46	1.02	1.02	0.48	2.83	64	1,486	2,175	1,522
Suburban	178	QU	1.85	1.86	1.50	1.50	0.42	1.19	22	497	923	746
Suburban	202	ON	1.28	1.29	1.27	1.27	0.25	0.94	91	1985	2,553	2,515
Suburban	203	ON	0.60	0.60	0.66	0.66	0.13	0.19	2	46	28	30
Suburban	204	ON	1.94	1.88	0.81	0.79	1.19	1.90	28	542	1,016	427
Suburban	206	ON	1.23	1.23	1.08	1.08	0.15	0.15	1	5	6	6
Suburban	207	ON	1.90	1.92	1.90	1.91	0.16	0.19	5	109	209	208
Suburban	208	ON	0.65	0.65	0.75	0.75	0.10	0.10	3	67	43	50
Suburban	211	ON	1.60	1.60	1.65	1.65	0.15	0.20	3	67	107	111
Suburban	216	ON	1.00	0.89	0.95	0.83	0.21	0.45	22	457	404	378
Suburban	217	ON	1.76	1.77	1.59	1.59	0.28	1.00	39	817	1,441	1,297
Suburban	218	ON	0.67	0.68	0.64	0.62	0.04	0.08	5	77	52	48
Suburban	219	ON	0.93	0.93	0.86	0.86	0.07	0.11	4	89	83	77

District	Zone	Prov.	GIS-Based Distance		Factor-Based Distance		Difference		Sample Size	Total Trips	Veh-Km Travelled	
			Average	W. Avg	Average	W. Avg	Average	Maximum			GIS	Factor
Suburban	220	ON	1.66	1.63	1.31	1.28	0.44	2.26	119	2266	3,691	2,898
Suburban	224	ON	2.79	2.79	2.95	2.95	0.16	0.16	4	100	278	294
Suburban	225	ON	1.30	1.30	0.97	0.97	0.33	0.33	1	25	32	24
Suburban	235	ON	0.93	0.93	0.77	0.77	0.18	0.55	13	300	279	231
Suburban	236	ON	1.49	1.53	1.09	1.14	0.47	1.36	27	564	861	643
Suburban	237	ON	1.76	1.75	1.52	1.51	0.33	1.25	80	1671	2,933	2,520
Suburban	238	ON	1.00	1.00	0.99	0.99	0.10	0.26	32	626	624	617
Suburban	239	ON	1.23	1.23	1.05	1.04	0.21	0.60	13	258	316	269
Suburban	240	ON	1.92	1.81	1.40	1.30	0.60	1.80	40	836	1,514	1,083
Suburban	241	ON	1.87	1.87	1.86	1.86	0.01	0.01	2	47	88	88
Suburban	245	ON	3.22	3.22	2.24	2.24	0.98	0.98	2	42	135	94
Suburban	248	QU	1.32	1.32	1.29	1.29	0.25	0.49	7	165	218	212
Suburban	249	QU	1.09	1.09	1.07	1.08	0.14	0.62	39	857	936	925
Suburban	250	QU	1.65	1.65	1.58	1.58	0.14	0.23	21	472	779	743
Suburban	251	QU	1.24	1.24	1.07	1.07	0.21	1.07	38	700	870	748
Urban	26	ON	2.61	2.61	2.37	2.37	0.24	0.24	2	47	124	112
Urban	27	ON	1.31	1.34	0.39	0.41	0.93	0.99	2	11	15	4
Urban	28	ON	1.19	1.19	1.24	1.24	0.20	0.46	38	893	1,062	1,111
Urban	31	ON	0.42	0.42	0.33	0.33	0.16	0.20	4	88	37	29
Urban	33	ON	0.81	0.82	1.00	1.01	0.19	0.49	27	574	468	578
Urban	34	ON	0.21	0.21	0.22	0.22	0.01	0.01	2	42	9	9
Urban	35	ON	1.09	1.09	1.08	1.08	0.05	0.07	4	91	99	98
Urban	37	ON	0.82	0.84	0.92	0.94	0.25	0.60	21	440	368	412
Urban	38	ON	0.53	0.53	0.70	0.70	0.18	0.26	3	67	35	47
Urban	39	ON	1.11	1.10	1.13	1.16	0.10	0.28	7	138	151	159
Urban	40	ON	0.77	0.77	0.89	0.90	0.20	0.51	20	436	338	392
Urban	41	ON	1.62	1.62	1.79	1.79	0.30	0.60	31	628	1,019	1,124
Urban	43	ON	1.71	1.71	0.79	0.79	0.96	3.25	14	283	485	224
Urban	44	ON	0.87	0.87	0.92	0.92	0.05	0.05	1	20	18	19
Urban	45	ON	0.83	0.83	0.83	0.83	0.14	0.43	7	152	125	126
Urban	46	ON	0.96	0.96	0.34	0.34	0.62	0.62	1	20	19	7
Urban	47	ON	1.30	1.37	1.28	1.36	0.23	0.87	94	2139	2,923	2,901
Urban	48	ON	0.80	0.80	0.73	0.73	0.14	0.48	5	123	99	90
Urban	49	ON	1.61	1.58	0.87	0.86	0.76	1.91	11	225	357	194
Urban	51	ON	0.67	0.67	0.59	0.59	0.08	0.26	6	128	85	75
Urban	53	ON	1.75	1.71	1.42	1.36	0.42	3.95	39	800	1,372	1,089
Urban	54	ON	1.11	1.12	0.96	0.96	0.28	2.30	47	960	1,073	925
Urban	55	ON	2.40	2.40	0.39	0.39	2.01	2.01	1	21	49	8
Urban	57	ON	1.49	1.49	1.18	1.18	0.37	2.08	51	1066	1,590	1,256
Urban	58	ON	0.71	0.71	0.60	0.60	0.11	0.11	1	5	4	3
Urban	61	ON	0.81	0.89	0.83	0.87	0.07	0.20	7	127	113	111
Urban	62	ON	0.49	0.47	0.64	0.63	0.15	0.18	2	30	14	19
Urban	63	ON	1.12	1.14	1.29	1.31	0.33	1.14	153	2988	3,408	3,903
Urban	64	ON	1.10	1.10	0.93	0.93	0.23	0.45	5	113	125	106
Urban	65	ON	1.54	1.53	1.38	1.37	0.30	1.02	40	899	1,378	1,235
Urban	66	ON	1.82	1.82	1.65	1.65	0.17	0.17	1	7	12	11
Urban	67	ON	1.13	1.13	0.98	0.97	0.23	0.66	61	1280	1,444	1,236
Urban	69	ON	1.70	1.71	0.87	0.87	0.90	1.92	15	306	522	266
Urban	70	ON	0.45	0.45	0.67	0.67	0.22	0.22	1	21	9	14
Urban	71	ON	0.39	0.39	0.10	0.10	0.29	0.29	1	4	2	0
Urban	72	ON	0.31	0.31	0.44	0.44	0.13	0.13	1	21	6	9
Urban	73	ON	0.84	0.84	0.95	0.95	0.12	0.22	7	140	117	133
Urban	74	ON	0.81	0.80	0.93	0.90	0.21	0.41	7	136	109	123
Urban	75	ON	1.36	1.36	1.43	1.44	0.14	0.34	12	243	331	351
Urban	76	ON	0.66	0.66	0.58	0.58	0.08	0.08	1	22	15	13
Urban	77	ON	1.34	1.34	1.26	1.27	0.13	0.48	44	978	1,312	1,237
Urban	80	ON	1.55	1.55	1.56	1.56	0.50	0.72	3	71	110	111
Urban	83	ON	1.93	1.92	1.29	1.31	0.70	2.05	10	223	428	291
Urban	84	ON	0.89	0.88	0.79	0.78	0.14	0.20	5	114	100	89
Urban	85	ON	1.15	1.16	1.21	1.21	0.17	0.40	60	1358	1,572	1,649
Urban	86	ON	0.47	0.47	0.55	0.55	0.08	0.08	1	23	11	13
Urban	87	ON	0.17	0.17	0.10	0.10	0.07	0.07	1	27	5	3
Urban	88	ON	1.74	1.85	1.49	1.60	0.41	1.38	31	634	1,171	1,013
Urban	89	ON	0.63	0.63	0.87	0.86	0.26	0.55	6	135	84	116
Urban	92	ON	1.28	1.28	1.29	1.31	0.25	0.59	54	1051	1,342	1,378
Urban	93	ON	1.17	1.16	0.92	0.91	0.37	0.71	7	176	204	160
Urban	94	ON	0.71	0.71	0.69	0.70	0.15	0.56	21	425	300	299
Urban	95	ON	1.09	1.10	0.92	0.93	0.24	0.54	45	1021	1,128	948
Urban	96	ON	0.98	1.00	1.08	1.09	0.22	0.76	44	1135	1,129	1,240
Urban	97	ON	1.02	1.03	1.05	1.06	0.21	0.56	24	506	521	536

District	Zone	Prov.	GIS-Based Distance*		Factor-Based Distance*		Difference**		Sample Size	Total Trips	Veh-Km Travelled	
			Average	W. Avg	Average	W. Avg	Average	Maximum			GIS	Factor
Urban	98	ON	1.11	1.11	1.11	1.11	0.19	0.28	12	260	289	288
Urban	99	ON	2.34	2.32	1.81	1.80	0.53	0.75	6	140	325	252
Urban	100	ON	1.49	1.49	1.22	1.23	0.42	2.21	26	599	894	735
Urban	102	ON	1.18	1.16	0.68	0.66	0.49	0.59	3	65	75	43
Urban	103	ON	0.78	0.80	0.51	0.52	0.27	0.35	7	172	137	90
Urban	104	ON	1.32	1.32	1.11	1.11	0.21	0.21	4	101	133	112
Urban	105	ON	0.67	0.67	0.15	0.15	0.52	0.52	1	21	14	3
Urban	107	ON	1.63	1.63	1.51	1.51	0.23	0.90	73	1579	2,566	2,388
Urban	108	ON	2.13	2.13	1.54	1.54	0.59	0.59	1	21	44	32
Urban	109	ON	1.64	1.63	1.25	1.22	0.52	1.64	39	904	1,469	1,105
Urban	110	ON	1.28	1.28	1.06	1.06	0.40	2.94	30	760	970	804
Urban	111	ON	0.96	1.03	0.70	0.74	0.40	0.79	7	71	73	52
Urban	112	ON	1.19	1.23	1.08	1.11	0.27	0.73	18	435	534	482
Urban	113	ON	0.88	0.88	0.84	0.84	0.09	0.14	5	103	91	86
Urban	114	ON	0.86	0.86	0.29	0.29	0.57	1.10	4	82	71	24
Urban	115	ON	1.74	1.74	1.50	1.50	0.34	1.11	76	1518	2,642	2,275
Urban	116	ON	1.66	1.67	1.55	1.55	0.34	1.63	50	1155	1,928	1,794
Urban	117	ON	1.52	1.52	1.43	1.43	0.20	0.74	85	1782	2,702	2,555
Urban	120	ON	2.13	1.91	1.53	1.47	0.65	2.58	13	211	404	311
Urban	121	ON	2.35	2.35	2.08	2.08	0.39	1.49	16	331	779	686
Urban	123	ON	1.92	1.92	1.66	1.66	0.46	3.19	92	1918	3,682	3,179
Urban	124	ON	5.60	5.60	5.47	5.47	0.13	0.13	1	22	124	121
Urban	125	ON	1.52	1.53	1.43	1.45	0.26	1.53	199	3713	5,681	5,401
Urban	126	ON	1.61	1.61	1.74	1.74	0.19	0.44	16	317	510	553
Urban	128	ON	2.59	1.79	2.50	2.01	0.72	1.20	3	33	59	66
Urban	148	QU	1.43	1.44	1.36	1.37	0.22	1.01	136	2,669	3,847	3,669
Urban	149	QU	1.18	1.18	1.02	1.03	0.26	0.52	16	316	373	324
Urban	150	QU	2.53	2.53	2.02	2.02	0.51	0.84	4	77	195	156
Urban	151	QU	1.33	1.35	1.19	1.21	0.40	1.12	41	787	1,061	954
Urban	152	QU	0.62	0.62	0.54	0.54	0.10	0.27	13	254	157	137
Urban	158	QU	0.71	0.69	0.72	0.69	0.17	0.73	80	1,393	961	961
Urban	159	QU	1.09	1.10	1.10	1.12	0.14	0.55	41	898	987	1,002
Urban	161	QU	1.48	1.48	1.49	1.49	0.16	0.48	96	1,927	2,845	2,870
Urban	162	QU	1.66	1.54	1.54	1.39	0.21	0.89	11	143	221	200
Urban	163	QU	0.91	0.96	0.87	0.93	0.04	0.06	2	43	42	40
Urban	164	QU	1.77	1.77	1.44	1.44	0.37	2.25	60	1,200	2,126	1,724
Urban	165	QU	1.86	1.84	1.26	1.25	0.65	3.31	117	1,985	3,657	2,488
Urban	166	QU	0.83	0.84	0.76	0.75	0.19	1.36	34	705	591	531
Urban	167	QU	1.36	1.36	1.35	1.34	0.19	0.96	51	1,183	1,612	1,591
Urban	168	QU	1.73	1.72	1.54	1.57	0.29	1.08	51	992	1,702	1,558
Urban	169	QU	1.10	1.10	0.93	0.93	0.24	1.70	43	876	961	816
Urban	170	QU	1.59	1.60	1.44	1.45	0.23	0.70	63	1,279	2,046	1,857
Urban	232	ON	1.34	1.34	1.16	1.16	0.37	3.82	44	879	1,178	1,016
Urban	252	QU	1.30	1.32	0.89	0.90	0.44	1.56	36	791	1,041	714
Urban	253	QU	1.09	1.09	1.00	1.00	0.18	0.44	55	1,140	1,242	1,137
Urban	256	QU	2.84	2.84	1.17	1.17	1.67	3.17	4	92	261	107
Urban	257	QU	1.08	1.10	0.83	0.91	0.25	1.32	58	1,044	1,146	955
Urban	258	QU	1.25	1.21	1.30	1.24	0.20	0.70	76	1,396	1,690	1,730

NOTES:

* All averages are based on the trips occurring in each district, not average zonal characteristics

** Computed using absolute values

Also note that some traffic zones may not have intra-zonal trips, and are thus excluded from the table

APPENDIX G

OPERATING MODE ANALYSIS

```

' .....
' This macro uses the 1995 O-D survey database to create a new
' database containing only:
'
'     unlinked auto trips
'     the first segment of linked auto trips
'
' This information can be used to model the cold-start emissions
' resulting from automobile use in the Ottawa-Carleton region.
'
' Input Table: TRIP2
' Output Tables: HotTrips_**HrSoakTime, ColdTrips_**HrSoakTime
' Temporary Tables: TripTemplate1, TripTemplate2
'
' Please note that this macro is intended to work with the 1995
' O-D Survey. Modifications will be required if other O-D
' databases are to be used.
'
' Jennifer Armstrong, Carleton University
' September 1999
' .....
Public Sub LinkedTrials2()

' Declare variables

Dim dbMyDB As Database
Set dbMyDB = CurrentDb()

Dim OldTripTable As Recordset
Set OldTripTable = dbMyDB.OpenRecordset("TRIP2", dbOpenTable)

Dim ColdTrips As Recordset
Set ColdTrips = dbMyDB.OpenRecordset("TripTemplate1", dbOpenTable)

Dim HotTrips As Recordset
Set HotTrips = dbMyDB.OpenRecordset("TripTemplate2", dbOpenTable)

Dim Household As Recordset
Set Household = dbMyDB.OpenRecordset("HOUSEHLD", dbOpenTable)

Dim HH_Num1, Per_Num1, OriginZone1, DestZone1 As Long
Dim Dist1, Dur1 As Double
Dim End_Time1, Start_Time1, Duration1 As Date
Dim OrigPurp1, DestPurp1 As String

Dim HH_Num2, Per_Num2, OriginZone2, DestZone2 As Long
Dim Dist2, Dur2 As Double
Dim End_Time2, Start_Time2, Duration2 As Date
Dim OrigPurp2, DestPurp2 As String

Dim Mode, strMsg, FileName, FinalPurp, Purpose As String
Dim Soak_Time, Start_Time, LinkedTrips, FinalDest, Vehicle, TestHH As Long
Dim SoakMin, PreviousEndTime As Date

' Initialize variables

LinkedTrips = 1
Vehicle = 1

' Allow user to input maximum soak time

strMsg = "Please enter the maximum soak time for hot start vehicle operation." & _
Chr(10) & "Note that user input must be in hours (i.e. 1.5)"

On Error GoTo 10
Soak_Time = InputBox(Prompt:=strMsg, Title:="User Data")

SoakMin = ((Soak_Time - Fix(Soak_Time)) * 60) + (60 * (Fix(Soak_Time)))

If SoakMin < 0 Or SoakMin > 600 Then GoTo 10

GoTo 20

10 Soak_Time = 1
SoakMin = 60
MsgBox "Your value is out of range. A default value of 1 hour will be assumed."

' Move to the first record in the original trip table

20 OldTripTable.MoveFirst

' Find the first record corresponding to the auto-driver mode

Mode = OldTripTable![Prime_Mode].Value

30 If Mode <> "D" Then

    OldTripTable.MoveNext
    Mode = OldTripTable![Prime_Mode].Value
    GoTo 30

End If

' For the selected record, save certain values

```

```

HH_Num1 = OldTripTable![HH_Num].Value
Per_Num1 = OldTripTable![Per_Num].Value
Start_Time = OldTripTable![Start_Time].Value
If Start_Time > 2359 Then
    Start_Time1 = Format(Start_Time - 2400, "00:##")
Else
    Start_Time1 = Format(Start_Time, "00:##")
End If
Duration1 = CInt(OldTripTable![Duration].Value)
Dur1 = OldTripTable![Duration].Value
End_Time1 = Format(DateAdd("n", Duration1, Start_Time1), "hh:nn")
OriginZone1 = OldTripTable![Orig_Zone].Value
DestZone1 = OldTripTable![Dest_Zone].Value
FinalDest = DestZone1
OrigPurp1 = OldTripTable![Orig_Purp].Value
DestPurp1 = OldTripTable![Dest_Purp].Value
FinalPurp = DestPurp1
Dist1 = OldTripTable![Distance].Value

' Find the next record corresponding to the auto-driver mode

On Error GoTo 500
40 OldTripTable.MoveNext
Mode = OldTripTable![Prime_Mode].Value
If Mode <> "D" Then GoTo 40

' For the selected record, save certain values

HH_Num2 = OldTripTable![HH_Num].Value
Per_Num2 = OldTripTable![Per_Num].Value
Start_Time = OldTripTable![Start_Time].Value
If Start_Time > 2359 Then
    Start_Time2 = Format(Start_Time - 2400, "00:##")
Else
    Start_Time2 = Format(Start_Time, "00:##")
End If
Duration2 = CInt(OldTripTable![Duration].Value)
Dur2 = OldTripTable![Duration].Value
End_Time2 = Format(DateAdd("n", Duration2, Start_Time2), "hh:nn")
OriginZone2 = OldTripTable![Orig_Zone].Value
DestZone2 = OldTripTable![Dest_Zone].Value
OrigPurp2 = OldTripTable![Orig_Purp].Value
DestPurp2 = OldTripTable![Dest_Purp].Value
Dist2 = OldTripTable![Distance].Value

' Compare the two records to determine if the trips are linked
' If the trips are linked, increment the linked trip counter and
' go to line 100. Otherwise, go to line 200

' If the households are different, the trips are not linked
If HH_Num1 <> HH_Num2 Then GoTo 200

' Determine the number of vehicles per household
Vehicle = 1

Household.MoveNext
50 TestHH = Household![HH_Num].Value
If TestHH <> HH_Num1 Then
    Household.MoveNext
    GoTo 50
End If

Vehicle = Household![num_veh].Value

' If 1 vehicle/household, the person driving does not matter
If Vehicle = 1 Then
    If DestZone1 = OriginZone2 And Abs(DateDiff("n", Start_Time2, End_Time1)) < SoakMin Then
        LinkedTrips = LinkedTrips + 1
        GoTo 100
    Else
        GoTo 200
    End If
End If

' If more than 1 vehicle/household, assume each auto driver has a separate vehicle
' that has not been driven previously by someone else in the family
If Per_Num1 = Per_Num2 And DestZone1 = OriginZone2 And _
Abs(DateDiff("n", Start_Time2, End_Time1)) < SoakMin Then
    LinkedTrips = LinkedTrips + 1
    GoTo 100
Else
    GoTo 200
End If

' .....
' This section of code is accessed if the two selected records correspond to
' a linked trip. In this case, the second record is written to the output
' table and the two records are combined into one trip. This new trip is
' then compared with the next auto trip in the 1995 O-D database to determine
' if it is also linked. When all the trip segments of a linked trip have been

```

```

' identified, the first trip in the sequence is written to the output table
' (line 200)
' .....

' Store the destination of the previous linked trip segment, as well as the end
' time (in order to compare this time with the start time of the next auto trip)

100 FinalDest = DestZone2
FinalPurp = DestPurp2
PreviousEndTime = End_Time2

' Write the second trip to the hot start trip table

Purpose = 'NHB'
If OrigPurp2 = 'H' Or DestPurp2 = 'H' Then Purpose = 'HBO'
If OrigPurp2 = 'H' And DestPurp2 = 'H' Then Purpose = 'HBH'
If (OrigPurp2 = 'W' Or OrigPurp2 = 'R') And DestPurp2 = 'H' Then Purpose = 'HBW'
If OrigPurp2 = 'H' And (DestPurp2 = 'W' Or DestPurp2 = 'R') Then Purpose = 'HBW'
If OrigPurp2 = 'H' And (DestPurp2 = 'S' Or DestPurp2 = 'C') Then Purpose = 'HBS'
If (OrigPurp2 = 'S' Or OrigPurp2 = 'C') And DestPurp2 = 'H' Then Purpose = 'HBS'
If OrigPurp2 = 'M' And DestPurp2 = 'H' Then Purpose = 'HBShop'
If OrigPurp2 = 'H' And DestPurp2 = 'M' Then Purpose = 'HBShop'

HotTrips.AddNew
HotTrips:[HH_Num] = HH_Num2
HotTrips:[Per_Num] = Per_Num2
HotTrips:[Orig_Zone] = OriginZone2
HotTrips:[Dest_Zone] = DestZone2
HotTrips:[Start_Time] = Start_Time2
HotTrips:[Duration] = Dur2
HotTrips:[Distance] = Dist2
HotTrips:[Veh/hh] = Vehicle
HotTrips:[Purpose] = Purpose
HotTrips.Update

' Find the next record corresponding to the auto mode

On Error GoTo 500
60 OldTripTable.MoveNext
Mode = OldTripTable:[Prime_Mode].Value
If Mode <> 'D' Then GoTo 60

' For the selected records, store certain values

HH_Num2 = OldTripTable:[HH_Num].Value
Per_Num2 = OldTripTable:[Per_Num].Value
Start_Time = OldTripTable:[Start_Time].Value
If Start_Time > 2359 Then
    Start_Time2 = Format(Start_Time - 2400, "00:##")
Else
    Start_Time2 = Format(Start_Time, "00:##")
End If
Duration2 = CInt(OldTripTable:[Duration].Value)
Dur2 = OldTripTable:[Duration].Value
End_Time2 = Format(DateAdd("n", Duration2, Start_Time2), "hh:nn")
OriginZone2 = OldTripTable:[Orig_Zone].Value
DestZone2 = OldTripTable:[Dest_Zone].Value
OrigPurp2 = OldTripTable:[Orig_Purp].Value
DestPurp2 = OldTripTable:[Dest_Purp].Value
Dist2 = OldTripTable:[Distance].Value

' Compare the two records to determine if the trips are linked
' If the trips are linked, increment the linked trip counter and
' go to line 100. Otherwise, go to line 200

' If the households are different, the trips are not linked

If HH_Num1 <> HH_Num2 Then GoTo 200

' If 1 vehicle/household, the person driving does not matter

If Vehicle = 1 Then
    If FinalDest = OriginZone2 And Abs(DateDiff("n", Start_Time2, PreviousEndTime)) < SoakMin Then
        LinkedTrips = LinkedTrips + 1
        GoTo 100
    Else
        GoTo 200
    End If
End If

' If more than 1 vehicle/household, assume each auto driver has a separate vehicle
' that has not been driven previously by someone else in the family

If Per_Num1 = Per_Num2 And FinalDest = OriginZone2 And _
Abs(DateDiff("n", Start_Time2, PreviousEndTime)) < SoakMin Then
    LinkedTrips = LinkedTrips + 1
    GoTo 100
Else
    GoTo 200
End If

' .....

' This section of code is accessed whenever the two selected records are not
' linked. The first record is written to the output table. The second record
' is then compared with the next auto trip in the 1995 O-D database to

```

```

' determine if the two trips are linked (i.e. the second record becomes the
' new first record and a new second record is selected from the database)
' .....

' Compute the trip purpose based on the trip origin and final destination

200 Purpose = "NHB"
If OrigPurpl = "H" Or FinalPurp = "H" Then Purpose = "HBO"
If OrigPurpl = "H" And FinalPurp = "H" Then Purpose = "HBH"
If (OrigPurpl = "W" Or OrigPurp = "R") And FinalPurp = "H" Then Purpose = "HBW"
If OrigPurpl = "H" And (FinalPurp = "W" Or FinalPurp = "R") Then Purpose = "HBW"
If OrigPurpl = "H" And (FinalPurp = "S" Or FinalPurp = "C") Then Purpose = "HBS"
If (OrigPurpl = "S" Or OrigPurp = "C") And FinalPurp = "H" Then Purpose = "HBS"
If OrigPurpl = "M" And FinalPurp = "H" Then Purpose = "HBShop"
If OrigPurpl = "H" And FinalPurp = "M" Then Purpose = "HBShop"

' Write the first trip (of a series of linked trips) to the output table

ColdTrips.AddNew
ColdTrips![HH_Num] = HH_Num1
ColdTrips![Per_Num] = Per_Num1
ColdTrips![Orig_Zone] = OriginZone1
ColdTrips![Dest_Zone] = DestZone1
ColdTrips![Final_Dest] = FinalDest
ColdTrips![Link_Trip] = LinkedTrips
ColdTrips![Start_Time] = Start_Time1
ColdTrips![Veh/hh] = Vehicle
ColdTrips![Purpose] = Purpose
ColdTrips![Duration] = Dur1
ColdTrips![Distance] = Dist1
ColdTrips.Update

' Reset the linked trip counter

LinkedTrips = 1

' Set the first trip record equal to the second record

HH_Num1 = HH_Num2
Per_Num1 = Per_Num2
Start_Time1 = Start_Time2
End_Time1 = End_Time2
OriginZone1 = OriginZone2
DestZone1 = DestZone2
FinalDest = DestZone1
OrigPurpl = OrigPurp2
DestPurpl = DestPurp2
FinalPurp = DestPurp1
Dist1 = Dist2
Duration1 = Duration2
Dur1 = Dur2

' Find the next record corresponding to the auto mode

On Error GoTo 500
70 OldTripTable.MoveNext
Mode = OldTripTable![Prime_Mode].Value
If Mode <> "D" Then GoTo 70

' For the selected record, store certain values

HH_Num2 = OldTripTable![HH_Num].Value
Per_Num2 = OldTripTable![Per_Num].Value
Start_Time = OldTripTable![Start_Time].Value
If Start_Time > 2359 Then
    Start_Time2 = Format(Start_Time - 2400, "00:##")
Else
    Start_Time2 = Format(Start_Time, "00:##")
End If
Duration2 = CInt(OldTripTable![Duration].Value)
Dur2 = OldTripTable![Duration].Value
End_Time2 = Format(DateAdd("n", Duration2, Start_Time2), "hh:nn")
OriginZone2 = OldTripTable![Orig_Zone].Value
DestZone2 = OldTripTable![Dest_Zone].Value
OrigPurp2 = OldTripTable![Orig_Purp].Value
DestPurp2 = OldTripTable![Dest_Purp].Value
Dist2 = OldTripTable![Distance].Value

' Compare the two records to determine if the trips are linked
' If the trips are linked, increment the linked trip counter and
' go to line 100. Otherwise, go to line 200

' If the households are different, the trips are not linked

If HH_Num1 <> HH_Num2 Then GoTo 200

' Determine the number of vehicles per household

Vehicle = 1
Household.MoveFirst
80 TestHH = Household![HH_Num].Value
If TestHH <> HH_Num1 Then
    Household.MoveNext
    GoTo 80
End If

```



```

Vehicle = Household![num_veh].Value

' If 1 vehicle/household, the person driving does not matter

If Vehicle = 1 Then
    If DestZone1 = OriginZone2 And Abs(DateDiff("n", Start_Time2, End_Time1)) < SoakMin Then
        LinkedTrips = LinkedTrips + 1
        GoTo 100
    Else
        GoTo 200
    End If
End If

' If more than 1 vehicle/household, assume each auto driver has a separate vehicle
' that has not been driven previously by someone else in the family

If Per_Num1 = Per_Num2 And DestZone1 = OriginZone2 And _
Abs(DateDiff("n", Start_Time2, End_Time1)) < SoakMin Then
    LinkedTrips = LinkedTrips + 1
    GoTo 100
Else
    GoTo 200
End If

500 ' Compute the trip purpose of the final trip

Purpose = "NHB"
If OrigPurpl = "H" Or FinalPurp = "H" Then Purpose = "HBO"
If OrigPurpl = "H" And FinalPurp = "H" Then Purpose = "HBH"
If (OrigPurpl = "W" Or OrigPurp = "R") And FinalPurp = "H" Then Purpose = "HEW"
If OrigPurpl = "H" And (FinalPurp = "W" Or FinalPurp = "R") Then Purpose = "HBW"
If OrigPurpl = "H" And (FinalPurp = "S" Or FinalPurp = "C") Then Purpose = "HBS"
If (OrigPurpl = "S" Or OrigPurp = "C") And FinalPurp = "H" Then Purpose = "HBS"
If OrigPurpl = "M" And FinalPurp = "H" Then Purpose = "HBShop"
If OrigPurpl = "H" And FinalPurp = "M" Then Purpose = "HBShop"

' Write the final trip to the output table

ColdTrips.AddNew
ColdTrips![HH_Num1] = HH_Num1
ColdTrips![Per_Num1] = Per_Num1
ColdTrips![Orig_Zone1] = OriginZone1
ColdTrips![Dest_Zone1] = DestZone1
ColdTrips![Final_Dest] = FinalDest
ColdTrips![Link_Trip] = LinkedTrips
ColdTrips![Start_Time] = Start_Time1
ColdTrips![Veh/hh] = Vehicle
ColdTrips![Purpose] = Purpose
ColdTrips![Duration] = Dur1
ColdTrips![Distance] = Dist1
ColdTrips.Update

' When all the records in the database have been examined, save the
' trip table under a new name and delete the records from the template
' table

FileName = "ColdTripsBadCodes_" & Soak_Time & "HrSoakTime"
DoCmd.CopyObject , FileName, acTable, "TripTemplate1"

ColdTrips.MoveFirst

Do Until ColdTrips.EOF
    ColdTrips.Delete
    ColdTrips.MoveNext
Loop

FileName = "HotTripsBadCodes_" & Soak_Time & "HrSoakTime"
DoCmd.CopyObject , FileName, acTable, "TripTemplate2"

HotTrips.MoveFirst

Do Until HotTrips.EOF
    HotTrips.Delete
    HotTrips.MoveNext
Loop

If Soak_Time = 4 Then GoTo 888

Soak_Time = 4
SoakMin = 240
GoTo 20

888 MsgBox "Macro has completed successfully!"
End Sub

```

```

' .....
' This macro imports time/distance values derived from GIS or EMME/2
' analysis. This information is required for modelling the cold-start
' vehicle emissions resulting from automobile use in Ottawa-Carleton.
'
' Input Table: TRIP2, User-specified data table
' Output Table: TRIP2
'
' For the macro to function properly, the AUTO_TRIPS table must contain two
' fields entitled "Duration" and "Distance" to store the new values.
' Likewise, travel time and distance values in the data table should be
' stored in fields entitled "Duration" and "Distance". In addition, the
' following field naming conventions should be followed:
'
'   Household Number = "HH_Num"
'   Person Number = "Per_Num"
'   Trip Number = "Trip_Num"
'   Origin Zone = "Orig_Zone"
'   Destination Zone = "Dest_Zone"
'
' If updating the TRIP table using zonal averages, a separate table
' containing the average values should be specified. The zone number
' should be stored in a field entitled "Zone" while the average
' duration/distance should be stored in fields entitled
' "AvgDur" / "AvgDist". If duration is unknown, an assumed zonal speed
' can be specified in a field entitled "Speed". The user should then
' specify that the duration of intra-zonal trips is to be computed using
' speed data in the opening dialogue sequence. Note that this procedure
' should only be selected AFTER intra-zonal distances have been updated
' in the TRIP table.
'
' Please note that this macro is intended to work with the 1995
' O-D Survey. Modifications will be required if other O-D
' databases are to be used.
'
' Jennifer Armstrong, Carleton University
' October 1999
' .....

Public Sub Distance1()

' Declare variables

Dim dbMyDB As Database
Set dbMyDB = CurrentDb()

Dim Query1, Query2, Query3, strMsg, DataFile, TypeOfData, DurOrDist As String
Dim UpperLimit, LowerLimit As Long

' Allow user to input source and nature of data

On Error GoTo 0
' Change to 10 once debugging finished!

strMsg = "Please enter the name of the MS Access table containing the information."
DataFile = InputBox(Prompt:=strMsg, Title:="User Input")

strMsg = "If the data table contains information by trip, enter 1. If the data table " & _
"contains information by origin/destination zone, enter 2. If you wish to update " & _
"distance/duration values for intra-zonal trips using zonal averages, enter 3. If " & _
"you wish to compute intra-zonal trip durations using average speed data, enter 4."

TypeOfData = InputBox(Prompt:=strMsg, Title:="User Input")

If (TypeOfData <> "1" And TypeOfData <> "2" And TypeOfData <> "3" And TypeOfData <> "4") Then
GoTo 10
End If

If TypeOfData = "2" Or TypeOfData = "4" Then

strMsg = "Enter the upper time limit in the format HHMM using the 24 hour clock. " & _
"(i.e. 5:20 p.m. = 1720)"
UpperLimit = InputBox(Prompt:=strMsg, Title:="User Input")

strMsg = "Enter the lower time limit in the format HHMM using the 24 hour clock. " & _
"(i.e. 5:20 p.m. = 1720)"
LowerLimit = InputBox(Prompt:=strMsg, Title:="User Input")

End If

If LowerLimit > UpperLimit Then GoTo 10
' If LowerLimit > 2400 Or UpperLimit > 2400 Then GoTo 10

If (TypeOfData = "1" Or TypeOfData = "2" Or TypeOfData = "3") Then

strMsg = "Enter 1 to store distance information, 2 to store travel time information."
DurOrDist = InputBox(Prompt:=strMsg, Title:="User Input")

Else

DurOrDist = "2"

End If

```

```

If DurOrDist <> "1" And DurOrDist <> "2" Then GoTo 10

' Determine whether distance of travel time values are to be updated

If DurOrDist = "1" Then DurOrDist = "Distance"
If DurOrDist = "2" Then DurOrDist = "Duration"

' If the data table contains information by trip, go to 100. If the data table
' contains information on zonal averages for intra-zonal trips, go to 200. If the
' data table contains information by origin/destination zone, go to 300.

If TypeOfData = "1" Then GoTo 100
If TypeOfData = "2" Then GoTo 300
If TypeOfData = "3" Then GoTo 200
If TypeOfData = "4" Then GoTo 400

' On error, end program

10 MsgBox "An input error has been encountered. Program will terminate."
GoTo 999

' .....
' This section of code is accessed if the data table contains information by trip

100 Dim qdf As QueryDef
Set qdf = dbMyDB.CreateQueryDef

If DurOrDist = "Distance" Then

Query1 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON (TRIP2.HH_NUM = " & DataFile & ".HH_NUM) " & _
        "AND (TRIP2.PER_NUM = " & DataFile & ".PER_NUM) AND (TRIP2.TRIP_NUM = " & DataFile & _
        ".TRIP_NUM) SET TRIP2.DISTANCE = [" & DataFile & "]![DISTANCE];"

Else

Query1 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON (TRIP2.HH_NUM = " & DataFile & ".HH_NUM) " & _
        "AND (TRIP2.PER_NUM = " & DataFile & ".PER_NUM) AND (TRIP2.TRIP_NUM = " & DataFile & _
        ".TRIP_NUM) SET TRIP2.DURATION = [" & DataFile & "]![DURATION];"

End If

dbMyDB.Execute Query1

GoTo 999

' .....
' This section of code is used to update distance/duration values on a trip by
' trip basis in cases where the co-ordinate information was coded incorrectly
' In such cases, an average zonal value is applied

' Move to the first record in the TRIP table

200 Dim qdf2 As QueryDef
Set qdf2 = dbMyDB.CreateQueryDef

If DurOrDist = "Distance" Then

Query2 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON TRIP2.ORIG_ZONE = " & DataFile & ".Zone " & _
        "SET TRIP2.DISTANCE = [" & DataFile & "]![AvgDist] " & _
        "WHERE (((TRIP2.ORIG_ZONE)=(DEST_ZONE)) AND ((TRIP2.DISTANCE)=null));"

Else

Query2 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON TRIP2.ORIG_ZONE = " & DataFile & ".Zone " & _
        "SET TRIP2.DURATION = [" & DataFile & "]![AvgDur] " & _
        "WHERE (((TRIP2.ORIG_ZONE)=(DEST_ZONE)) AND ((TRIP2.DURATION)=null));"

End If

dbMyDB.Execute Query2

GoTo 999

' .....
' This section of code is accessed if the data table contains information by origin/
' destination

300 Dim qdf3 As QueryDef
Set qdf3 = dbMyDB.CreateQueryDef

If DurOrDist = "Distance" Then

Query3 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON (TRIP2.ORIG_ZONE = " & DataFile & ".Orig_Zone) " & _
        "AND (TRIP2.DEST_ZONE = " & DataFile & ".Dest_Zone) " & _
        "SET TRIP2.DISTANCE = [" & DataFile & "]![Distance] " & _
        "WHERE (((TRIP2.START_TIME)<=" & UpperLimit & ") AND ((TRIP2.START_TIME)>=" & LowerLimit & "));"

Else

Query3 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON (TRIP2.ORIG_ZONE = " & DataFile & ".Orig_Zone) " & _
        "AND (TRIP2.DEST_ZONE = " & DataFile & ".Dest_Zone) " & _
        "SET TRIP2.DURATION = [" & DataFile & "]![Duration] " & _
        "WHERE (((TRIP2.START_TIME)<=" & UpperLimit & ") AND ((TRIP2.START_TIME)>=" & LowerLimit & "));"

End If

```

```

dbMyDB.Execute Query3

GoTo 999

' .....
' This section of code is accessed if duration values for intra-zonal trips are
' to be computed using average speed data

400 Dim qdf4 As QueryDef
Set qdf4 = dbMyDB.CreateQueryDef

Query4 = "UPDATE TRIP2 INNER JOIN " & DataFile & " ON TRIP2.ORIG_ZONE = " & DataFile & ".ZONE " & _
"SET TRIP2.DURATION = [TRIP2].[Distance] / [" & DataFile & "].[SPEED] * 60 " & _
"WHERE (((TRIP2.ORIG_ZONE)=[DEST_ZONE]) AND (((TRIP2.START_TIME)<=" & UpperLimit & _
") AND ((TRIP2.START_TIME)>=" & LowerLimit & ")));";

dbMyDB.Execute Query4

GoTo 999

' .....
' Display message when macro has completed successfully

strMsg = "Macro is complete!"
MsgBox (strMsg)

999 End Sub

```

Data Used to Derive Fraction of 1995 Ottawa-Hull Fleet Equipped with Catalytic Converters

Vehicle Age	Year	Fraction of Fleet	Fraction of Model Year With Catalytic Converter	Fraction of Fleet With Catalytic Converter
0	1995	0.050	1.000	0.050
1	1994	0.096	1.000	0.096
2	1993	0.104	1.000	0.104
3	1992	0.101	1.000	0.101
4	1991	0.097	1.000	0.097
5	1990	0.091	1.000	0.091
6	1989	0.083	1.000	0.083
7	1988	0.075	1.000	0.075
8	1987	0.063	0.907	0.057
9	1986	0.054	0.882	0.048
10	1985	0.046	0.791	0.036
11	1984	0.037	0.912	0.034
12	1983	0.030	0.750	0.023
13	1982	0.022	0.717	0.016
14	1981	0.016	0.803	0.013
15	1980	0.011	0.845	0.009
16	1979	0.007	Not Known	?
17	1978	0.005	Not Known	?
18	1977	0.003	Not Known	?
19	1976	0.003	Not Known	?
20	1975	0.000	Not Known	0.000
21	1974	0.000	Not Known	0.000
22	1973	0.000	Not Known	0.000
23	1972	0.000	Not Known	0.000
24	1971	0.006	0.000	0.000
TOTAL	N/A	1.000	N/A	0.932

Based on data from Philipolt, 1993

Therefore, between 93% and 95% of vehicles in the 1995 fleet have catalytic converters

Based on the above data, it was assumed that 94% of the vehicle fleet was equipped with a catalytic converter in 1995

Model Year	Fraction of Cars Built to Lower Canadian Standards
1980	0.5
1981	0.857
1982	0.857
1983	0.857
1984	0.857
1985	0.897
1986	0.402
1987	0.339
1988	0

Consider Canada-wide inspection and maintenance program:

- survey suggests that 88.7% of vehicles have catalytic converters based on Canadian data from 1991 to 1995
- due to fleet turn-over, this value will be higher for the 1995 fleet
- survey was based on 8221 vehicle inspections, but may be biased since participation was voluntary

Year	Tests
1991	565
1992	1592
1993	1792
1994	2059
1995	2213
TOTAL	8221

- a similar program between 1986 and 1990 showed 66.4% of Canadian vehicles with a catalytic converter
- data from Environment Canada, 1997

Summary of Trip Start Modes in the National Capital Region

Trips in the National Capital Region by Trip Purpose and Time of Day

Trip Purpose	AM Peak Hour	Early Morning	AM Peak Period	Midday	PM Peak Hour	Evening	PM Peak Period	Overall Day
Home-based shop	1335	621	7194	84819	14795	60618	36676	189927
Non home-based	26990	4801	52924	128548	38973	60858	86618	333749
Home-based other	33551	10221	69762	96815	37754	180515	87082	444395
Home-based school	5182	370	9746	12050	2115	8266	6426	36858
Home-based work	68020	38211	127050	54291	52821	59532	107663	386747
TOTAL	135078	54223	266676	376523	146459	369788	324466	1391676

Percent Cold Start Trips, Assuming All Vehicles have Catalytic Converters

Trip Purpose	AM Peak Hour	Early Morning	AM Peak Period	Midday	PM Peak Hour	Evening	PM Peak Period	Overall Day
Home-based shop	84.9	67.1	80.2	62.8	33.3	51.7	38.0	55.1
Non home-based	7.4	9.9	9.0	46.0	67.4	51.9	65.1	45.6
Home-based other	85.6	90.9	83.2	66.1	35.5	68.6	39.5	65.2
Home-based school	98.7	94.4	98.7	92.5	92.6	95.0	93.5	94.9
Home-based work	99.3	99.1	98.9	83.0	95.4	95.1	96.0	95.3
OVERALL	77.4	89.2	76.4	61.8	66.2	67.9	66.0	68.3

* Assumes a 1 hour soak period

Percent Cold Start Trips, Assuming No Vehicles have Catalytic Converters

Trip Purpose	AM Peak Hour	Early Morning	AM Peak Period	Midday	PM Peak Hour	Evening	PM Peak Period	Overall Day
Home-based shop	83.2	67.1	79.0	40.2	13.0	16.8	14.2	29.3
Non home-based	5.0	8.2	4.5	13.9	54.3	21.8	49.8	23.1
Home-based other	85.2	90.6	82.2	40.3	18.8	24.2	19.5	37.4
Home-based school	97.7	94.4	97.9	58.9	81.4	41.0	74.1	68.2
Home-based work	99.0	98.8	98.1	60.7	83.7	78.7	84.8	86.2
OVERALL	76.6	88.8	74.8	34.8	52.0	31.7	49.7	47.2

* Assumes a 4 hour soak period

Percent Cold Start Trips, Assuming 94% of the Fleet has Catalytic Converters

Trip Purpose	AM Peak Hour	Early Morning	AM Peak Period	Midday	PM Peak Hour	Evening	PM Peak Period	Overall Day
Home-based shop	84.8	67.1	80.1	61.5	32.1	49.6	36.6	53.6
Non home-based	7.3	9.8	8.7	44.1	66.6	50.1	64.1	44.3
Home-based other	85.6	90.8	83.1	64.6	34.5	65.9	38.3	63.5
Home-based school	98.6	94.4	98.7	90.4	92.0	91.7	92.4	93.3
Home-based work	99.3	99.1	98.9	81.6	94.7	94.1	95.3	94.7
OVERALL	77.3	89.2	76.3	60.2	65.4	65.7	65.0	67.0

Summary of Operating Mode Fractions Computed from 1995 OD Survey

Travel Summary, Assuming 94% of Vehicles have Catalytic Converters

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
Vehicle-Km Travelled								
Cold Start	356,824	1,086,243	554,238	1,268,126	495,520	1,082,797	1,460,633	5,254,623
Hot Start	36,222	299,760	147,515	711,838	220,328	490,081	615,888	2,153,789
Stable	486,354	1,569,445	781,314	1,190,374	841,143	1,809,906	1,380,480	6,436,559
TOTAL	879,400	2,955,448	1,483,067	3,170,339	1,556,990	3,382,783	3,457,001	13,844,971
% of Vehicle-Km Travelled								
Cold Start	40.6	36.8	37.4	40.0	31.8	32.0	42.3	38.0
Hot Start	4.1	10.1	9.9	22.5	14.2	14.5	17.8	15.6
Stable	55.3	53.1	52.7	37.5	54.0	53.5	39.9	46.5
TOTAL	100	100	100	100	100	100	100	100

Travel Summary, Assuming All Vehicles have Catalytic Converters

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
Vehicle-Km Travelled								
Cold Start	356,924	1,087,596	554,543	1,301,228	501,563	1,097,924	1,506,698	5,350,369
Hot Start	36,121	298,407	147,210	678,737	214,284	474,954	569,824	2,058,042
Stable	486,354	1,569,445	781,314	1,190,374	841,143	1,809,906	1,380,480	6,436,559
TOTAL	879,400	2,955,448	1,483,067	3,170,339	1,556,990	3,382,783	3,457,001	13,844,971
% of Vehicle-Km Travelled								
Cold Start	40.6	36.8	37.4	41.0	32.2	32.5	43.6	38.6
Hot Start	4.1	10.1	9.9	21.4	13.8	14.0	16.5	14.9
Stable	55.3	53.1	52.7	37.5	54.0	53.5	39.9	46.5
TOTAL	100	100	100	100	100	100	100	100

Travel Summary, Assuming No Vehicles have Catalytic Converters

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
Vehicle-Km Travelled								
Cold Start	355,250	1,065,038	549,463	749,540	400,836	845,803	738,957	3,754,588
Hot Start	37,796	320,965	152,291	1,230,424	315,011	727,075	1,337,565	3,653,824
Stable	486,354	1,569,445	781,314	1,190,374	841,143	1,809,906	1,380,480	6,436,559
TOTAL	879,400	2,955,448	1,483,067	3,170,339	1,556,990	3,382,783	3,457,001	13,844,971
% of Vehicle-Km Travelled								
Cold Start	40.4	36.0	37.0	23.6	25.7	25.0	21.4	27.1
Hot Start	4.3	10.9	10.3	38.8	20.2	21.5	38.7	26.4
Stable	55.3	53.1	52.7	37.5	54.0	53.5	39.9	46.5
TOTAL	100	100	100	100	100	100	100	100

Percentage of Daily VKT Occurring in each Time Period

	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening	TOTAL
% of Total VKT	6.4	21.3	10.7	22.9	11.2	24.4	25.0	100.0

Notes:

Trips within the AM and PM peak hour are also part of the AM and PM peak period

External trips and trips with inaccurate origin/destination records are excluded

Vehicle-Kilometers of Travel By Operating Mode - Based on EMME/2 Traffic Assignment of Trip Tables from 1995 OD Survey

Facility Type	Area	Early Morning Period			AM Peak Period			Midday			PM Peak Period		
		Start	Total	Cold	Start	Total	Cold	Start	Total	Cold	Start	Total	Cold
Local	core	101	209	94	1,611	4,003	911	806	1,106	525	3,126	3,822	2,358
Minor Arterial/Collector	core	4,675	16,510	4,093	38,197	78,792	23,797	20,084	28,066	12,669	60,599	83,535	44,750
Major Arterial/Collector	core	1,984	6,219	1,712	4,900	17,024	3,056	3,608	5,547	2,137	10,712	19,649	8,239
Freeways/Rural Hwys	core	3,750	15,069	3,286	14,632	44,384	8,652	14,132	25,321	8,708	26,072	47,326	19,939
Centroid Connectors	core	366	1,128	306	6,016	10,888	3,685	3,173	4,156	1,914	8,548	10,477	6,295
All Roads	core	10,876	39,134	9,490	65,355	155,091	40,101	41,803	64,195	25,953	109,057	164,810	81,581
Local	urban	2,204	3,706	2,125	16,287	22,521	11,525	9,626	11,932	5,256	18,775	28,075	11,451
Minor Arterial/Collector	urban	23,406	43,440	21,636	138,761	233,759	100,421	78,160	104,391	42,739	161,267	279,586	110,161
Major Arterial/Collector	urban	9,955	24,562	9,387	51,810	119,723	38,769	27,551	46,051	16,103	67,518	152,727	51,079
Freeways/Rural Hwys	urban	28,068	90,831	25,749	67,786	221,950	47,853	68,861	135,809	41,706	83,121	258,078	62,866
Centroid Connectors	urban	6,520	10,765	6,071	46,092	66,499	33,158	30,605	38,831	15,807	53,278	78,516	33,411
All Roads	urban	70,154	173,304	64,968	320,736	664,451	231,725	214,803	337,094	121,611	383,958	796,982	268,968
Local	suburbs	1,276	1,468	1,230	5,428	6,643	4,433	2,658	3,578	1,482	5,367	10,246	2,894
Minor Arterial/Collector	suburbs	7,937	10,569	7,464	33,574	46,575	26,788	17,308	22,897	10,307	37,520	73,931	22,375
Major Arterial/Collector	suburbs	2,911	7,920	2,852	17,255	39,688	14,249	7,421	17,271	4,775	14,330	53,894	9,287
Freeways/Rural Hwys	suburbs	11,653	38,023	11,222	23,169	97,700	18,510	14,726	71,582	8,816	20,510	130,472	13,266
Centroid Connectors	suburbs	4,683	5,864	4,382	20,092	25,055	15,603	11,826	15,126	6,557	20,608	35,051	10,235
All Roads	suburbs	28,459	63,843	27,250	99,518	215,661	79,584	53,940	130,453	31,936	98,336	303,594	58,057
Local	rural	60	87	59	158	250	131	132	146	64	273	321	179
Minor Arterial/Collector	rural	1,329	3,445	1,277	6,142	13,975	5,038	1,911	5,039	1,114	7,201	20,229	5,237
Major Arterial/Collector	rural	9,718	28,397	9,297	19,996	101,240	17,172	11,274	49,701	6,805	20,775	164,647	12,659
Freeways/Rural Hwys	rural	17,901	80,314	16,736	39,364	277,407	32,245	26,901	225,634	16,776	34,523	378,163	22,760
Centroid Connectors	rural	13,805	18,243	13,276	36,181	47,643	31,661	11,795	22,790	7,412	21,303	71,829	14,761
All Roads	rural	42,813	130,485	40,644	101,841	440,515	86,247	52,013	303,310	32,171	84,076	635,190	55,596
Local	All	3,641	5,469	3,507	23,483	33,416	17,000	13,221	16,762	7,326	27,541	42,465	16,882
Minor Arterial/Collector	All	37,347	73,963	34,470	216,675	373,101	156,043	117,464	160,393	66,829	266,588	457,282	182,523
Major Arterial/Collector	All	24,568	67,099	23,247	93,961	277,675	73,246	49,854	118,570	29,819	113,335	390,918	81,265
Freeways/Rural Hwys	All	61,372	224,237	57,092	144,951	641,440	107,259	124,620	458,425	76,006	164,226	814,039	118,831
Centroid Connectors	All	25,374	36,000	24,035	108,380	150,085	84,107	57,400	80,902	31,690	103,737	195,873	64,702
All Roads	All	152,302	406,767	142,351	587,450	1,475,718	437,656	362,558	835,053	211,670	675,427	1,900,576	464,202

Facility Type	Area	Evening Period			PM Peak Hour			AM Peak Hour		
		Start	Total	Cold	Start	Total	Cold	Start	Total	Cold
Local	core	894	1,016	520	3,144	4,120	2,392	1,716	5,124	1,073
Minor Arterial/Collector	core	16,367	22,720	11,599	62,212	92,362	46,612	34,161	95,625	20,989
Major Arterial/Collector	core	2,868	4,684	2,093	10,107	22,679	7,780	4,008	22,435	2,239
Freeways/Rural Hwys	core	11,670	20,173	8,529	25,780	48,900	19,707	11,374	50,219	7,811
Centroid Connectors	core	2,951	3,588	1,877	8,999	11,056	6,587	5,223	11,800	3,194
All Roads	core	34,750	52,181	24,619	110,243	179,116	83,079	56,482	185,203	35,306
Local	urban	8,588	10,683	4,891	20,163	31,346	12,860	19,680	31,140	15,253
Minor Arterial/Collector	urban	61,030	82,638	37,628	169,926	315,291	119,113	150,962	312,528	113,545
Major Arterial/Collector	urban	24,478	39,342	15,513	70,514	171,972	54,023	50,917	165,187	39,668
Freeways/Rural Hwys	urban	61,034	114,912	44,178	77,155	274,555	59,051	52,835	259,231	39,583
Centroid Connectors	urban	25,023	31,390	14,424	55,282	83,741	35,751	49,130	77,439	37,719
All Roads	urban	180,153	278,964	116,635	393,040	876,905	280,797	323,524	845,524	245,768
Local	Suburbs	3,078	4,263	1,664	4,983	11,281	2,751	7,598	9,454	6,448
Minor Arterial/Collector	Suburbs	18,553	24,783	10,314	38,542	80,612	23,728	45,963	69,113	38,457
Major Arterial/Collector	Suburbs	5,927	13,314	3,494	13,241	57,579	8,433	20,273	54,764	17,627
Freeways/Rural Hwys	Suburbs	17,785	60,650	12,473	21,220	139,738	14,654	27,608	116,459	22,607
Centroid Connectors	Suburbs	12,333	16,268	6,861	20,645	36,945	11,010	25,699	32,487	21,167
All Roads	Suburbs	57,676	119,278	34,806	98,632	326,156	60,576	127,141	282,278	106,306
Local	rural	69	112	19	308	377	191	156	367	122
Minor Arterial/Collector	rural	2,239	5,144	1,600	7,605	25,100	5,332	8,341	23,975	7,251
Major Arterial/Collector	rural	11,166	41,206	6,964	21,889	184,324	13,885	27,695	159,299	24,678
Freeways/Rural Hwys	rural	15,632	149,452	10,800	36,430	414,364	24,199	46,505	340,654	38,668
Centroid Connectors	rural	9,622	22,980	6,740	20,980	77,352	14,070	49,983	68,020	45,488
All Roads	rural	38,728	218,894	26,123	87,212	701,516	57,677	132,679	592,314	116,206
Local	All	12,629	16,074	7,094	28,599	47,124	18,193	29,149	46,085	22,896
Minor Arterial/Collector	All	98,189	135,285	61,141	278,284	513,364	194,785	239,427	501,241	180,243
Major Arterial/Collector	All	44,439	98,545	28,064	115,752	436,554	84,122	102,893	401,685	84,212
Freeways/Rural Hwys	All	106,121	345,187	75,981	160,585	877,557	117,610	138,321	766,563	108,669
Centroid Connectors	All	49,929	74,226	29,903	105,907	209,094	67,418	130,035	189,745	107,567
All Roads	All	311,307	669,317	202,182	689,127	2,083,693	482,129	639,826	1,905,319	503,587

Note: Travel estimates correspond to the representative hour used to model travel activity within each analysis period

VKT estimates may vary slightly from those presented elsewhere due to later modifications in the external trip matrices and traffic zone tags

Operating Mode Fractions By Road Classification - Based on EMMIE/2 Traffic Assignment of Trip Tables from 1995 OD Survey

Facility Type	Area	Early Morning			AM Peak Period			Midday			PM Peak Period			Evening		
		% Hot	% Cold	% Stable	% Hot	% Cold	% Stable	% Hot	% Cold	% Stable	% Hot	% Cold	% Stable	% Hot	% Cold	% Stable
Local	Core	3.4	44.8	51.8	17.5	22.8	59.8	25.4	47.5	27.1	20.1	61.7	18.2	36.8	51.2	12.0
Minor Arterial/Collector	Core	3.5	24.8	71.7	18.3	30.2	51.5	26.4	45.1	28.4	19.0	53.6	27.5	21.0	51.1	28.0
Major Arterial/Collector	Core	4.4	27.5	68.1	10.8	17.9	71.2	26.5	38.5	35.0	12.6	41.9	45.5	16.5	44.7	38.8
Freeways/Rural Hwys	Core	3.1	21.8	75.1	13.5	19.5	67.0	21.4	34.4	44.2	13.0	42.1	44.9	15.6	42.3	42.2
Centroid Connectors	Core	5.3	27.1	67.5	21.4	33.8	44.7	30.3	46.1	23.6	21.5	60.1	18.4	29.9	52.3	17.8
All Roads	Core	3.5	24.2	72.2	16.3	25.9	57.9	24.7	40.4	34.9	16.7	49.5	33.8	19.4	47.2	33.4
Local	Urban	2.2	57.3	40.5	21.1	51.2	27.7	36.6	44.1	19.3	26.1	40.8	33.1	34.6	45.8	19.6
Minor Arterial/Collector	Urban	4.1	49.8	46.1	16.4	43.0	40.6	33.9	40.9	25.1	18.3	39.4	42.3	28.3	45.5	26.1
Major Arterial/Collector	Urban	2.3	38.2	59.5	10.9	32.4	56.7	24.9	35.0	40.2	10.8	33.4	55.8	22.8	39.4	37.8
Freeways/Rural Hwys	Urban	2.6	28.3	69.1	9.0	21.6	69.5	20.0	30.7	49.3	7.8	24.4	67.8	14.7	38.4	46.9
Centroid Connectors	Urban	4.2	56.4	39.4	19.4	49.9	30.7	38.1	40.7	21.2	25.3	42.6	32.1	33.8	46.0	20.3
All Roads	Urban	3.0	37.5	59.5	13.4	34.9	51.7	27.6	36.1	36.3	14.4	33.7	51.8	22.8	41.8	35.4
Local	Suburbs	3.1	83.8	13.1	15.0	66.7	18.3	32.9	41.4	25.7	24.1	28.2	47.6	33.2	39.0	27.8
Minor Arterial/Collector	Suburbs	4.5	70.6	24.9	14.6	57.5	27.9	30.6	45.0	24.4	20.5	30.3	49.2	33.2	41.6	25.1
Major Arterial/Collector	Suburbs	0.7	36.0	63.2	7.6	35.9	56.5	15.3	27.6	57.0	9.4	17.2	73.4	18.3	26.2	55.5
Freeways/Rural Hwys	Suburbs	0.9	29.8	69.4	4.8	18.9	76.3	8.3	12.3	79.4	5.6	10.2	84.3	8.8	20.6	70.7
Centroid Connectors	Suburbs	5.1	74.7	20.1	17.9	62.3	19.8	34.8	43.3	21.8	29.6	29.2	41.2	33.6	42.2	24.2
All Roads	Suburbs	1.9	42.7	55.4	9.2	36.9	53.9	16.9	24.5	58.7	13.3	19.1	67.6	19.2	29.2	51.6
Local	Rural	1.8	67.5	30.7	10.5	52.5	36.9	46.6	43.4	10.0	29.4	55.6	15.0	44.9	16.6	38.5
Minor Arterial/Collector	Rural	1.5	37.1	61.4	7.9	36.0	56.0	15.8	22.1	62.1	9.7	25.9	64.4	12.4	31.1	56.5
Major Arterial/Collector	Rural	1.5	32.7	65.8	2.8	17.0	80.2	9.0	13.7	77.3	4.9	7.7	87.4	10.2	16.9	72.9
Freeways/Rural Hwys	Rural	1.5	20.8	77.7	2.6	11.6	85.8	4.5	7.4	88.1	3.1	6.0	90.9	3.2	7.2	89.5
Centroid Connectors	Rural	2.9	72.8	24.3	9.5	66.5	24.1	19.2	32.5	48.2	9.1	20.5	70.3	12.5	29.3	58.1
All Roads	Rural	1.7	31.1	67.2	3.5	19.6	76.9	6.5	10.6	82.9	4.5	8.8	86.8	5.8	11.9	82.3
Local	All	2.5	64.1	33.4	19.4	50.9	29.7	35.2	43.7	21.1	25.1	39.8	35.1	34.4	44.1	21.4
Minor Arterial/Collector	All	3.9	46.6	49.5	16.3	41.8	41.9	31.6	41.7	26.8	18.4	39.9	41.7	27.4	45.2	27.4
Major Arterial/Collector	All	2.0	34.6	63.4	7.5	26.4	66.2	16.9	25.1	58.0	8.2	20.8	71.0	16.6	28.5	54.9
Freeways/Rural Hwys	All	1.9	25.5	72.6	5.9	16.7	77.4	10.6	16.6	72.8	5.6	14.6	79.8	8.7	22.0	69.3
Centroid Connectors	All	3.7	66.8	29.5	16.2	56.0	27.8	31.8	39.2	29.1	19.9	33.0	47.0	27.0	40.3	32.7
All Roads	All	2.4	35.0	62.6	10.2	29.7	60.2	18.1	25.3	56.6	11.1	24.4	64.5	16.3	30.2	53.5

APPENDIX H

VEHICLE FLEET CHARACTERISTICS

1998 Vehicle Fleet Data for Ottawa-Hull

Automobiles

Model Year	Vehicle Age	Number of Vehicles		Fraction of Vehicles		Fraction of Vehicles*		1990 Ont. Fleet	MOBILE5 Default
		Ottawa-Hull	Canada	Ottawa-Hull	Canada	Ottawa-Hull	Canada		
1983 or earlier	15+	16000	809689	0.041	0.075	0.034	0.067	0.024	0.077
1984	15	9092	338703	0.023	0.031	0.018	0.024	0.011	0.019
1985	14	13568	469869	0.034	0.044	0.029	0.038	0.016	0.024
1986	13	20204	651999	0.051	0.061	0.043	0.052	0.022	0.037
1987	12	23651	692310	0.060	0.064	0.056	0.062	0.03	0.047
1988	11	29426	828096	0.075	0.077	0.067	0.071	0.037	0.054
1989	10	29745	823260	0.076	0.077	0.075	0.077	0.046	0.05
1990	9	31501	814480	0.080	0.076	0.078	0.076	0.054	0.051
1991	8	31902	775112	0.081	0.072	0.081	0.074	0.063	0.05
1992	7	33835	795526	0.086	0.074	0.083	0.073	0.075	0.056
1993	6	29028	689339	0.074	0.064	0.080	0.069	0.083	0.077
1994	5	26250	640194	0.067	0.060	0.070	0.062	0.091	0.081
1995	4	26381	672573	0.067	0.063	0.067	0.061	0.097	0.084
1996	3	20606	519466	0.052	0.048	0.060	0.055	0.101	0.082
1997	2	28214	682121	0.072	0.063	0.062	0.056	0.104	0.083
1998	1	24155	548726	0.061	0.051	0.067	0.057	0.096	0.079
1999	0	164	6247	0.000	0.001	0.031	0.026	0.05	0.049
TOTAL		393722	10757710	1.000	1.000	1.000	1.000	1.000	1.000

Light Trucks

Model Year	Vehicle Age	Number of Vehicles		Fraction of Vehicles		Fraction of Vehicles*		1990 Ont. Fleet	MOBILE5 Default
		Ottawa-Hull	Canada	Ottawa-Hull	Canada	Ottawa-Hull	Canada		
1983 or earlier	15+	5778	502573	0.040	0.087	0.035	0.078	0.008	0.122
1984	15	2766	153812	0.019	0.027	0.015	0.023	0.005	0.028
1985	14	4423	205720	0.031	0.036	0.025	0.031	0.009	0.036
1986	13	5794	269853	0.041	0.047	0.036	0.041	0.012	0.046
1987	12	6648	286839	0.047	0.050	0.044	0.048	0.019	0.047
1988	11	9609	387001	0.067	0.067	0.057	0.058	0.023	0.053
1989	10	8935	380198	0.063	0.066	0.065	0.066	0.032	0.03
1990	9	8814	345454	0.062	0.060	0.062	0.063	0.04	0.031
1991	8	8675	335672	0.061	0.058	0.061	0.059	0.05	0.036
1992	7	10293	352815	0.072	0.061	0.066	0.060	0.063	0.044
1993	6	10922	364800	0.076	0.063	0.074	0.062	0.08	0.059
1994	5	10549	389893	0.074	0.067	0.075	0.065	0.095	0.069
1995	4	11074	409782	0.077	0.071	0.076	0.069	0.111	0.084
1996	3	10382	375274	0.073	0.065	0.075	0.068	0.121	0.084
1997	2	13623	519492	0.095	0.090	0.084	0.077	0.125	0.084
1998	1	14557	489888	0.102	0.085	0.099	0.087	0.122	0.084
1999	0	114	9101	0.001	0.002	0.051	0.043	0.085	0.063
TOTAL		142956	5778167	1.000	1.000	1.000	1.000	1.000	1.000

* Adjusted for July conditions

Ottawa-Hull data obtained from Natural Resources Canada

Ontario data obtained from Environment Canada (Philpott 1993)

Summary:

Light trucks in Ottawa-Hull	142956	26.6
Automobiles in Ottawa-Hull	393722	73.4
TOTAL	536678	100%

These results agree well with data from the 1996 Classification and Occupancy counts

Fuel Data for the 1998 Ottawa-Hull Vehicle Fleet

Vehicle Type	Fuel Type	Number of Vehicles		Percentage of Fleet		%s Used in Analysis
		Canada Fleet	Ottawa-Hull Fleet	Canada Fleet	Ottawa-Hull Fleet	
Passenger Car	Unknown	195,042	4,442	1.8	1.1	
Passenger Car	Diesel	102,311	2,361	1.0	0.6	0.6
Passenger Car	Gas	10,459,212	386,876	97.2	98.3	99.4
Passenger Car	Natural Gas	58	0	0.0	0.0	
Passenger Car	Propane	586	28	0.0	0.0	
Passenger Car	Methanol	3	0	0.0	0.0	
Passenger Car	Flex Fuel - Methanol/Gas	498	15	0.0	0.0	
TOTAL		10,757,710	393,722	100	100	
Light Truck	Unknown	89,443	754	1.5	0.5	
Light Truck	Diesel	258,823	4,385	4.5	3.1	3.1
Light Truck	Electric	7	0	0.0	0.0	
Light Truck	Gas	5,424,408	137,625	93.9	96.3	96.9
Light Truck	Natural Gas	126	2	0.0	0.0	
Light Truck	Propane	5,288	190	0.1	0.1	
Light Truck	Gas/Propane Switchable	67	0	0.0	0.0	
Light Truck	Flex Fuel - Methanol/Gas	5	0	0.0	0.0	
TOTAL		5,778,167	142,956	100	100	

* Based on data obtained from Natural Resources Canada

* Assume unknown vehicles are gas-fuelled

APPENDIX I

THE EMISSION CALCULATOR

Forms within the Emission Calculator

Emission Calculator

GHG Vehicle Mix Descriptions

Read vehicle mix from file
Enter description from file

Link Description: Area=1 Link Type=1

Vehicle Mix

	Description	Ratio to:	Pass. Veh.	Transit Veh.		Description	Ratio to:	Pass. Veh.	Transit Veh.
1	autos (gas)	81.6	☒	☐	8	taxis	2.2	☒	☐
2	light trucks (gas)	18.4	☒	☐	9	other vehicles	0.5	☒	☐
3	transit	100	☐	☒	10			☐	☒
4	commercial lgt trks (gas)	2.3	☒	☐	11			☐	☒
5	non-transit buses	0.2	☒	☐	12			☐	☒
6	heavy veh's (gas)	0.3	☒	☐	13			☐	☒
7	heavy veh's (diesel)	0.8	☒	☐	14			☐	☒

Note: Vehicle ratios expressed as a ratio to passenger / transit vehicles, multiplied by 100.

Switch to a new area / facility type combination

Save data in file
Restart
Quit
Continue

Emission Calculator

Fuel Consumption Equations / GHG Emission Factors

Read equation / formula
Enter equation using formula

Vehicle Description	Fuel Consumption as a Function of Average Travel Speed (litre/km)	GHG Emission Factor (grams / litre of fuel)
pv autos (gas)	$\text{if}(\text{AvgSpd} < 4.0, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgS})))$	2457
pv light trucks (gas)	$\text{if}(\text{AvgSpd} < 4.0, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgS})))$	2517
transit	$\text{if}(\text{AvgSpd} < 4.0, 0.7889759, \text{if}(\text{AvgSpd} < 104, (1.008840431 - 0.628403958 * (\text{AvgSpd})))$	2764
commercial light trucks (gas)	$\text{if}(\text{AvgSpd} < 4.0, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgS})))$	2517
non-transit buses	$\text{if}(\text{AvgSpd} < 4.0, 0.7889759, \text{if}(\text{AvgSpd} < 104, (1.008840431 - 0.628403958 * (\text{AvgSpd})))$	2764
heavy veh's (gas)	$\text{if}(\text{AvgSpd} < 4.0, 0.5705789, \text{if}(\text{AvgSpd} < 104, (0.7300554499 - 0.4557576897 * (\text{AvgS})))$	2479
heavy veh's (diesel)	$\text{if}(\text{AvgSpd} < 4.0, 0.7889759, \text{if}(\text{AvgSpd} < 104, (1.008840431 - 0.628403958 * (\text{AvgSpd})))$	2764
taxis	$\text{if}(\text{AvgSpd} < 4.0, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgS})))$	2457
other vehicles	$\text{if}(\text{AvgSpd} < 4.0, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgS})))$	2457

Link Type = 1
View help notes
Switch to a new link type

Save data in file
Restart
Quit
Continue

Emission Calculator

Please select the type of output you would prefer.

☐ Data summarized by link classification

☐ Greenhouse gas values only

☒ Link by link output (suitable for input into EMME/2)

☐ Greenhouse gas and fuel consumption data

Continue

Emission Calculator

MOBILE5 Vehicle Mix Descriptions

Link Description: **Area=1** Link Type=1

Vehicle Mix

	Ratio to Pass Vehicles	Ratio to Transit Vehicles		Ratio to Pass Vehicles	Ratio to Transit Vehicles
Light Duty Gas Vehicles (LDGV)	<input type="text" value="86"/>	<input type="text" value="0"/>	Light Duty Diesel Vehicles (LDDV)	<input type="text" value="0.5"/>	<input type="text" value="0"/>
Light Duty Gas Trucks 1T (LDGT1)	<input type="text" value="19"/>	<input type="text" value="0"/>	Light Duty Diesel Trucks (LDDT)	<input type="text" value="0.6"/>	<input type="text" value="0"/>
Light Duty Gas Trucks 2T (LDGT2)	<input type="text" value="0.1"/>	<input type="text" value="0"/>	Heavy Duty Diesel Vehicles (HDDV)	<input type="text" value="0.7"/>	<input type="text" value="100"/>
Heavy Duty Gas Vehicles (HDGV)	<input type="text" value="0"/>	<input type="text" value="0"/>	Motorcycles (MC)	<input type="text" value="0.5"/>	<input type="text" value="0"/>

Emission Calculator

Trip Length Distribution

Trip Length	Percentage of VKT
Under 10 minutes	<input type="text" value="6.7"/>
10 to 20 minutes	<input type="text" value="18.5"/>
20 to 30 minutes	<input type="text" value="16.8"/>
30 to 40 minutes	<input type="text" value="13.2"/>
40 to 50 minutes	<input type="text" value="8.3"/>
Over 50 minutes	<input type="text" value="36.5"/>

The trip length distribution is based on the fraction of VKT associated with trips of a particular length. For example, the fraction of VKT corresponding to trips under 10 minutes should be calculated as the fraction of VKT that occurs in trips that end within 10 minutes of their start not the fraction of VKT that occurs within the first 10 minutes of all trips.

Note: Percentage of VKT MUST add to 100!

Emission Calculator

Temperature Data and Other MOBILE5 Inputs

Please enter the temperature data in degrees Celsius

Maximum daily temperature	<input type="text" value="12.5"/>	<p>Note that the ambient temperature should correspond to the analysis period being studied. For example, if the PM Peak Period is being analyzed, the ambient temperature should correspond to temperatures in the late afternoon. If the analysis period is the entire day, enter 999 for the ambient temperature. In this situation, MOBILE5 will compute the ambient temperature based on the daily min. and max. temperatures.</p>
Minimum daily temperature	<input type="text" value="3.7"/>	
Ambient temperature	<input type="text" value="11"/>	
Fuel data		
Volatility class	<input type="text" value="C"/>	
Reid vapour pressure (psi)	<input type="text" value="14.4"/>	

Region variable	<input type="text" value="1"/>	Month of evaluation	☒ July
Analysis year	<input type="text" value="1995"/>		☒ January

Emission Calculator

Operating Mode Fractions

Area=1
Link Type=1

Link Description:

Vehicles With Catalytic Converters

	% of VKT
Hot Start VKT	27.3
Cold Start VKT	20.6
Stabilized Operation	52.1

Vehicles Without Catalytic Converters

	% of VKT
Hot Start VKT	27.3
Cold Start VKT	20.6
Stabilized Operation	52.1

NOTE: All values will be rounded to one decimal place.

Switch to a new area / facility type combination

Save data in file
Restart
Quit
Continue

Emission Calculator

MOBILE5 Files

Select the MOBILE5 input file containing the control and one-time data section:

Select File

D:_thesis\Emissions\AirQuality\mobile5_0

Select the MOBILE5C executable file used for calculating vehicle emissions:

Select File

D:_thesis\VisualBasic\ProgramFiles\Mobile

Quit

Continue

APPENDIX J

MOBILE5 INPUT DATA – TRIP LENGTH DISTRIBUTIONS

Summary of Trip Length Distributions Used in Emission Calculations

Trip Length Distribution from Trip Records in 1995 OD Survey Database

Duration (min)	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening
< 10	12.0	15.7	15.9	34.3	16.4	17.2	30.6
11-20	33.4	33.3	34.4	38.2	30.3	30.0	38.7
21-30	29.6	26.2	25.7	17.5	23.4	23.4	20.1
31-40	19.4	16.1	15.6	7.6	17.0	16.7	8.2
41-50	4.7	6.3	6.2	1.9	8.2	8.3	1.9
> 51	1.0	2.5	2.3	0.4	4.8	4.4	0.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total VKT	879,400	2,955,448	1,483,067	3,170,339	1,556,990	3,382,783	3,457,001

* Excludes external trips and trips with incorrect origin/destination data; includes intra-zonal trips

Intra-zonal Trip Length Distribution from Data in the 1995 OD Survey Database

Duration (min)	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening
< 10	61.8	61.9	64.1	67.3	64.1	64.0	70.9
11-20	33.5	33.7	32.8	29.1	29.8	30.8	25.0
21-30	2.4	4.2	2.6	2.3	4.7	4.1	2.5
31-40	0.0	0.2	0.5	0.3	0.0	0.0	1.0
41-50	2.4	0.0	0.0	0.0	0.0	0.0	0.6
> 51	0.0	0.0	0.0	1.0	1.3	1.2	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total VKT	12,783	76,022	34,880	139,993	44,605	101,866	148,964

* Excludes external trips and trips with incorrect origin/destination data

External Trip Length Distribution

Duration (min)	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening
< 10	0.2	0.2	0.2	0.3	0.2	0.2	0.2
11-20	0.5	0.5	0.5	0.4	0.4	0.4	0.4
21-30	4.4	4.4	4.4	4.9	5.1	5.1	5.1
31-40	10.7	10.7	10.8	13.5	15.3	15.2	14.9
41-50	20.3	20.3	20.5	19.6	21.2	21.2	21.1
> 51	64.0	63.9	63.6	61.3	57.8	57.9	58.3
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
TOTAL VKT	81,101	429,836	509,145	390,608	650,619	583,389	232,408

* Based on EMME/2 external trip tables for representative hour

EMME/2 Trip Length Distribution

Duration (min)	Early Morning	AM Peak Period	AM Peak Hour	Midday	PM Peak Hour	PM Peak Period	Evening
< 10	6.3	10.7	6.7	18.2	8.1	9.5	18.9
11-20	23.8	25.6	18.3	23.1	19.0	21.1	25.2
21-30	26.0	20.0	18.2	12.3	16.4	18.1	16.9
31-40	21.1	13.1	16.8	11.0	15.7	15.0	11.3
41-50	11.4	9.5	14.1	11.2	13.0	12.0	10.0
> 51	11.4	21.2	26.0	24.1	27.8	24.3	17.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total VKT	422,033	1,556,960	2,001,594	888,466	2,165,452	1,974,841	698,856

* Based on EMME/2 trip tables for representative hour (includes external trips, but not intra-zonal trips)

* Total VKT may differ slightly from values presented elsewhere due to EMME/2 calculation process

Daily Distribution of Travel*

Period	Total VKT	% VKT
Early Morning	879,400	6.4
AM Peak Period	2,955,448	21.3
Midday	3,170,339	22.9
PM Peak Period	3,382,783	24.4
Evening	3,457,001	25.0
TOTAL	13,844,971	100.0

* Used to weight EMME/2 trip length distribution

Trip Length Distribution

Duration (min)	Weighted*	MOBILE5
< 10	13.9	6.7
11-20	23.7	18.5
21-30	17.4	16.8
31-40	13.2	13.2
41-50	10.7	8.3
> 51	21.1	36.5
Total	100.0	100.0

* Based on EMME/2 output

Note that all trip durations (including those in the 1995 OD Survey database) were derived from traffic assignments in EMME/2 (with the exception of intra-zonal trips which were analyzed using TransCAD GIS)

Trips within the AM and PM peak hour are also part of the AM and PM peak period

APPENDIX K

GREENHOUSE GAS INPUT DATA

Summary of Inputs Used in Greenhouse Gas Analysis

Greenhouse Gas Emission Factors

Vehicle Type	Fuel	GHG Factor
Auto	Gas	2457
Light Truck	Gas	2517
Bus	Diesel	2764
Heavy Vehicle	Gas	2479
Heavy Vehicle	Diesel	2764
Taxis	Gas	2457
Other	Gas	2457

* Based on data from Environment Canada, 1999

Fuel Consumption Equations

Vehicle Type	Fuel	Road Type	Fuel Equation
Auto	Gas	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgSpd} * 0.1) + 0.0772803044 * ((\text{AvgSpd} * 0.1)^2) - 0.0125152243 * ((\text{AvgSpd} * 0.1)^3) + 0.0009706108 * ((\text{AvgSpd} * 0.1)^4) - 0.0000285520 * ((\text{AvgSpd} * 0.1)^5)), 0.1030736))$
Light Truck	Gas	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgSpd} * 0.1) + 0.0772803044 * ((\text{AvgSpd} * 0.1)^2) - 0.0125152243 * ((\text{AvgSpd} * 0.1)^3) + 0.0009706108 * ((\text{AvgSpd} * 0.1)^4) - 0.0000285520 * ((\text{AvgSpd} * 0.1)^5)), 0.1030736))$
Buses	Diesel	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.7889759, \text{if}(\text{AvgSpd} < 104, (1.008840431 - 0.628403958 * (\text{AvgSpd} * 0.1) + 0.210402862 * ((\text{AvgSpd} * 0.1)^2) - 0.034973746 * ((\text{AvgSpd} * 0.1)^3) + 0.002805941 * ((\text{AvgSpd} * 0.1)^4) - 0.000085231 * ((\text{AvgSpd} * 0.1)^5)), 0.3457916))$
Heavy Vehicles	Gas	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.5705789, \text{if}(\text{AvgSpd} < 104, (0.7300554499 - 0.4557576897 * (\text{AvgSpd} * 0.1) + 0.1524461930 * ((\text{AvgSpd} * 0.1)^2) - 0.0252463634 * ((\text{AvgSpd} * 0.1)^3) + 0.0020137458 * ((\text{AvgSpd} * 0.1)^4) - 0.0000608289 * ((\text{AvgSpd} * 0.1)^5)), 0.2372422))$
Heavy Vehicles	Diesel	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.7889759, \text{if}(\text{AvgSpd} < 104, (1.008840431 - 0.628403958 * (\text{AvgSpd} * 0.1) + 0.210402862 * ((\text{AvgSpd} * 0.1)^2) - 0.034973746 * ((\text{AvgSpd} * 0.1)^3) + 0.002805941 * ((\text{AvgSpd} * 0.1)^4) - 0.000085231 * ((\text{AvgSpd} * 0.1)^5)), 0.3457916))$
Taxis	Gas	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgSpd} * 0.1) + 0.0772803044 * ((\text{AvgSpd} * 0.1)^2) - 0.0125152243 * ((\text{AvgSpd} * 0.1)^3) + 0.0009706108 * ((\text{AvgSpd} * 0.1)^4) - 0.0000285520 * ((\text{AvgSpd} * 0.1)^5)), 0.1030736))$
Other	Gas	Arterial	$\text{if}(\text{AvgSpd} < 4, 0.2968866, \text{if}(\text{AvgSpd} < 104, (0.3790550946 - 0.2343923179 * (\text{AvgSpd} * 0.1) + 0.0772803044 * ((\text{AvgSpd} * 0.1)^2) - 0.0125152243 * ((\text{AvgSpd} * 0.1)^3) + 0.0009706108 * ((\text{AvgSpd} * 0.1)^4) - 0.0000285520 * ((\text{AvgSpd} * 0.1)^5)), 0.1030736))$
Auto	Gas	Freeway	$\text{if}(\text{AvgSpd} < 4, 0.3689833, \text{if}(\text{AvgSpd} < 104, (0.4405972907 - 0.1921995414 * (\text{AvgSpd} * 0.1) + 0.0337319978 * ((\text{AvgSpd} * 0.1)^2) - 0.0020476045 * ((\text{AvgSpd} * 0.1)^3) - 0.0000116308 * ((\text{AvgSpd} * 0.1)^4) + 0.0000036738 * ((\text{AvgSpd} * 0.1)^5)), 0.0978084))$
Light Truck	Gas	Freeway	$\text{if}(\text{AvgSpd} < 4, 0.3689833, \text{if}(\text{AvgSpd} < 104, (0.4405972907 - 0.1921995414 * (\text{AvgSpd} * 0.1) + 0.0337319978 * ((\text{AvgSpd} * 0.1)^2) - 0.0020476045 * ((\text{AvgSpd} * 0.1)^3) - 0.0000116308 * ((\text{AvgSpd} * 0.1)^4) + 0.0000036738 * ((\text{AvgSpd} * 0.1)^5)), 0.0978084))$
Buses	Diesel	Freeway	$\text{if}(\text{AvgSpd} < 4, 1.3763866, \text{if}(\text{AvgSpd} < 104, (1.629186798 - 0.665156070 * (\text{AvgSpd} * 0.1) + 0.082332556 * ((\text{AvgSpd} * 0.1)^2) + 0.001719648 * ((\text{AvgSpd} * 0.1)^3) - 0.000836586 * ((\text{AvgSpd} * 0.1)^4) + 0.000037479 * ((\text{AvgSpd} * 0.1)^5)), 0.3240435))$
Heavy Vehicles	Gas	Freeway	$\text{if}(\text{AvgSpd} < 4, 0.4278646, \text{if}(\text{AvgSpd} < 104, (0.5258148481 - 0.2698340004 * (\text{AvgSpd} * 0.1) + 0.0652467134 * ((\text{AvgSpd} * 0.1)^2) - 0.0072867052 * ((\text{AvgSpd} * 0.1)^3) + 0.0004036275 * ((\text{AvgSpd} * 0.1)^4) - 0.0000088212 * ((\text{AvgSpd} * 0.1)^5)), 0.2287104))$

APPENDIX L

TRAVEL DATA AGGREGATION

Comparison of Vehicle Emission Estimates*

Time Period	Analysis Type	VKT	VOC's (kg)	CO (kg)	Nox (kg)	GHG's (kg)	Fuel Use (litres)
Early Morning	Aggregated Link	1,066,293	1,411	12,975	1,376	237,095	95,981
	Link by Link	1,066,302	1,477	13,636	1,369	237,100	95,983
	Trip Based	1,062,714	1,379	12,386	1,248	225,422	91,237
AM Peak Period	Aggregated Link	3,912,875	5,615	53,060	4,585	877,358	355,105
	Link by Link	3,912,889	5,795	55,059	4,569	877,538	355,178
	Trip Based	3,930,440	5,476	51,780	4,379	879,431	355,852
Midday	Aggregated Link	5,275,566	6,788	58,615	6,258	1,172,055	474,109
	Link by Link	5,275,566	6,907	59,989	6,239	1,172,073	474,117
	Trip Based	5,256,746	6,716	57,225	5,805	1,121,812	453,653
PM Peak Period	Aggregated Link	4,587,225	6,451	57,904	5,030	1,030,673	417,212
	Link by Link	4,587,225	6,597	59,636	5,013	1,030,938	417,319
	Trip Based	4,583,897	6,475	58,716	4,865	1,037,062	419,656
Evening	Aggregated Link	4,847,511	6,441	57,335	6,066	1,081,886	438,182
	Link by Link	4,847,569	6,587	58,936	6,047	1,081,923	438,197
	Trip Based	4,879,468	6,464	56,263	5,649	1,041,787	421,804
Entire Day	Aggregated Link	19,689,471	26,708	239,889	23,315	4,399,066	1,780,588
	Link by Link	19,689,551	27,362	247,255	23,237	4,399,573	1,780,793
	Trip Based	19,713,265	26,509	236,371	21,945	4,301,514	1,742,201

* Includes emissions from passenger vehicles only

Note that the VKT totals in this table may differ slightly from the values presented elsewhere due to adjustments to the AM external trip matrix and traffic zone tags. Also, the totals include travel in external zones, while external travel was eliminated from the daily emission estimates

APPENDIX M

DAILY VEHICLE EMISSIONS IN THE NATIONAL CAPITAL REGION

**Summary of Daily Vehicle Emissions in the National Capital Region
(based on data from 1995 OD Survey)**

Vehicle emissions from all vehicle categories

Time Period	VKT (x1000)	VOC's (kg)	CO (kg x 10)	N0x (kg)	GHG's (kg)	Gasoline (litres)	Diesel (litres)
Early Morning	1,162	1,621	1,467	2,026	295,739	99,242	18,220
AM Peak Period	4,142	6,266	5,887	6,221	1,028,297	363,320	46,974
Midday	5,411	7,299	6,284	8,986	1,386,095	465,107	85,104
PM Peak Period	4,698	6,932	6,244	6,264	1,138,763	417,946	38,132
Evening	4,882	6,851	6,084	7,391	1,180,770	428,904	43,759
TOTAL	20,294	28,969	25,966	30,888	5,029,663	1,774,519	232,190

Vehicle emissions from all vehicle categories

Time Period	Percentage Distribution						
	VKT	VOC's	CO	N0x	GHG's	Gasoline	Diesel
Early Morning	6	6	6	7	6	6	8
AM Peak Period	20	22	23	20	20	20	20
Midday	27	25	24	29	28	26	37
PM Peak Period	23	24	24	20	23	24	16
Evening	24	24	23	24	23	24	19
TOTAL	100	100	100	100	100	100	100

Vehicle emissions from passenger vehicles only

Time Period	VKT (x1000)	VOC's (kg)	CO (kg x 10)	N0x (kg)	GHG's (kg)	Gasoline (litres)
Early Morning	1,021	1,437	1,329	1,313	227,272	92,004
AM Peak Period	3,670	5,596	5,340	4,281	825,429	334,087
Midday	4,677	6,378	5,590	5,580	1,043,263	422,023
PM Peak Period	4,236	6,288	5,727	4,639	956,938	387,366
Evening	4,438	6,262	5,630	5,586	993,448	402,364
TOTAL	18,042	25,962	23,616	21,399	4,046,351	1,637,846

Vehicle emissions from passenger vehicles only

Time Period	Percentage Distribution					
	VKT	VOC's	CO	N0x	GHG's	Gasoline
Early Morning	6	6	6	6	6	6
AM Peak Period	20	22	23	20	20	20
Midday	26	25	24	26	26	26
PM Peak Period	23	24	24	22	24	24
Evening	25	24	24	26	25	25
TOTAL	100	100	100	100	100	100

Percentage increase in vehicle emissions due to commercial vehicles and buses

Time Period	% Increase in Emissions: Total Vehicles Compared to Passenger Vehicles					
	VKT	VOC's	CO	N0x	GHG's	Gasoline
Early Morning	14	13	10	54	30	8
AM Peak Period	13	12	10	45	25	9
Midday	16	14	12	61	33	10
PM Peak Period	11	10	9	35	19	8
Evening	10	9	8	32	19	7
TOTAL	12	12	10	44	24	8

Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Morning Period

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	96,700	117,509	1,123,895	189,958
	Urban	377,889	503,167	4,618,557	704,685
	Suburban	147,611	215,835	1,937,374	276,443
	Rural	217,509	255,109	2,236,652	326,504
	TOTAL	839,709	1,091,620	9,916,479	1,497,591
Quebec	Core	24,088	37,533	360,190	38,600
	Urban	137,696	242,442	2,197,496	229,141
	Suburban	42,665	71,722	654,516	75,330
	Rural	104,138	150,463	1,309,021	164,903
	TOTAL	308,586	502,159	4,521,222	507,973
Overall	Core	120,787	155,041	1,484,085	228,557
	Urban	515,586	745,609	6,816,053	933,826
	Suburban	190,275	287,556	2,591,890	351,773
	Rural	321,647	405,572	3,545,673	491,408
	TOTAL	1,148,295	1,593,779	14,437,700	2,005,564
External	TOTAL	93,123	97,695	833,886	139,849

Ontario	Local	16,146	41,213	383,172	54,685
	Minor	153,175	275,554	2,613,987	293,308
	Major	144,889	187,042	1,669,612	214,991
	Freeway	447,839	432,642	3,891,701	785,797
	Centroid	70,921	147,583	1,324,840	97,036
	Transit	6,739	7,586	33,166	51,775
	TOTAL	839,709	1,091,620	9,916,479	1,497,591
Quebec	Local	4,811	14,854	138,425	16,393
	Minor	74,910	159,015	1,479,202	129,746
	Major	51,500	81,667	740,475	75,618
	Freeway	148,991	177,263	1,538,541	245,929
	Centroid	28,372	69,356	624,560	40,264
	Transit	3	4	20	22
	TOTAL	308,586	502,159	4,521,222	507,973
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	2,719	1,842	16,785	3,616
	Freeway	60,226	51,652	457,342	89,507
	Centroid	30,177	44,200	359,759	46,726
	Transit	0	0	0	0
	TOTAL	93,123	97,695	833,886	139,849

TOTAL	1,241,418	1,691,474	15,271,586	2,145,413
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Intra-zonal Trips				
Core	86	271	2,734	116
Urban	1,214	3,678	34,396	1,697
Suburban	913	2,362	21,731	1,305
Rural	11,485	20,832	171,918	17,072
TOTAL	13,698	27,143	230,780	20,190

NCR TOTAL (Excluding external zones)	1,161,993	1,620,922	14,668,480	2,025,755
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AM Peak Period

		VKT	VOC's (g)	CO (g)	NO _x (g)
		393,540	645,936	6,412,872	585,560
		1,562,186	2,524,998	24,199,953	2,238,373
		524,851	844,929	7,803,985	829,718
		772,561	776,970	6,768,985	1,184,077
		3,253,137	4,792,834	45,185,795	4,837,728
		71,405	115,820	1,215,779	100,946
		376,476	681,179	6,462,691	567,826
		116,446	169,364	1,566,226	196,406
		242,200	343,954	2,983,740	396,942
		806,527	1,310,316	12,228,436	1,262,120
		464,945	761,756	7,628,651	686,506
		1,938,662	3,206,177	30,662,644	2,806,199
		641,297	1,014,293	9,370,211	1,026,124
		1,014,760	1,120,924	9,752,725	1,581,019
		4,059,664	6,103,150	57,414,231	6,099,849
		510,403	509,282	4,225,953	794,815

		78,032	237,970	2,437,542	139,186
		861,605	1,725,982	17,014,627	1,279,536
		695,391	861,591	7,799,953	998,035
		1,278,529	1,238,072	11,020,389	1,903,237
		332,814	721,603	6,879,989	465,759
		6,765	7,615	33,295	51,975
		3,253,137	4,792,834	45,185,795	4,837,728
		20,840	69,648	710,552	38,190
		243,450	491,408	4,801,498	368,500
		133,317	188,370	1,715,073	198,011
		320,207	350,874	3,013,044	529,520
		88,710	210,011	1,988,249	127,877
		3	4	20	22
		806,527	1,310,316	12,228,436	1,262,120
		0	0	0	0
		0	0	0	0
		15,062	10,673	89,246	22,554
		328,296	275,323	2,315,454	494,579
		167,045	223,287	1,821,253	277,682
		0	0	0	0
		510,403	509,282	4,225,953	794,815

4,570,067	6,612,432	61,640,184	6,894,663
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1,097	3,393	35,508	1,473
14,927	42,610	413,412	20,610
8,816	22,634	212,011	12,681
57,384	94,539	790,471	86,630
82,224	163,175	1,451,401	121,395

4,141,888	6,266,325	58,865,632	6,221,243
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Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Midday

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	420,432	700,741	6,234,637	765,934
	Urban	1,943,522	2,933,096	25,731,956	3,225,127
	Suburban	740,825	917,414	7,719,523	1,273,914
	Rural	1,145,987	1,094,954	8,621,579	1,826,099
	TOTAL	4,250,766	5,646,205	48,307,695	7,091,074
Quebec	Core	50,751	84,326	769,531	85,046
	Urban	428,451	693,107	6,323,702	703,467
	Suburban	187,332	246,845	2,163,782	318,681
	Rural	339,130	390,297	3,188,312	558,749
	TOTAL	1,005,663	1,414,575	12,445,326	1,665,944
Overall	Core	471,183	785,067	7,004,168	850,980
	Urban	2,371,973	3,626,204	32,055,658	3,928,595
	Suburban	928,157	1,164,259	9,883,305	1,592,595
	Rural	1,485,117	1,485,251	11,809,891	2,384,848
	TOTAL	5,256,429	7,060,780	60,753,021	8,757,018
External	TOTAL	1,045,687	1,022,803	7,848,496	1,663,778

Ontario	Local	98,683	233,528	2,312,506	208,328
	Minor	862,746	1,621,746	15,142,078	1,404,527
	Major	649,953	814,138	6,767,405	1,003,328
	Freeway	2,204,875	2,219,016	17,162,477	3,786,277
	Centroid	418,507	739,764	6,844,474	565,674
	Transit	16,002	18,013	78,754	122,940
	TOTAL	4,250,766	5,646,205	48,307,695	7,091,074
Quebec	Local	25,592	61,193	607,061	57,056
	Minor	284,836	501,438	4,653,187	459,519
	Major	175,155	227,962	1,895,316	278,636
	Freeway	399,260	415,592	3,370,682	706,031
	Centroid	120,815	208,380	1,919,033	164,649
	Transit	6	10	47	53
	TOTAL	1,005,663	1,414,575	12,445,326	1,665,944
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	35,230	29,558	219,201	56,696
	Freeway	657,816	586,512	4,491,080	1,022,518
	Centroid	352,640	406,733	3,138,215	584,565
	Transit	0	0	0	0
	TOTAL	1,045,687	1,022,803	7,848,496	1,663,778

Total	6,302,116	8,083,583	68,601,517	10,420,796
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Intra-zonal Trips				
Core	1,374	3,213	33,994	1,717
Urban	29,592	58,078	563,606	38,774
Suburban	16,774	31,349	295,671	23,262
Rural	106,471	145,699	1,191,977	165,424
TOTAL	154,210	238,340	2,085,249	229,177

Overall Total (Excluding external zones)	5,410,640	7,299,120	62,838,270	8,986,194
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PM Peak Period

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
	Core	369,276	810,045	7,682,824	536,214
	Urban	1,642,014	2,803,548	25,920,596	2,157,922
	Suburban	611,143	807,539	7,170,649	795,820
	Rural	1,004,590	990,062	7,927,953	1,341,784
	TOTAL	3,627,023	5,411,194	48,702,022	4,831,739
	Core	68,573	161,939	1,603,451	94,748
	Urban	427,268	660,683	6,148,545	551,841
	Suburban	179,214	211,947	1,833,635	245,862
	Rural	287,120	322,449	2,679,334	394,439
	TOTAL	962,174	1,357,018	12,264,966	1,286,890
	Core	437,848	971,984	9,286,275	630,962
	Urban	2,069,281	3,464,231	32,069,142	2,709,763
	Suburban	790,357	1,019,486	9,004,285	1,041,681
	Rural	1,291,710	1,312,511	10,607,287	1,736,223
	TOTAL	4,589,197	6,768,212	60,966,988	6,118,630
External	TOTAL	579,614	547,285	4,166,750	784,339

	Local	86,412	238,071	2,428,005	137,686
	Minor	912,143	1,848,435	17,735,211	1,232,017
	Major	865,962	1,091,908	9,343,104	1,108,008
	Freeway	1,371,691	1,548,951	12,838,076	1,835,402
	Centroid	384,674	676,917	6,327,405	471,450
	Transit	6,141	6,912	30,221	47,177
	TOTAL	3,627,023	5,411,194	48,702,022	4,831,739
	Local	24,942	60,776	623,579	38,811
	Minor	287,503	516,180	4,979,934	377,820
	Major	154,819	199,663	1,755,502	197,711
	Freeway	386,102	401,257	3,241,038	540,684
	Centroid	108,806	179,138	1,664,896	131,844
	Transit	2	4	18	20
	TOTAL	962,174	1,357,018	12,264,966	1,286,890
	Local	0	0	0	0
	Minor	0	0	0	0
	Major	17,620	14,794	110,500	23,319
	Freeway	371,306	327,636	2,494,368	490,951
	Centroid	190,688	204,855	1,561,882	270,068
	Transit	0	0	0	0
	TOTAL	579,614	547,285	4,166,750	784,339

Total	5,168,811	7,315,497	65,133,738	6,902,968
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1,053	2,964	31,296	1,319
18,632	37,449	379,394	23,227
13,680	23,085	225,362	17,386
75,672	100,575	841,703	103,298
109,037	164,073	1,477,755	145,229

Overall Total (Excluding external zones)	4,698,235	6,932,284	62,444,743	6,263,859
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Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Evening Period

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	372,102	669,202	6,098,265	673,486
	Urban	1,727,301	2,752,389	24,596,132	2,804,202
	Suburban	743,122	1,001,691	8,911,106	1,130,539
	Rural	903,975	825,174	6,845,147	1,157,087
	TOTAL	3,746,499	5,248,456	46,450,650	5,765,314
Quebec	Core	49,975	85,481	779,414	83,234
	Urban	436,246	685,439	6,319,167	660,539
	Suburban	171,989	216,158	1,959,558	254,218
	Rural	320,008	359,883	3,078,093	419,353
	TOTAL	978,217	1,346,960	12,136,231	1,417,344
Overall	Core	422,077	754,683	6,877,679	756,720
	Urban	2,163,546	3,437,828	30,915,299	3,464,741
	Suburban	915,111	1,217,849	10,870,664	1,384,756
	Rural	1,223,982	1,185,057	9,923,240	1,576,440
	TOTAL	4,724,717	6,595,416	58,586,881	7,182,659
External	TOTAL	660,862	576,722	4,626,358	844,356

Ontario	Local	108,933	258,614	2,573,104	226,554
	Minor	794,244	1,575,134	14,840,557	1,268,122
	Major	590,599	755,091	6,505,527	776,888
	Freeway	1,810,538	1,882,545	15,389,141	2,831,589
	Centroid	423,920	756,511	7,052,426	521,830
	Transit	18,266	20,561	89,895	140,332
	TOTAL	3,746,499	5,248,456	46,450,650	5,765,314
Quebec	Local	25,696	58,917	575,786	58,325
	Minor	280,595	483,780	4,544,921	420,514
	Major	154,850	201,073	1,740,406	206,035
	Freeway	393,706	398,541	3,372,210	582,931
	Centroid	123,364	204,639	1,902,854	149,480
	Transit	7	11	53	60
	TOTAL	978,217	1,346,960	12,136,231	1,417,344
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	18,951	14,133	112,495	21,431
	Freeway	423,276	337,053	2,727,632	540,503
	Centroid	218,635	225,536	1,786,231	282,422
	Transit	0	0	0	0
	TOTAL	660,862	576,722	4,626,358	844,356

Total	5,385,578	7,172,139	63,213,239	8,027,015
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Intra-zonal Trips				
Core	1,461	3,677	38,074	1,830
Urban	27,291	56,940	548,725	35,136
Suburban	22,343	43,232	410,521	29,176
Rural	105,744	151,396	1,255,766	141,819
TOTAL	156,840	255,245	2,253,087	207,962

Overall Total (Excluding external zones)	4,881,557	6,850,661	60,839,967	7,390,621
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Daily Emissions

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
		1,652,050	2,943,433	27,552,493	2,751,152
		7,252,911	11,517,199	105,067,195	11,130,309
		2,767,551	3,787,407	33,542,636	4,306,434
		4,044,622	3,942,269	32,400,316	5,835,551
		15,717,134	22,190,308	198,562,641	24,023,447
		264,791	485,098	4,728,364	402,574
		1,806,137	2,962,850	27,451,601	2,712,815
		697,647	916,036	8,177,717	1,090,497
		1,292,594	1,567,046	13,238,499	1,934,387
		4,061,169	5,931,029	53,596,181	6,140,272
		1,916,841	3,428,531	32,280,858	3,153,726
		9,059,048	14,480,049	132,518,796	13,843,124
		3,465,198	4,703,442	41,720,353	5,396,930
		5,337,216	5,509,315	45,638,815	7,769,938
		19,778,303	28,121,337	252,158,822	30,163,719
		2,889,689	2,753,788	21,701,442	4,227,136

		388,206	1,009,395	10,134,328	766,439
		3,583,914	7,046,851	67,346,460	5,477,510
		2,946,794	3,709,770	32,085,601	4,101,249
		7,113,471	7,321,226	60,301,784	11,142,302
		1,630,836	3,042,378	28,429,135	2,121,749
		53,913	60,688	265,332	414,198
		15,717,134	22,190,308	198,562,641	24,023,447
		101,879	265,388	2,655,402	208,774
		1,171,294	2,151,822	20,458,742	1,756,098
		669,641	898,736	7,846,772	956,011
		1,648,268	1,743,527	14,535,515	2,605,096
		470,066	871,524	8,099,592	614,114
		20	32	158	178
		4,061,169	5,931,029	53,596,181	6,140,272
		0	0	0	0
		0	0	0	0
		89,582	71,000	548,227	127,616
		1,840,920	1,578,177	12,485,875	2,638,058
		959,186	1,104,611	8,667,340	1,461,463
		0	0	0	0
		2,889,689	2,753,788	21,701,442	4,227,136

22,667,991	30,875,125	273,860,264	34,390,855
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5,071	13,518	141,607	6,455
91,656	198,755	1,939,534	119,444
62,527	122,661	1,165,295	83,811
356,755	513,041	4,251,836	514,244
516,010	847,975	7,498,271	723,953

20,294,312	28,969,312	259,657,093	30,887,672
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Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Morning Period

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	80,815	97,305	985,063	99,493
	Urban	328,042	441,296	4,172,768	427,300
	Suburban	129,122	191,916	1,757,782	174,031
	Rural	195,207	229,017	2,026,791	239,740
	TOTAL	733,186	959,535	8,942,403	940,564
Quebec	Core	20,880	32,662	323,353	23,577
	Urban	122,718	219,353	2,018,187	157,838
	Suburban	37,993	64,868	598,423	52,896
	Rural	93,448	135,561	1,186,040	121,555
	TOTAL	275,039	452,443	4,128,002	355,867
Overall	Core	101,696	129,967	1,308,416	123,071
	Urban	450,760	660,649	6,190,954	585,138
	Suburban	167,115	256,784	2,356,205	226,927
	Rural	288,655	364,578	3,214,830	361,295
	TOTAL	1,008,225	1,411,978	13,070,405	1,296,431
External	TOTAL	84,916	89,164	766,577	107,023

Ontario	Local	10,911	32,568	334,366	12,890
	Minor	127,107	235,489	2,332,671	144,993
	Major	127,060	164,788	1,499,257	143,403
	Freeway	401,423	387,227	3,519,374	555,894
	Centroid	66,685	139,462	1,256,736	83,384
	Transit	0	0	0	0
	TOTAL	733,186	959,535	8,942,403	940,564
Quebec	Local	3,285	12,203	122,938	4,134
	Minor	64,769	141,191	1,341,976	79,016
	Major	45,881	73,112	670,455	54,876
	Freeway	134,395	160,226	1,399,177	182,872
	Centroid	26,708	65,711	593,457	34,969
	Transit	0	0	0	0
	TOTAL	275,039	452,443	4,128,002	355,867
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	2,367	1,544	14,579	2,338
	Freeway	54,503	46,431	415,120	66,563
	Centroid	28,046	41,188	336,879	38,121
	Transit	0	0	0	0
	TOTAL	84,916	89,164	766,577	107,023

Total	1,093,141	1,501,142	13,836,983	1,403,453
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Intra-zonal Trips					
Core	81	256	2,591	105	
Urban	1,163	3,534	33,076	1,574	
Suburban	865	2,248	20,720	1,175	
Rural	10,674	19,454	161,300	14,117	
TOTAL	12,783	25,491	217,688	16,971	

NCR TOTAL	1,021,008	1,437,469	13,288,093	1,313,402
(Excluding external zones)				

AM Peak Period

		VKT	VOC's (g)	CO (g)	NO _x (g)
		341,934	562,133	5,698,355	383,105
		1,398,106	2,276,751	22,154,798	1,597,166
		464,263	756,983	7,092,936	561,912
		673,799	674,493	5,995,430	761,106
		2,878,102	4,270,360	40,941,519	3,303,288
		62,164	100,445	1,078,279	66,965
		338,129	618,681	5,938,083	412,957
		103,093	151,439	1,417,638	134,668
		212,146	302,606	2,659,299	264,591
		715,532	1,173,171	11,093,299	879,180
		404,098	662,578	6,776,634	450,069
		1,736,235	2,895,432	28,092,881	2,010,123
		567,356	908,422	8,510,574	696,579
		885,945	977,099	8,654,729	1,025,697
		3,593,634	5,443,531	52,034,818	4,182,469
		455,252	453,975	3,811,892	547,805

		68,860	217,516	2,272,519	83,071
		760,866	1,538,863	15,398,648	887,476
		607,821	755,598	6,972,496	666,837
		1,131,657	1,084,058	9,830,698	1,286,301
		308,898	674,324	6,467,158	379,603
		0	0	0	0
		2,878,102	4,270,360	40,941,519	3,303,288
		18,308	63,732	662,251	22,387
		214,238	437,091	4,337,179	250,887
		116,783	165,502	1,529,577	135,617
		283,944	310,347	2,694,145	366,130
		82,259	196,499	1,870,148	104,159
		0	0	0	0
		715,532	1,173,171	11,093,299	879,180
		0	0	0	0
		0	0	0	0
		12,657	8,654	75,234	12,347
		291,559	241,707	2,062,140	337,156
		151,036	203,615	1,674,518	198,302
		0	0	0	0
		455,252	453,975	3,811,892	547,805

4,048,886	5,897,506	55,846,710	4,730,273
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1,009	3,126	32,782	1,284
14,162	40,551	393,915	18,667
8,302	21,401	201,120	11,098
52,549	87,019	732,408	67,804
76,022	152,097	1,360,225	98,852

3,669,656	5,595,628	53,395,043	4,281,321
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Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Midday

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	352,453	597,415	5,439,868	444,096
	Urban	1,695,632	2,598,137	23,184,578	2,072,267
	Suburban	639,511	799,950	6,857,442	771,004
	Rural	978,443	928,498	7,423,039	1,073,470
	TOTAL	3,666,038	4,923,999	42,904,928	4,360,836
Quebec	Core	42,344	71,184	669,918	48,446
	Urban	377,499	618,480	5,732,755	467,324
	Suburban	162,777	216,620	1,927,155	201,983
	Rural	288,000	329,793	2,744,030	328,557
	TOTAL	870,620	1,236,076	11,073,857	1,046,310
Overall	Core	394,797	668,599	6,109,786	492,542
	Urban	2,073,131	3,216,616	28,917,333	2,539,591
	Suburban	802,288	1,016,570	8,784,597	972,986
	Rural	1,266,442	1,258,291	10,167,069	1,402,027
	TOTAL	4,536,658	6,160,076	53,978,786	5,407,146
External	TOTAL	911,262	889,909	6,900,348	1,042,221

Ontario	Local	82,122	203,436	2,106,837	95,134
	Minor	741,880	1,417,994	13,530,394	871,705
	Major	552,188	698,623	5,927,710	601,361
	Freeway	1,903,508	1,917,035	14,936,934	2,341,146
	Centroid	386,340	686,912	6,403,053	451,491
	Transit	0	0	0	0
	TOTAL	3,666,038	4,923,999	42,904,928	4,360,836
Quebec	Local	20,962	52,650	548,813	24,560
	Minor	244,538	436,354	4,145,865	280,285
	Major	148,628	194,275	1,645,666	170,105
	Freeway	345,282	359,731	2,939,743	441,453
	Centroid	111,210	193,066	1,793,770	129,908
	Transit	0	0	0	0
	TOTAL	870,620	1,236,076	11,073,857	1,046,310
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	28,388	23,288	177,692	26,459
	Freeway	570,526	505,401	3,905,966	632,340
	Centroid	312,348	361,220	2,816,690	383,422
	Transit	0	0	0	0
	TOTAL	911,262	889,909	6,900,348	1,042,221

Total	5,447,920	7,049,985	60,879,133	6,449,367
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Intra-zonal Trips				
Core	1,254	2,935	31,157	1,506
Urban	27,970	54,952	535,331	34,662
Suburban	15,706	29,451	279,360	19,729
Rural	95,063	130,679	1,080,269	116,845
TOTAL	139,993	218,016	1,926,118	172,741

NCR TOTAL (Excluding external zones)	4,676,652	6,378,091	55,904,903	5,579,887
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PM Peak Period

		VKT	VOC's (g)	CO (g)	NO _x (g)
		327,880	728,489	6,982,619	384,945
		1,491,529	2,566,021	23,946,893	1,657,329
		553,876	734,305	6,605,436	592,804
		892,109	875,886	7,106,555	925,222
		3,265,394	4,904,701	44,641,503	3,560,300
		61,071	145,419	1,454,533	68,736
		389,347	604,863	5,683,827	425,024
		162,608	193,018	1,685,416	185,049
		256,082	286,474	2,407,370	276,832
		869,108	1,229,775	11,231,146	955,641
		388,951	873,908	8,437,152	453,681
		1,880,876	3,170,884	29,630,719	2,082,353
		716,483	927,323	8,290,852	777,852
		1,148,191	1,162,360	9,513,925	1,202,055
		4,134,501	6,134,475	55,872,649	4,515,941
		526,122	497,415	3,818,468	577,589

		77,782	219,472	2,277,615	89,150
		821,014	1,676,601	16,232,575	930,693
		769,507	975,658	8,445,184	798,915
		1,236,713	1,396,038	11,699,925	1,342,624
		360,378	636,932	5,986,204	398,918
		0	0	0	0
		3,265,394	4,904,701	44,641,503	3,560,300
		22,434	55,673	582,831	24,747
		258,171	465,135	4,538,312	278,364
		137,921	177,921	1,582,910	144,419
		348,699	362,721	2,952,953	396,993
		101,882	168,324	1,574,140	111,117
		0	0	0	0
		869,108	1,229,775	11,231,146	955,641
		0	0	0	0
		0	0	0	0
		15,137	12,608	95,308	14,108
		335,720	296,077	2,272,804	359,545
		175,265	188,730	1,450,355	203,936
		0	0	0	0
		526,122	497,415	3,818,468	577,589

4,660,623	6,631,890	59,691,117	5,093,531
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982	2,771	29,307	1,192
17,711	35,665	362,089	21,459
13,041	22,021	216,129	15,907
70,132	93,297	787,218	84,647
101,866	153,755	1,394,743	123,206

4,236,368	6,288,230	57,267,393	4,639,147
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Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Evening Period

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	323,357	591,230	5,511,970	433,798
	Urban	1,561,252	2,515,955	22,784,662	2,067,366
	Suburban	679,452	922,172	8,302,101	860,853
	Rural	833,190	758,430	6,328,179	945,807
	TOTAL	3,397,251	4,787,787	42,926,912	4,307,824
Quebec	Core	42,952	74,447	698,630	50,108
	Urban	397,076	628,447	5,867,851	499,091
	Suburban	157,879	199,206	1,823,242	200,684
	Rural	294,104	329,956	2,839,250	339,058
	TOTAL	892,011	1,232,055	11,228,973	1,088,941
Overall	Core	366,309	665,678	6,210,599	483,906
	Urban	1,958,328	3,144,402	28,652,513	2,566,457
	Suburban	837,331	1,121,378	10,125,343	1,061,537
	Rural	1,127,293	1,088,386	9,167,430	1,284,865
	TOTAL	4,289,262	6,019,843	54,155,885	5,396,765
External	TOTAL	616,188	537,618	4,322,320	709,970

Ontario	Local	91,869	228,561	2,373,123	108,573
	Minor	699,964	1,415,372	13,586,898	844,030
	Major	534,452	687,361	5,985,455	602,383
	Freeway	1,667,261	1,735,659	14,248,543	2,273,074
	Centroid	403,706	720,835	6,732,893	479,763
	Transit	0	0	0	0
	TOTAL	3,397,251	4,787,787	42,926,912	4,307,824
Quebec	Local	20,971	50,769	523,838	24,417
	Minor	249,739	435,567	4,167,555	290,142
	Major	140,276	182,667	1,594,763	162,394
	Freeway	363,664	368,290	3,127,114	475,180
	Centroid	117,360	194,762	1,815,704	136,809
	Transit	0	0	0	0
	TOTAL	892,011	1,232,055	11,228,973	1,088,941
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	17,057	12,615	101,680	16,322
	Freeway	392,285	311,891	2,531,079	445,484
	Centroid	206,845	213,112	1,689,562	248,164
	Transit	0	0	0	0
	TOTAL	616,188	537,618	4,322,320	709,970

Total	4,905,450	6,557,461	58,478,206	6,106,735
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Intra-zonal Trips				
Core	1,368	3,443	35,721	1,697
Urban	26,091	54,436	525,337	33,220
Suburban	21,463	41,529	395,556	27,494
Rural	100,042	143,232	1,190,248	126,421
TOTAL	148,964	242,640	2,146,862	188,832

NCR TOTAL (Excluding external zones)	4,438,226	6,262,483	56,302,748	5,585,597
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Daily Emissions

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	1,426,439	2,576,572	24,617,875	1,745,436
	Urban	6,474,561	10,398,160	96,243,699	7,821,427
	Suburban	2,466,224	3,405,325	30,615,697	2,960,603
	Rural	3,572,748	3,466,325	28,879,994	3,945,346
	TOTAL	13,939,971	19,846,382	180,357,265	16,472,812
Quebec	Core	229,411	424,158	4,224,713	257,832
	Urban	1,624,769	2,689,824	25,240,702	1,962,235
	Suburban	624,351	825,151	7,451,874	775,279
	Rural	1,143,778	1,384,389	11,837,950	1,330,594
	TOTAL	3,622,310	5,323,521	48,755,273	4,325,939
Overall	Core	1,655,850	3,000,730	28,842,588	2,003,268
	Urban	8,099,330	13,087,983	121,484,400	9,783,662
	Suburban	3,090,575	4,230,476	38,067,571	3,735,881
	Rural	4,716,526	4,850,714	40,717,984	5,275,940
	TOTAL	17,562,281	25,169,902	229,112,543	20,798,751
External	TOTAL	2,593,739	2,468,081	19,619,605	2,984,608

Ontario	Local	331,544	901,553	9,364,461	388,818
	Minor	3,150,829	6,284,318	61,081,185	3,678,897
	Major	2,591,029	3,282,028	28,830,102	2,812,899
	Freeway	6,340,562	6,520,017	54,235,474	7,799,040
	Centroid	1,526,007	2,858,466	26,846,044	1,793,159
	Transit	0	0	0	0
	TOTAL	13,939,971	19,846,382	180,357,265	16,472,812
Quebec	Local	85,961	235,027	2,440,671	100,245
	Minor	1,031,456	1,915,337	18,530,888	1,178,693
	Major	589,489	793,478	7,023,370	667,411
	Freeway	1,475,984	1,561,316	13,113,132	1,862,628
	Centroid	439,419	818,362	7,647,217	516,962
	Transit	0	0	0	0
	TOTAL	3,622,310	5,323,521	48,755,278	4,325,939
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	75,607	58,709	464,493	71,575
	Freeway	1,644,594	1,401,506	11,187,109	1,841,088
	Centroid	873,539	1,007,865	7,968,003	1,071,945
	Transit	0	0	0	0
	TOTAL	2,593,739	2,468,081	19,619,605	2,984,608

Total	20,156,020	27,637,983	248,732,148	23,783,359
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4,695	12,530	131,558	5,784
87,097	189,137	1,849,749	109,581
59,378	116,650	1,112,886	75,403
328,459	473,681	3,951,443	409,835
479,629	791,999	7,045,637	600,602

NCR TOTAL (Excluding external zones)	18,041,910	25,961,901	236,158,180	21,399,354
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Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Morning Period

Description		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
Ontario	Core	96,624	27,459,176	8,266	2,544
	Urban	377,705	100,567,045	32,407	7,404
	Suburban	147,466	38,237,042	12,578	2,581
	Rural	217,383	50,615,467	18,338	1,895
	TOTAL	839,177	216,878,729	71,590	14,425
Quebec	Core	24,069	6,293,169	2,092	407
	Urban	137,644	34,174,385	11,797	1,816
	Suburban	42,623	10,659,398	3,720	528
	Rural	104,070	24,705,741	8,898	975
	TOTAL	308,407	75,832,692	26,506	3,725
Overall	Core	120,693	33,752,344	10,359	2,951
	Urban	515,349	134,741,429	44,204	9,221
	Suburban	190,089	48,896,439	16,297	3,109
	Rural	321,453	75,321,208	27,236	2,870
	TOTAL	1,147,584	292,711,421	98,096	18,151
External	TOTAL	93,094	21,391,185	7,857	707

Ontario	Local	16,140	6,445,257	1,166	1,289
	Minor	153,119	44,240,879	13,050	4,339
	Major	144,808	34,602,893	12,020	1,761
	Freeway	447,437	110,775,381	39,103	5,098
	Centroid	70,934	16,254,649	6,251	288
	Transit	6,739	4,559,670	0	1,650
	TOTAL	839,177	216,878,729	71,590	14,425
Quebec	Local	4,810	1,932,930	358	379
	Minor	74,886	20,071,535	6,539	1,415
	Major	51,472	12,301,321	4,437	481
	Freeway	148,857	34,938,986	12,635	1,338
	Centroid	28,379	6,585,996	2,537	113
	Transit	3	1,923	0	1
	TOTAL	308,407	75,832,692	26,506	3,726
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	2,717	614,986	217	28
	Freeway	60,172	14,196,638	5,183	500
	Centroid	30,206	6,579,561	2,458	179
	Transit	0	0	0	0
	TOTAL	93,094	21,391,185	7,857	707

Total	1,240,678	314,102,607	105,953	18,859
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Intra-zonal Trips				
Core	86	21,901	9	0
Urban	1,216	287,983	114	3
Suburban	911	212,518	83	3
Rural	11,495	2,504,926	941	63
TOTAL	13,709	3,027,329	1,147	69

NCR TOTAL	1,161,293	295,738,750	99,242	18,220
(Excluding external zones)				

AM Peak Period

		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
		393,629	104,647,586	36,683	5,067
		1,562,068	383,667,569	137,815	15,559
		524,570	130,863,803	45,642	6,495
		772,131	185,783,242	63,902	9,985
		3,252,397	804,962,200	284,042	37,106
		71,450	20,827,326	7,457	871
		376,478	93,675,509	33,776	3,686
		116,387	29,349,758	10,258	1,438
		242,043	60,063,011	20,719	3,177
		806,357	203,915,604	72,210	9,171
		465,079	125,474,912	44,140	5,938
		1,938,545	477,343,077	171,591	19,245
		640,956	160,213,561	55,900	7,933
		1,014,174	245,846,253	84,621	13,162
		4,058,755	1,008,877,804	356,252	46,277
		509,960	119,932,061	42,177	5,632

		78,105	25,831,800	8,590	1,667
		861,780	232,318,627	82,676	10,118
		695,416	169,500,661	59,527	8,038
		1,277,397	289,444,665	101,864	13,569
		332,934	83,289,172	31,385	2,059
		6,765	4,577,275	0	1,656
		3,252,397	804,962,200	284,042	37,106
		20,866	7,115,445	2,347	477
		243,481	65,845,514	23,207	3,065
		133,337	32,834,839	11,611	1,488
		319,923	75,825,100	26,671	3,567
		88,747	22,292,776	8,374	574
		3	1,931	0	1
		806,357	203,915,604	72,210	9,171
		0	0	0	0
		0	0	0	0
		15,062	3,588,506	1,176	244
		328,004	78,173,779	27,604	3,582
		166,894	38,169,775	13,396	1,807
		0	0	0	0
		509,960	119,932,061	42,177	5,632

4,568,715	1,128,809,864	398,428	51,909
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1,100	297,418	116	4
14,997	3,648,528	1,421	50
8,899	2,158,387	811	55
58,067	13,315,162	4,720	589
83,064	19,419,494	7,068	697

4,141,818	1,028,297,298	363,320	46,974
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Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Midday

Description		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
Ontario	Core	420,432	114,989,798	37,140	8,387
	Urban	1,943,522	500,664,914	169,694	29,294
	Suburban	740,656	192,042,781	63,550	12,571
	Rural	1,146,215	283,433,015	94,427	17,935
	TOTAL	4,250,825	1,091,130,508	364,811	68,187
Quebec	Core	50,751	13,599,756	4,415	974
	Urban	428,451	110,352,578	38,036	5,897
	Suburban	187,254	47,917,175	16,240	2,792
	Rural	339,211	86,602,472	28,573	5,726
	TOTAL	1,005,666	258,471,981	87,264	15,390
Overall	Core	471,182	128,589,554	41,555	9,361
	Urban	2,371,973	611,017,492	207,730	35,190
	Suburban	927,910	239,959,956	79,790	15,364
	Rural	1,485,425	370,035,486	123,000	23,661
	TOTAL	5,256,491	1,349,602,488	452,076	83,577
External	TOTAL	1,045,715	254,041,356	86,265	14,621

PM Peak Period

		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
		369,610	95,809,709	34,694	3,661
		1,641,909	397,354,513	147,851	11,591
		610,679	145,294,834	53,521	4,673
		1,003,828	234,096,288	83,793	9,641
		3,626,025	872,555,345	319,859	29,567
		68,682	20,727,479	7,642	672
		427,267	107,586,734	40,107	3,071
		179,069	43,195,369	15,947	1,358
		286,904	69,425,395	24,897	2,822
		961,922	240,934,978	88,592	7,923
		438,291	116,537,188	42,336	4,333
		2,069,175	504,941,248	187,958	14,662
		789,748	188,490,203	69,468	6,031
		1,290,732	303,521,683	108,690	12,463
		4,587,947	1,113,490,323	408,452	37,490
		579,263	131,207,440	47,869	4,618

Ontario	Local	98,683	32,273,134	9,242	3,411
	Minor	862,669	230,555,270	77,225	14,341
	Major	650,090	160,389,866	53,697	9,934
	Freeway	2,204,875	554,014,722	185,976	33,898
	Centroid	418,507	103,070,500	38,671	2,687
	Transit	16,002	10,827,016	0	3,917
	TOTAL	4,250,825	1,091,130,508	364,811	68,187
Quebec	Local	25,592	8,713,057	2,416	991
	Minor	284,804	76,263,558	25,417	4,847
	Major	175,189	43,377,346	14,556	2,656
	Freeway	399,260	100,735,483	33,946	6,047
	Centroid	120,815	29,377,969	10,929	847
	Transit	6	4,567	0	2
	TOTAL	1,005,666	258,471,981	87,264	15,390
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	35,258	8,777,728	2,718	737
	Freeway	657,816	162,691,535	55,410	9,241
	Centroid	352,640	82,572,093	28,137	4,643
	Transit	0	0	0	0
	TOTAL	1,045,715	254,041,356	86,265	14,621

		86,523	28,537,408	9,950	1,433
		912,329	240,101,270	88,943	7,359
		865,577	205,761,289	75,223	7,108
		1,370,455	299,049,536	109,188	10,511
		385,000	94,951,084	36,555	1,653
		6,141	4,154,757	0	1,503
		3,626,025	872,555,345	319,859	29,567
		24,981	8,229,400	2,863	419
		287,489	77,465,631	28,527	2,517
		154,795	37,352,262	13,730	1,227
		385,754	91,370,567	33,285	3,279
		108,900	26,515,365	10,188	479
		2	1,753	0	1
		961,922	240,934,978	88,592	7,923
		0	0	0	0
		0	0	0	0
		17,605	4,038,223	1,393	212
		370,971	84,831,039	31,050	2,913
		190,688	42,338,178	15,426	1,493
		0	0	0	0
		579,263	131,207,440	47,869	4,618

Total	6,302,206	1,603,643,845	538,341	98,198
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5,167,210	1,244,697,762	456,320	42,108
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Intra-zonal Trips					
Core	Core	1,376	352,122	139	3
	Urban	29,648	7,086,173	2,759	97
	Suburban	16,869	4,057,380	1,525	103
	Rural	107,326	24,996,620	8,609	1,324
	TOTAL	155,219	36,492,295	13,032	1,527

		1,056	281,949	112	2
		18,703	4,526,313	1,793	36
		13,745	3,260,382	1,272	42
		76,304	17,203,670	6,317	563
		109,809	25,272,314	9,494	642

NCR TOTAL (Excluding external zones)	5,411,709	1,386,094,784	465,107	85,104
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4,697,755	1,138,762,637	417,946	38,132
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Summary: Vehicle Emissions From All Vehicle Classes, Trip Data from 1995 OD Survey

Evening Period

Description		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
Ontario	Core	372,102	99,687,395	33,165	6,439
	Urban	1,727,523	429,658,670	153,218	18,538
	Suburban	742,993	180,544,314	65,811	6,471
	Rural	904,091	202,164,007	77,072	4,179
	TOTAL	3,746,709	912,054,386	329,266	35,628
Quebec	Core	49,975	13,157,055	4,312	910
	Urban	436,318	106,978,211	38,869	3,977
	Suburban	171,974	41,005,785	15,264	1,185
	Rural	320,054	73,238,378	27,703	1,707
	TOTAL	978,321	234,379,429	86,147	7,780
Overall	Core	422,077	112,844,450	37,477	7,350
	Urban	2,163,842	536,636,881	192,087	22,515
	Suburban	914,967	221,550,099	81,075	7,656
	Rural	1,224,145	275,402,385	104,775	5,886
	TOTAL	4,725,030	1,146,433,815	415,414	43,407
External	TOTAL	661,069	146,241,496	56,172	2,659

Ontario	Local	108,962	34,712,011	10,072	3,562
	Minor	794,244	207,568,947	71,227	11,460
	Major	590,599	134,604,350	50,094	3,890
	Freeway	1,810,538	424,760,488	158,946	11,566
	Centroid	424,100	98,049,949	38,928	678
	Transit	18,266	12,358,643	0	4,471
	TOTAL	3,746,709	912,054,386	329,266	35,628
Quebec	Local	25,712	8,420,276	2,254	1,033
	Minor	280,595	71,885,904	25,224	3,463
	Major	154,850	35,302,763	13,248	921
	Freeway	393,706	90,348,934	34,173	2,135
	Centroid	123,451	28,416,338	11,248	225
	Transit	7	5,213	0	2
	TOTAL	978,321	234,379,429	86,147	7,780
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	18,951	4,077,664	1,533	102
	Freeway	423,276	95,989,437	36,718	1,899
	Centroid	218,842	46,174,395	17,921	657
	Transit	0	0	0	0
	TOTAL	661,069	146,241,496	56,172	2,659

Total		5,386,099	1,292,675,311	471,586	46,066
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Intra-zonal Trips					
	Core	1,464	366,141	147	1
	Urban	27,369	6,399,119	2,557	32
	Suburban	22,322	5,144,273	2,058	21
	Rural	105,844	22,426,232	8,729	297
	TOTAL	157,000	34,335,764	13,490	352

NCR TOTAL	4,882,030	1,180,769,579	428,904	43,759
(Excluding external zones)				

Daily Emissions

		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
		1,652,397	442,593,665	149,948	26,099
		7,252,727	1,811,912,711	640,986	82,386
		2,766,364	686,982,774	241,102	32,792
		4,043,647	956,092,018	337,533	43,636
		15,715,134	3,897,581,168	1,369,569	184,912
		264,926	74,604,785	25,918	3,834
		1,806,158	452,767,416	162,584	18,447
		697,306	172,127,485	61,429	7,301
		1,292,282	314,034,997	110,789	14,407
		4,060,672	1,013,534,683	360,720	43,990
		1,917,322	517,198,450	175,866	29,933
		9,058,884	2,264,680,127	803,570	100,833
		3,463,670	859,110,259	302,531	40,093
		5,335,929	1,270,127,015	448,322	58,043
		19,775,806	4,911,115,851	1,730,289	228,902
		2,889,102	672,813,538	240,340	28,237

		388,413	127,799,610	39,020	11,362
		3,584,141	954,784,994	333,122	47,616
		2,946,490	704,859,059	250,560	30,730
		7,110,701	1,678,044,791	595,077	74,641
		1,631,475	395,615,353	151,790	7,365
		53,913	36,477,361	0	13,197
		15,715,134	3,897,581,168	1,369,569	184,912
		101,962	34,411,107	10,238	3,300
		1,171,255	311,532,142	108,913	15,307
		669,643	161,168,531	57,582	6,773
		1,647,501	393,219,071	140,709	16,367
		470,292	113,188,444	43,278	2,237
		20	15,387	0	6
		4,060,672	1,013,534,683	360,720	43,990
		0	0	0	0
		0	0	0	0
		89,593	21,097,107	7,036	1,324
		1,840,239	435,882,429	155,965	18,135
		959,270	215,834,003	77,338	8,779
		0	0	0	0
		2,889,102	672,813,538	240,340	28,237

Total		22,664,907	5,583,929,389	1,970,628	257,139
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	Core	5,083	1,319,532	523	11
	Urban	91,934	21,948,115	8,643	218
	Suburban	62,746	14,832,939	5,749	223
	Rural	359,036	80,446,609	29,315	2,836
	TOTAL	518,800	118,547,196	44,230	3,288

20,294,606	5,029,663,047	1,774,519	232,190
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Daily Emissions / Fuel Use by Location All Vehicles

Daily Emissions / Fuel Use by Road Classification All Vehicles

Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Morning Period

Description		VKT	GHG's (g)	Gasoline (litres)
Ontario	Core	80,815	18,849,650	7,635
	Urban	328,042	74,511,631	30,174
	Suburban	129,122	28,823,481	11,667
	Rural	195,207	41,659,903	16,853
	TOTAL	733,186	163,844,664	66,328
Quebec	Core	20,880	4,772,833	1,934
	Urban	122,718	27,201,572	11,016
	Suburban	37,993	8,515,756	3,447
	Rural	93,448	20,252,903	8,194
	TOTAL	275,039	60,743,063	24,591
Overall	Core	101,696	23,622,482	9,568
	Urban	450,760	101,713,203	41,190
	Suburban	167,115	37,339,237	15,114
	Rural	288,655	61,912,806	25,047
	TOTAL	1,008,225	224,587,727	90,919
External	TOTAL	84,916	18,045,344	7,301

Ontario	Local	10,911	2,765,063	1,120
	Minor	127,107	29,941,778	12,127
	Major	127,060	27,216,634	11,013
	Freeway	401,423	89,218,456	36,120
	Centroid	66,685	14,702,734	5,948
	Transit	0	0	0
	TOTAL	733,186	163,844,664	66,328
Quebec	Local	3,285	848,062	343
	Minor	64,769	14,997,709	6,073
	Major	45,881	10,080,167	4,080
	Freeway	134,395	28,845,413	11,678
	Centroid	26,708	5,971,712	2,416
	Transit	0	0	0
	TOTAL	275,039	60,743,063	24,591
External	Local	0	0	0
	Minor	0	0	0
	Major	2,367	481,030	194
	Freeway	54,503	11,832,206	4,790
	Centroid	28,046	5,732,108	2,317
	Transit	0	0	0
	TOTAL	84,916	18,045,344	7,301

Total	1,093,141	242,633,072	98,220
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Intra-zonal Trips				
	Core	81	20,171	8
	Urban	1,163	269,968	109
	Suburban	865	196,682	80
	Rural	10,674	2,197,371	888
	TOTAL	12,783	2,684,191	1,085

NCR TOTAL	1,021,008	227,271,919	92,004
(Excluding external zones)			

AM Peak Period

VKT	GHG's (g)	Gasoline (litres)
341,934	82,233,503	33,304
1,398,106	315,698,688	127,827
464,263	103,871,151	42,028
673,799	143,247,695	57,927
2,878,102	645,051,037	261,086
62,164	16,664,258	6,750
338,129	77,401,913	31,341
103,093	23,257,655	9,411
212,146	46,589,412	18,843
715,532	163,913,238	66,344
404,098	98,897,761	40,054
1,736,235	393,100,602	159,168
567,356	127,128,805	51,439
885,945	189,837,106	76,770
3,593,634	808,964,275	327,431
455,252	95,940,082	38,807

68,860	20,145,315	8,156
760,866	187,401,542	75,884
607,821	133,653,847	54,073
1,131,657	230,502,157	93,293
308,898	73,348,176	29,680
0	0	0
2,878,102	645,051,037	261,086
18,308	5,498,030	2,226
214,238	52,551,027	21,275
116,783	26,043,632	10,539
283,944	60,252,054	24,386
82,259	19,568,496	7,918
0	0	0
715,532	163,913,238	66,344
0	0	0
0	0	0
12,657	2,573,690	1,040
291,559	62,344,185	25,233
151,036	31,022,207	12,534
0	0	0
455,252	95,940,082	38,807

4,048,886	904,904,356	366,237
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1,009	265,643	108
14,162	3,345,800	1,355
8,302	1,909,204	772
52,549	10,944,308	4,422
76,022	16,464,955	6,657

3,669,656	825,429,229	334,087
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Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Midday

Description		VKT	GHG's (g)	Gasoline (litres)
Ontario	Core	352,453	82,364,798	33,345
	Urban	1,695,632	384,371,318	155,556
	Suburban	639,511	142,710,267	57,715
	Rural	978,443	208,107,275	84,119
	TOTAL	3,666,038	817,553,657	330,735
Quebec	Core	42,344	9,783,296	3,963
	Urban	377,499	86,572,439	35,041
	Suburban	162,777	36,423,467	14,730
	Rural	287,999	62,910,264	25,424
	TOTAL	870,620	195,689,466	79,159
Overall	Core	394,797	92,148,094	37,308
	Urban	2,073,131	470,943,757	190,597
	Suburban	802,288	179,133,734	72,445
	Rural	1,266,442	271,017,539	109,543
	TOTAL	4,536,658	1,013,243,123	409,894
External	TOTAL	911,262	192,852,440	77,948

PM Peak Period

VKT	GHG's (g)	Gasoline (litres)
327,880	78,712,942	31,891
1,491,529	340,459,744	137,900
553,876	123,206,646	49,859
892,109	189,596,131	76,660
3,265,394	731,975,463	296,310
61,071	17,279,551	7,003
389,347	92,380,708	37,417
162,608	36,578,570	14,803
256,082	56,504,717	22,851
869,108	202,743,547	82,074
388,951	95,992,493	38,894
1,880,876	432,840,452	175,317
716,483	159,785,216	64,662
1,148,191	246,100,849	99,511
4,134,501	934,719,009	378,384
526,122	109,939,719	44,470

Ontario	Local	82,122	21,682,897	8,777
	Minor	741,880	174,277,475	70,557
	Major	552,188	118,727,269	48,010
	Freeway	1,903,508	412,844,843	166,976
	Centroid	386,340	90,021,174	36,416
	Transit	0	0	0
	TOTAL	3,666,038	817,553,657	330,735
Quebec	Local	20,962	5,655,893	2,289
	Minor	244,538	57,250,465	23,169
	Major	148,628	32,036,137	12,954
	Freeway	345,282	75,327,337	30,466
	Centroid	111,210	25,419,634	10,281
	Transit	0	0	0
	TOTAL	870,620	195,689,466	79,159
External	Local	0	0	0
	Minor	0	0	0
	Major	28,388	5,776,955	2,332
	Freeway	570,526	123,032,859	49,761
	Centroid	312,348	64,042,625	25,854
	Transit	0	0	0
	TOTAL	911,262	192,852,440	77,948

77,782	23,397,638	9,476
821,014	203,150,976	82,287
769,507	169,927,677	68,749
1,236,713	249,800,354	101,121
360,378	85,698,818	34,678
0	0	0
3,265,394	731,975,463	296,310
22,434	6,719,644	2,722
258,171	65,048,917	26,341
137,921	31,015,581	12,551
348,699	76,075,556	30,796
101,882	23,883,849	9,664
0	0	0
869,108	202,743,547	82,074
0	0	0
0	0	0
15,137	3,079,173	1,244
335,720	70,920,968	28,709
175,265	35,939,578	14,517
0	0	0
526,122	109,939,719	44,470

Total	5,447,920	1,206,095,563	487,841
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4,660,623	1,044,658,728	422,854
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Intra-zonal Trips				
	Core	1,254	314,485	127
	Urban	27,970	6,492,815	2,629
	Suburban	15,706	3,579,761	1,448
	Rural	95,063	19,632,953	7,926
	TOTAL	139,993	30,020,014	12,130

982	258,210	105
17,711	4,214,876	1,708
13,041	3,011,770	1,219
70,132	14,734,576	5,952
101,866	22,219,432	8,983

NCR TOTAL	4,676,651	1,043,263,137	422,023
(Excluding external zones)			

4,236,368	956,938,442	387,366
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Summary: Vehicle Emissions From Passenger Vehicles, Trip Data from 1995 OD Survey

Evening Period

Description		VKT	GHG's (g)	Gasoline (litres)
Ontario	Core	323,357	75,976,089	30,791
	Urban	1,561,252	355,417,110	144,013
	Suburban	679,452	153,142,708	62,013
	Rural	833,190	177,737,611	71,933
	TOTAL	3,397,251	762,273,518	308,751
Quebec	Core	42,952	9,812,907	3,978
	Urban	397,076	90,223,471	36,562
	Suburban	157,879	35,405,736	14,337
	Rural	294,104	63,884,526	25,853
	TOTAL	892,010	199,326,641	80,729
Overall	Core	366,309	85,788,996	34,770
	Urban	1,958,328	445,640,581	180,575
	Suburban	837,331	188,548,444	76,350
	Rural	1,127,293	241,622,137	97,786
	TOTAL	4,289,262	961,600,158	389,481
External	TOTAL	616,188	130,680,164	52,893

Ontario	Local	91,869	23,817,332	9,650
	Minor	699,964	163,887,674	66,415
	Major	534,452	114,727,171	46,446
	Freeway	1,667,261	367,911,145	149,016
	Centroid	403,706	91,930,196	37,225
	Transit	0	0	0
	TOTAL	3,397,251	762,273,518	308,751
Quebec	Local	20,971	5,317,316	2,155
	Minor	249,739	58,084,118	23,531
	Major	140,276	30,265,981	12,252
	Freeway	363,664	79,105,650	32,040
	Centroid	117,360	26,553,576	10,751
	Transit	0	0	0
	TOTAL	892,010	199,326,641	80,729
External	Local	0	0	0
	Minor	0	0	0
	Major	17,057	3,466,383	1,401
	Freeway	392,285	85,008,292	34,431
	Centroid	206,845	42,205,488	17,061
	Transit	0	0	0
	TOTAL	616,188	130,680,164	52,893

Total	4,905,450	1,092,280,322	442,374
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Intra-zonal Trips				
	Core	1,368	339,317	138
	Urban	26,091	6,036,831	2,447
	Suburban	21,463	4,903,167	1,985
	Rural	100,042	20,568,540	8,315
	TOTAL	148,964	31,847,856	12,884

NCR TOTAL	4,438,226	993,448,014	402,364
(Excluding external zones)			

Daily Emissions

VKT	GHG's (g)	Gasoline (litres)
1,426,439	338,136,981	136,966
6,474,560	1,470,458,491	595,470
2,466,224	551,754,252	223,282
3,572,748	760,348,615	307,492
13,939,971	3,120,698,339	1,263,210
229,411	58,312,845	23,628
1,624,769	373,780,104	151,377
624,351	140,181,184	56,728
1,143,778	250,141,821	101,165
3,622,309	822,415,954	332,897
1,655,850	396,449,826	160,594
8,099,330	1,844,238,594	746,847
3,090,574	691,935,436	280,010
4,716,526	1,010,490,437	408,657
17,562,281	3,943,114,292	1,596,108
2,593,739	547,457,748	221,419

331,544	91,808,245	37,178
3,150,829	758,659,444	307,270
2,591,029	564,252,598	228,291
6,340,562	1,350,276,955	546,525
1,526,007	355,701,098	143,946
0	0	0
13,939,971	3,120,698,339	1,263,210
85,961	24,038,944	9,736
1,031,456	247,932,236	100,389
589,489	129,441,497	52,376
1,475,984	319,606,009	129,367
439,419	101,397,268	41,029
0	0	0
3,622,309	822,415,954	332,897
0	0	0
0	0	0
75,607	15,377,232	6,211
1,644,594	353,138,509	142,924
873,539	178,942,007	72,283
0	0	0
2,593,739	547,457,748	221,419

20,156,020	4,490,572,041	1,817,527
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4,695	1,197,826	485
87,097	20,360,290	8,248
59,378	13,600,584	5,503
328,459	68,077,749	27,502
479,629	103,236,448	41,738

18,041,910	4,046,350,741	1,637,846
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APPENDIX N

1995 AND 2021 VEHICLE EMISSIONS

Summary: Vehicle Emissions from All Vehicle Classes

2021 Model, PM Peak Hour

Description		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
Ontario	Core	210,219	59,748,027	21,769	2,165
	Urban	931,747	233,366,568	86,933	6,721
	Suburban	533,816	131,045,298	48,471	4,035
	Rural	775,055	179,955,191	64,142	7,645
	TOTAL	2,450,836	604,115,083	221,315	20,566
Quebec	Core	42,352	14,329,196	5,357	399
	Urban	235,269	58,266,329	21,826	1,569
	Suburban	144,689	33,697,181	12,401	1,055
	Rural	258,028	62,232,964	22,400	2,432
	TOTAL	680,338	168,525,670	61,985	5,521
Overall	Core	252,571	74,077,223	27,127	2,563
	Urban	1,167,016	291,632,897	108,759	8,290
	Suburban	678,505	164,742,479	60,873	5,129
	Rural	1,033,083	242,188,155	86,542	10,103
	TOTAL	3,131,175	772,640,754	283,300	26,087
External	TOTAL	489,558	108,580,586	39,702	3,742

Ontario	Local	53,601	18,757,092	6,735	767
	Minor	596,982	161,108,315	59,721	4,892
	Major	720,694	174,428,793	63,453	6,299
	Freeway	795,541	174,836,026	63,748	6,223
	Centroid	279,499	71,895,730	27,658	1,267
	Transit	4,518	3,089,127	0	1,118
	TOTAL	2,450,836	604,115,083	221,315	20,566
Quebec	Local	12,578	4,228,210	1,500	190
	Minor	165,097	45,675,381	16,893	1,417
	Major	115,963	28,004,194	10,367	855
	Freeway	314,237	72,220,176	26,408	2,503
	Centroid	71,607	17,847,216	6,817	357
	Transit	857	550,492	0	199
	TOTAL	680,338	168,525,670	61,985	5,521
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	19,199	4,413,668	1,523	231
	Freeway	315,366	69,272,997	25,450	2,294
	Centroid	154,992	34,893,921	12,729	1,217
	Transit	0	0	0	0
	TOTAL	489,558	108,580,586	39,702	3,742

NCR TOTAL (excluding external)		3,131,175	772,640,754	283,300	26,087
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1995 Model, PM Peak Hour

		VKT	GHG's (g)	Gasoline (litres)	Diesel (litres)
	Core	170,870	46,491,518	16,924	1,697
	Urban	692,974	168,633,299	62,743	4,923
	Suburban	260,559	61,770,409	22,734	2,004
	Rural	450,011	104,899,592	37,551	4,317
	TOTAL	1,574,415	381,794,817	139,953	12,942
	Core	37,839	13,739,885	5,123	395
	Urban	224,468	58,889,663	22,036	1,607
	Suburban	107,407	25,377,850	9,382	787
	Rural	175,916	42,548,938	15,284	1,707
	TOTAL	545,629	140,556,335	51,823	4,496
	Core	208,709	60,231,402	22,047	2,092
	Urban	917,442	227,522,962	84,779	6,530
	Suburban	367,966	87,148,259	32,116	2,791
	Rural	625,927	147,448,530	52,835	6,025
	TOTAL	2,120,044	522,351,153	191,776	17,438
	TOTAL	272,677	61,480,699	22,441	2,154

	Local	36,831	12,008,501	4,185	605
	Minor	402,601	107,478,100	39,864	3,250
	Major	374,697	89,247,999	32,595	3,111
	Freeway	588,190	129,619,151	47,281	4,596
	Centroid	169,495	41,680,576	16,028	742
	Transit	2,602	1,760,490	0	637
	TOTAL	1,574,415	381,794,817	139,953	12,942
	Local	12,655	4,259,178	1,516	186
	Minor	150,678	43,549,408	16,125	1,337
	Major	93,808	23,431,559	8,661	727
	Freeway	234,213	55,945,444	20,403	1,987
	Centroid	54,274	13,370,002	5,118	258
	Transit	1	743	0	0
	TOTAL	545,629	140,556,335	51,823	4,496
	Local	0	0	0	0
	Minor	0	0	0	0
	Major	8,150	1,869,381	645	98
	Freeway	174,884	39,701,151	14,540	1,355
	Centroid	89,643	19,910,167	7,256	700
	Transit	0	0	0	0
	TOTAL	272,677	61,480,699	22,441	2,154

		2,120,044	522,351,153	191,776	17,438
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Summary: Vehicle Emissions from Passenger Vehicles Only

2021 Model, PM Peak Hour

Description		VKT	GHG's (g)	Gasoline (litres)
Ontario	Core	186,706	49,396,703	20,014
	Urban	846,825	200,243,388	81,109
	Suburban	485,075	111,761,993	45,225
	Rural	685,626	144,780,668	58,530
	TOTAL	2,204,232	506,182,751	204,878
Quebec	Core	37,850	12,117,448	4,911
	Urban	214,625	50,255,582	20,360
	Suburban	130,989	28,435,316	11,508
	Rural	230,927	50,909,776	20,591
	TOTAL	614,391	141,729,122	57,370
Overall	Core	224,555	61,515,151	24,925
	Urban	1,061,451	250,508,970	101,468
	Suburban	616,064	140,197,309	56,733
	Rural	916,553	195,690,444	79,121
	TOTAL	2,818,623	647,911,874	262,248
External	TOTAL	444,364	91,231,057	36,902

1995 Model, PM Peak Hour

VKT	GHG's (g)	Gasoline (litres)
151,796	38,390,447	15,554
629,602	144,474,783	58,518
236,247	52,317,999	21,172
399,997	84,978,754	34,360
1,417,643	320,161,984	129,604
33,780	11,583,304	4,694
204,782	50,743,602	20,553
97,489	21,501,774	8,702
157,101	34,684,002	14,027
493,152	118,512,682	47,976
185,576	49,973,752	20,249
834,385	195,218,385	79,071
333,736	73,819,773	29,874
557,099	119,662,756	48,386
1,910,795	438,674,666	177,580
247,666	51,544,787	20,850

Ontario	Local	48,722	15,844,422	6,417
	Minor	537,035	136,260,295	55,183
	Major	639,010	143,195,556	57,925
	Freeway	717,649	145,974,959	59,092
	Centroid	261,816	64,907,518	26,261
	Transit	0	0	0
	TOTAL	2,204,232	506,182,751	204,878
Quebec	Local	11,369	3,514,915	1,424
	Minor	148,255	38,432,449	15,561
	Major	103,763	23,454,800	9,492
	Freeway	284,208	60,365,012	24,436
	Centroid	66,795	15,961,947	6,457
	Transit	0	0	0
	TOTAL	614,391	141,729,122	57,370
External	Local	0	0	0
	Minor	0	0	0
	Major	16,508	3,368,113	1,360
	Freeway	285,399	58,202,335	23,561
	Centroid	142,456	29,660,609	11,981
	Transit	0	0	0
	TOTAL	444,364	91,231,057	36,902

33,124	9,843,514	3,987
362,315	91,001,868	36,861
332,869	73,596,725	29,775
530,808	108,163,100	43,785
158,527	37,556,777	15,197
0	0	0
1,417,643	320,161,984	129,604
11,456	3,555,521	1,440
135,479	36,727,481	14,873
83,757	19,583,726	7,926
211,788	46,659,640	18,888
50,673	11,986,314	4,849
0	0	0
493,152	118,512,682	47,976
0	0	0
0	0	0
7,008	1,425,402	576
158,266	33,213,572	13,445
82,393	16,905,814	6,829
0	0	0
247,666	51,544,787	20,850

NCR TOTAL (excluding external)	2,818,623	647,911,874	262,248
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1,910,795	438,674,666	177,580
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Summary: Vehicle Emissions from All Vehicle Categories

2021 Model, PM Peak Hour

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	210,000	489,716	4,733,147	299,961
	Urban	931,772	1,571,746	14,581,446	1,201,716
	Suburban	534,207	748,462	6,770,022	676,968
	Rural	775,649	796,037	6,479,675	1,011,941
	TOTAL	2,451,628	3,605,961	32,564,290	3,190,586
Quebec	Core	42,282	127,922	1,269,933	59,666
	Urban	235,269	373,920	3,381,951	306,868
	Suburban	144,811	168,774	1,413,939	187,695
	Rural	258,226	271,412	2,212,678	343,915
	TOTAL	680,588	942,028	8,278,501	898,144
Overall	Core	252,282	617,637	6,003,080	359,627
	Urban	1,167,041	1,945,666	17,963,397	1,508,585
	Suburban	679,018	917,235	8,183,961	864,663
	Rural	1,033,875	1,067,449	8,692,353	1,355,856
	TOTAL	3,132,216	4,547,988	40,842,791	4,088,730
External	TOTAL	489,860	482,159	3,806,448	639,153

Ontario	Local	53,532	149,969	1,511,265	81,856
	Minor	596,936	1,153,059	11,009,614	795,507
	Major	721,067	888,670	7,671,541	917,509
	Freeway	796,259	915,764	7,723,512	1,017,763
	Centroid	279,317	493,375	4,625,621	342,874
	Transit	4,518	5,124	22,736	35,078
	TOTAL	2,451,628	3,605,961	32,564,290	3,190,586
Quebec	Local	12,559	35,538	355,452	19,572
	Minor	165,105	320,437	3,048,197	221,093
	Major	115,992	149,967	1,304,475	145,429
	Freeway	314,521	314,313	2,462,476	417,483
	Centroid	71,555	120,979	1,104,452	87,999
	Transit	857	794	3,449	6,567
	TOTAL	680,588	942,028	8,278,501	898,144
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	19,216	17,735	133,014	26,290
	Freeway	315,652	305,538	2,456,571	399,402
	Centroid	154,992	158,886	1,216,863	213,461
	Transit	0	0	0	0
	TOTAL	489,860	482,159	3,806,448	639,153

NCR TOTAL (excluding external)	3,132,216	4,547,988	40,842,791	4,088,730
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1995 Model, PM Peak Hour

VKT	VOC's (g)	CO (g)	NO _x (g)
170,707	371,937	3,540,546	243,713
693,011	1,110,322	10,120,026	898,259
260,759	329,479	2,874,855	337,212
450,351	439,694	3,482,085	601,173
1,574,827	2,251,433	20,017,512	2,080,357
37,777	123,970	1,238,994	54,402
224,476	395,319	3,683,915	294,080
107,497	123,139	1,027,422	144,670
176,049	186,016	1,520,497	232,761
545,800	828,444	7,470,829	725,913
208,484	495,907	4,779,540	298,116
917,487	1,505,642	13,803,941	1,192,339
368,256	452,618	3,902,277	481,882
626,400	625,711	5,002,582	833,934
2,120,627	3,079,877	27,488,341	2,806,270
272,842	253,167	1,905,347	366,533

36,782	89,626	900,042	57,858
402,503	780,084	7,416,377	537,580
374,865	451,956	3,819,574	476,991
588,721	648,645	5,321,204	780,008
169,355	278,193	2,547,509	207,928
2,602	2,929	12,806	19,990
1,574,827	2,251,433	20,017,512	2,080,357
12,635	35,392	355,666	19,538
150,682	316,542	3,058,332	203,282
93,826	128,700	1,145,788	119,326
234,424	257,050	2,085,641	317,115
54,231	90,759	825,395	66,643
1	2	8	9
545,800	828,444	7,470,829	725,913
0	0	0	0
0	0	0	0
8,157	7,457	55,859	11,201
175,042	156,539	1,183,535	230,466
89,643	89,172	665,952	124,867
0	0	0	0
272,842	253,167	1,905,347	366,533

2,120,627	3,079,877	27,488,341	2,806,270
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Summary: Vehicle Emissions from Passenger Vehicles Only

2021 Model, PM Peak Hour

Description		VKT	VOC's (g)	CO (g)	NO _x (g)
Ontario	Core	186,706	440,635	4,302,399	215,352
	Urban	846,825	1,437,739	13,467,993	920,873
	Suburban	485,075	681,761	6,244,717	508,355
	Rural	685,626	699,792	5,785,890	686,193
	TOTAL	2,204,232	3,259,927	29,800,999	2,330,772
Quebec	Core	37,850	115,707	1,155,627	44,607
	Urban	214,625	343,020	3,128,159	240,264
	Suburban	130,989	153,036	1,295,939	139,517
	Rural	230,927	241,180	1,989,799	241,452
	TOTAL	614,391	852,943	7,569,524	665,839
Overall	Core	224,555	556,342	5,458,026	259,959
	Urban	1,061,451	1,780,759	16,596,152	1,161,136
	Suburban	616,064	834,798	7,540,656	647,872
	Rural	916,553	940,972	7,775,689	927,644
	TOTAL	2,818,623	4,112,871	37,370,523	2,996,611
External	TOTAL	444,364	436,866	3,483,734	469,925

Ontario	Local	48,722	139,125	1,421,824	56,064
	Minor	537,035	1,043,134	10,056,790	597,098
	Major	639,010	789,773	6,910,493	649,145
	Freeway	717,649	824,099	7,037,194	739,324
	Centroid	261,816	463,796	4,374,697	289,140
	Transit	0	0	0	0
	TOTAL	2,204,232	3,259,927	29,800,999	2,330,772
Quebec	Local	11,369	32,789	332,686	13,184
	Minor	148,255	288,826	2,773,112	164,916
	Major	103,763	134,029	1,178,585	108,156
	Freeway	284,208	284,031	2,243,905	306,467
	Centroid	66,795	113,268	1,041,236	73,116
	Transit	0	0	0	0
	TOTAL	614,391	852,943	7,569,524	665,839
External	Local	0	0	0	0
	Minor	0	0	0	0
	Major	16,508	15,112	115,015	16,200
	Freeway	285,399	275,868	2,239,903	293,188
	Centroid	142,456	145,887	1,128,816	160,536
	Transit	0	0	0	0
	TOTAL	444,364	436,866	3,483,734	469,925

NCR TOTAL (excluding external)	2,818,623	4,112,871	37,370,523	2,996,611
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1995 Model, PM Peak Hour

VKT	VOC's (g)	CO (g)	NO _x (g)
151,796	334,445	3,216,032	175,495
629,602	1,015,091	9,344,609	688,312
236,247	299,210	2,644,001	250,727
399,997	388,906	3,120,177	414,984
1,417,643	2,037,652	18,324,819	1,529,518
33,780	112,087	1,126,214	40,301
204,782	362,281	3,403,449	229,238
97,489	111,889	942,634	109,069
157,101	164,835	1,363,801	162,365
493,152	751,092	6,836,098	540,973
185,576	446,532	4,342,246	215,796
834,385	1,377,372	12,748,058	917,550
333,736	411,099	3,586,635	359,796
557,099	553,741	4,483,978	577,349
1,910,795	2,788,744	25,160,917	2,070,491
247,666	229,711	1,744,201	269,844

33,124	82,317	842,878	37,379
362,315	706,536	6,780,436	405,484
332,869	402,852	3,445,847	342,260
530,808	584,697	4,848,266	569,070
158,527	261,249	2,407,392	175,325
0	0	0	0
1,417,643	2,037,652	18,324,819	1,529,518
11,456	32,686	333,130	13,251
135,479	285,845	2,786,044	151,576
83,757	115,150	1,036,655	87,811
211,788	232,350	1,901,430	232,636
50,673	85,060	778,839	55,700
0	0	0	0
493,152	751,092	6,836,098	540,973
0	0	0	0
0	0	0	0
7,008	6,359	48,294	6,880
158,266	141,431	1,078,339	169,076
82,393	81,921	617,567	93,888
0	0	0	0
247,666	229,711	1,744,201	269,844

1,910,795	2,788,744	25,160,917	2,070,491
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PM Peak Hour Emissions by Road Classification Ontario Zones, Passenger Vehicles Only

PM Peak Hour Emissions by Road Classification Quebec Zones, Passenger Vehicles Only