Vehicle Activity Data for Emissions Modelling in Urban Areas of the Canadian Prairie Region

By

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ABSTRACT

This research develops and applies a methodology to calculate vehicle activity inputs for spatial and temporal modelling of emissions from on-road vehicles using traffic count data. The thesis: (1) provides an understanding of emissions modelling in Canada and the U.S. and discusses the traffic activity data inputs required by vehicle emissions modelling software; (2) develops a methodology to collect and prepare vehicle activity data for an urban centre and applies this methodology by estimating vehicle activity for Winnipeg and Saskatoon; and (3) estimates vehicle emissions for Winnipeg and Saskatoon and then compares the sensitivity of estimating emissions using locally developed vehicle activity to estimating emissions using default vehicle activity.

Emissions models are used to create baseline estimates of existing conditions, assess compliance of regulated sources, and measure progress against targets. It is critical to develop jurisdiction-specific input values to accurately reflect on-road motor vehicle emissions. The methodology this research develops and applies to Winnipeg and Saskatoon is applicable to any jurisdiction in need of developing their own vehicle activity inputs for emissions modelling. Comparisons between developed inputs and software default inputs indicate significant differences. The emissions estimates calculated using these different inputs emphasizes the importance of obtaining jurisdiction-specific input values for emissions modelling.

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1. INTRODUCTION

1.1. THE RESEARCH

This research develops and applies a methodology to calculate vehicle activity inputs for spatial and temporal modelling of emissions from on-road vehicles, using traffic count data. The research produces four vehicle activity inputs to be used in the MOBILE6.2C emissions model: vehicle miles travelled (VMT) by vehicle class, VMT by road facility type, VMT by hour, and VMT by speed for Winnipeg, Manitoba; and Saskatoon, Saskatchewan. The format of the inputs is specifically guided by the input requirements of the MOBILE6.2C model, for this reason vehicle miles travelled is used throughout the research and not vehicle kilometres travelled.

1.2. BACKGROUND AND NEED

Canada signed the Copenhagen Accord in December 2009, thus committing to reducing its greenhouse gas emissions to 17 percent below 2005 levels by 2020. This same target was also set by the United States. The Government of Canada’s initial focus in tackling climate change has been through regulation of the transportation sector (Government of Canada, 2011).

Air pollution comes from a variety of sources, including combustion of fossil fuels from the transportation sector. The transportation sector is responsible for 33 percent of energy-related greenhouse gas emissions in Canada (Environment Canada, 2010b). The gasoline and diesel fuel consumed by on-road vehicles comprise over 68 percent of the greenhouse gas created by the transportation sector (Environment Canada, 2010b) and the emissions generated by this sector are a major contributor to air pollution.

In the U.S., the 1990 Clean Air Act (the Act) requires States to attain and maintain the National Ambient Air Quality Standards (NAAQS). The Act places most of the responsibility on states to prevent and control air pollution and in order for a State to operate an air quality program, the State must adopt a plan and obtain approval of the plan from the EPA. In order to demonstrate compliance with the Act and EPA rules, a State Implementation Plan (SIP) must be developed (U.S. EPA, 2011a). State Implementation Plans are the regulations and other materials for meeting clean air standards and associated Clean Air Act requirements. They include planning documents such as area specific emissions estimates and modelling analyses demonstrating that the air will meet air quality standards.

In Canada, Environment Canada is responsible for maintaining an inventory of data, providing emission estimates for all types of transportation, and preparing annual reports to the United Nations on Canadian emissions. Through the National Pollutant Release Inventory (NPRI), Environment Canada compiles air emission estimates for mobile sources (motor vehicles). The Air Quality Research Division carries out measurements and research of emissions and quantifies the emission contribution from mobile sources. This is completed to fulfil national and international reporting obligations.

As cities seek ways to coordinate emission mitigation programs and regulate the transportation sector, there is a need to establish emissions benchmarks which can be used to develop future emissions reduction targets for on-road vehicles. Benchmark estimates require a high level of spatial and temporal specificity, and an understanding of the emissions characteristics of all vehicle types. These benchmarks can be used to understand changes in emissions attributable to government programs (e.g., subsidies to purchase hybrid vehicles, congestion pricing, ethanol-based fuel mandates), night-time deliveries, mode shifts (e.g., passenger car to bus), anticipated urban growth, and roadway network changes. The reliability and accuracy of modelled emission rates are of increasing importance to understand these effects. Governments and the public are becoming increasingly concerned with energy security and climate change; engineers help design, develop, and implement transportation systems that address these concerns.

The quantity of on-road vehicle emissions and the quality of emissions estimates are affected by many factors (U.S. EPA, 2004): vehicle activity attributes (e.g., vehicle-distance travelled, speed); ambient environmental conditions (e.g., temperature, barometric pressure); vehicle fleet characteristics (e.g., age, engine type); fuel specifications (e.g., sulphur content, oxygenate blend); and programs, regulations, and technologies directed at mitigating air pollution effects (e.g., heavy duty vehicle engine standards). Vehicle activity attributes are critical for modelling on-road traffic emissions and although national default distributions have been developed, there is sufficient variation in roadway network characteristics between areas that the use of locally developed distributions is preferred. These locally developed vehicle activity attributes are difficult to obtain and estimate.

Vehicle activity data refers to on-road vehicle miles travelled and its characteristics which are affected by the transportation network. It includes data for the distribution of VMT accumulated by vehicle class, the distribution of speed experienced on the network, and the temporal distribution of VMT (U.S. EPA, 2004). All of these inputs can have a significant impact on emissions produced. For example, gram per mile emissions of carbon dioxide for light duty gasoline vehicles, light duty gasoline trucks, and articulated diesel trucks are 365, 532, and 1647 respectively based on MOBILE6.2C analysis conducted for year 2006 using default inputs produced by the U.S. Environmental Protection Agency. Vehicles maintain maximum fuel efficiency in a broad range from about 30 to 60 miles per hour (Victoria Transport Policy Institute, 2011). Per mile emissions of carbon monoxide (CO), volatile organic compounds (VOCs), and nitrogen oxides (NOx) follow the same trend of being minimized from about 30 to 60 miles per hour, and increase at higher and lower speeds. Because emissions are affected by speed it is not only the calculated speed for each hour which is important but also the amount of VMT assigned to each hour.

This research develops and applies a methodology to obtain vehicle activity data for emissions modelling by facility type, hour of day, and speed. The research provides engineers and other professionals with specific information that can assist in the development of local vehicle activity inputs for emissions modelling in urban areas. The emissions model results can then be used as indicators to inform policy analysts, decision makers and the public for analysis ranging from estimating the national impacts of motor vehicle emissions control strategies to estimating human exposure to pollutants at a specific intersection.

1.3. OBJECTIVES AND SCOPE

Specific objectives of this research are to:

- Understand emissions modelling in Canada and the U.S.
- Understand the traffic activity data inputs required by vehicle emissions modelling software.

- Develop a methodology to collect and prepare vehicle activity data for an urban centre.
- Estimate vehicle emissions for Winnipeg and Saskatoon.
- Compare the limitations and sensitivity of estimating emissions using locally developed vehicle activity inputs relative to using default activity inputs.

The methodology is applied to Winnipeg, Manitoba, and Saskatoon, Saskatchewan. Emissions estimates are prepared using MOBILE6.2C, which is the most recent Canadian version of the MOBILE software program designed by the U.S. Environmental Protection Agency (EPA) to estimate emissions from on-road vehicles. The U.S. EPA has recently released the Motor Vehicle Emissions Simulator (MOVES) software to replace MOBILE; although the Canadian government is considering shifting to MOVES it is not yet available for the Canadian context. This research also describes the MOVES software, compares the inputs to those of MOBILE and discusses issues that will need to be addressed before implementation of MOVES in Canada.

1.4. THESIS ORGANIZATION

This thesis is organized into five chapters. Chapter 2 describes vehicle emissions, the need for vehicle emissions modelling, vehicle emissions modelling software, the state of practice of emissions modelling, and the three main methods for obtaining input data: default values, travel demand models, and traffic counts.

Chapter 3 describes the general methodology to obtain the required MOBILE6.2C input data and then applies the methodology to Winnipeg and Saskatoon to illustrate the data collection process.

Chapter 4 provides VMT estimates by vehicle class, VMT by hour, and example tables of VMT by road facility type and VMT by speed. A comparison is provided between the emissions estimates using locally developed vehicle activity inputs and the U.S. based software default inputs. This chapter then provides the results of the emissions estimate for Winnipeg and Saskatoon using the MOBILE6.2C model and compares each of these estimates to an emissions estimate using default vehicle activity inputs.

Chapter 6 discusses research findings and conclusions, and opportunities for future research.

1.5. TERMINOLOGY

The following terms are used throughout the thesis.

Emission: Release of pollutants into the air from a source (FHWA, 2010).

MOBILE6.2: A software program designed by the United States Environmental Protection Agency in 2004 to estimate emissions from on-road vehicles.

MOBILE6.2C: The Canadian-specific version of the MOBILE6.2 model created by Environment Canada to address differences between Canada and the U.S.

MOVES: The most recent emissions simulator developed by the United States Environmental Protection Agency for modelling emissions from on-road vehicles.

Mobile sources: Moving objects that release pollution. Mobile sources are divided into two groups: on-road vehicles, which include cars, trucks, and buses, and nonroad vehicles, which include trains, planes, lawn mowers, and some portable equipment (FHWA, 2010).

On-road vehicles: These vehicles include cars, trucks, buses and motorcycles. On-road vehicles do not include non-road vehicles (e.g., trains, planes, and lawn mowers).

Vehicle activity data: This refers to characteristics of vehicle operations and on-road vehicle miles travelled which are affected by the transportation network. It includes data for the distribution of VMT accumulated by vehicle class, the distribution of speed experienced on the network, and the temporal distribution of VMT.

Vehicle miles traveled (VMT): A standard area wide measure of travel activity. The most conventional VMT calculation is to multiply average length of trip by the total number of trips, or to sum the traffic volumes on links multiplied by link length (U.S. Environmental Protection Agency, 1999). The specific MOBILE6.2C do not require absolute VMT, rather it requires relative proportion of VMT. Therefore VMT can be calculated as hourly traffic volume multiplied by link length or daily traffic volume multiplied by link length so that VMT is represented as the appropriate proportion for each specific activity input.

2. VEHICLE EMISSIONS MODELLING

This chapter describes vehicle emissions, the need for vehicle emissions modelling, vehicle emissions modelling software, the state of practice of emissions modelling, and the three main methods for obtaining vehicle activity input data for emissions modelling: (1) default values, (2) travel demand models, and (3) traffic counts.

2.1. CLASSIFICATION AND DESCRIPTION OF EMISSIONS

Motor vehicle emissions can be classified into two categories according to their impacts: pollutants and greenhouse gases (Natural Resources Canada, 2011). One of the key differences between these categories is related to the variability of their impacts. The impacts of pollutant emissions are highly variable, depending upon factors such as population, geography, climate, and the exposure and sensitivity of human, animal or plant life. The impacts of greenhouse gas emissions are not as variable, as they all accumulate in the earth's atmosphere and contribute to global warming (Delcan, 2007).

2.1.1. Pollutants

Air pollutants are any substance in air that could, in high enough concentration, harm humans, animals, vegetation, or material (FHWA, 2010). Pollutants may include almost any natural or artificial composition of airborne matter. They may be in the form of solid particles, liquid droplets, gases or any combination thereof. Generally, they fall into two main groups: (1) those emitted directly from identifiable sources, and (2) those produced in the air by interaction between two or more primary pollutants, or by reaction with normal atmospheric constituents (FHWA, 2010).

Emission of these substances to the atmosphere is known to affect human health and contribute to problems such as ground level ozone, smog, and acid rain. Environment Canada has classified six key air pollutants (described below) as Criteria Air Contaminants (CACs). The CACs are tracked via the National CAC Emissions Inventory[1].

Particulate Matter (PM) – Particulate matter refers to microscopic solid and liquid particles, of various origins, that remain suspended in the air for any length of time. Total particulate matter (TPM) is classified into two size ranges, as the particle size is the primary determinant of the health and environmental impacts. Fine particulates ($PM_{2.5}$) are any particulate matter with a diameter less than or equal to 2.5 microns; PM_{10} are any particulate matter with a diameter less than or equal to 10 microns. $PM_{2.5}$ are generated as secondary products of motor vehicle fuel consumption, formed from gaseous vehicle emissions like NO_x or SO_2. Links between particulate matter and aggravated cardiac and respiratory diseases are indicated in numerous studies. Particulates can also have adverse effects on vegetation and visibility, can remain suspended in the air for days or weeks, and can travel thousands of kilometres from the point of emission (Environment Canada, 2011a).

Sulphur Oxides (SO_x) – Oxides of sulphur (of which sulphur dioxide, SO_2, is the most common) are a product of the combustion of fossil fuels that contain sulphur. Vehicle emissions of SO_2 are significantly lower than other pollutants; however they can impact both human health and the environment. Sulphur dioxide is closely related to sulphuric acid, and plays an important role in the production of acid rain (Environment Canada, 2011a).

[1] The National Pollutant Release Inventory tracks a total of 300 substances on an annual basis; however, the CACs have been specifically identified as key air pollutants.

Nitrogen Oxides (NO_x) – Oxides of nitrogen (of which nitrogen dioxide, NO_2, is the most common) are a group of gaseous products of the burning of nitrogen in fossil fuel and nitrogen compounds in air. Nitrogen dioxide can have adverse effects on respiratory systems and vegetation; some NO_x are toxic. Nitrogen oxides are major components of acid rain and can also react with volatile organic compounds to form smog (Environment Canada, 2011a).

Volatile Organic Compounds (VOC) **–** Volatile organic compounds are a large group of carbon-containing gases and vapours that are products of gasoline combustion. Many of the VOCs have been assessed to be toxic. The more reactive VOCs combine with NO_x in photochemical reactions in the atmosphere to form ground-level ozone, a major component of smog (Environment Canada, 2011a).

Carbon Monoxide (CO) – Carbon monoxide is a toxic gaseous product of incomplete combustion of gasoline and diesel fuel present in all tailpipe exhaust, more significantly in poorly maintained vehicles. Carbon monoxide emissions, which increase at lower temperatures, have significant health impacts. Infants, elderly persons, and individuals with heart or respiratory problems are particularly sensitive; however CO can also have a variety of negative impacts on healthy individuals (Environment Canada, 2011a).

Ammonia (NH_3) – Ammonia is poisonous if inhaled in large quantities and is irritating to the eyes, nose, and throat in lesser amounts. It combines in the atmosphere with sulphates and nitrates to form $PM_{2.5}$ (Environment Canada, 2011a).

2.1.2. Greenhouse Gases

The term “greenhouse gases” is derived from the “greenhouse effect”. The greenhouse effect is the process by which the absorption of infrared radiation by the atmosphere warms the Earth. Greenhouse gases refer to the natural and man-made gases in the atmosphere that insulate the planet from heat loss (FHWA, 2010).

Environment Canada is responsible for preparing Canada's official greenhouse gas national inventory with input from numerous experts and scientists across Canada. The National Inventory Report (NIR) contains Canada's annual greenhouse gas emission estimates dating back to 1990. The three key greenhouse gases generated by on-road vehicle use are: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The NIR lists all pollutants in terms of CO_2 equivalents. CO_2 equivalent (CO_2 eq.) is the amount of CO_2 from a different greenhouse gas required to produce a similar effect. Emissions of CH_4 and N_2O are more difficult to estimate accurately than those for because emission factors depend on vehicle technology, fuel, and operating characteristics while CO_2 emission factors are dependent on the amount and type of fuel combusted (IPCC, 2006).

Carbon Dioxide (CO_2) – Carbon dioxide is a by-product of fossil fuel combustion in automobiles. CO_2 is also a naturally occurring, colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is the most significant component of all greenhouse gas emissions in Canada, and represents approximately 98 percent of greenhouse gas emissions (in CO2 eq.) from road transportation (Environment Canada, 2010a).

Methane (CH_4) – Methane is a flammable gaseous product of fuel combustion and evaporative emissions. Methane emissions from vehicles are very small and represent less than one percent of greenhouse gas emissions (in CO2 eq.) from road transportation in Canada (Environment Canada, 2010a).

Nitrous Oxide (N_2O) – Nitrous Oxide (N_2O) is a gaseous product of incomplete combustion of automotive fuels as well as a by-product of catalytic converters. Nitrous oxide represents approximately two percent of greenhouse gas emissions (in CO2 eq.) from road transportation in Canada (Environment Canada, 2010a).

2.2. VEHICLE EMISSIONS MODELLING TOOLS

Vehicle emissions models are designed to provide estimates of current and future emissions from on-road vehicles to address a wide variety of air pollution modelling needs. Emission rates are derived from emissions tests conducted under standard conditions such as temperature, fuel, and driving cycle (Swisher and Hallmark, 2003). Models incorporate adjustments to basic emission rates for conditions that differ from standard testing. Adjustments are used both to reflect how an in-use vehicle population is different from the tested samples and for conditions different from those used in the testing program.

Models require users to input data for local conditions so that these adjustments can be applied to the basic emission rates calculated from the conditions present in the standard testing. Figure 1 shows common inputs that emissions models require and illustrates the emission estimation process.

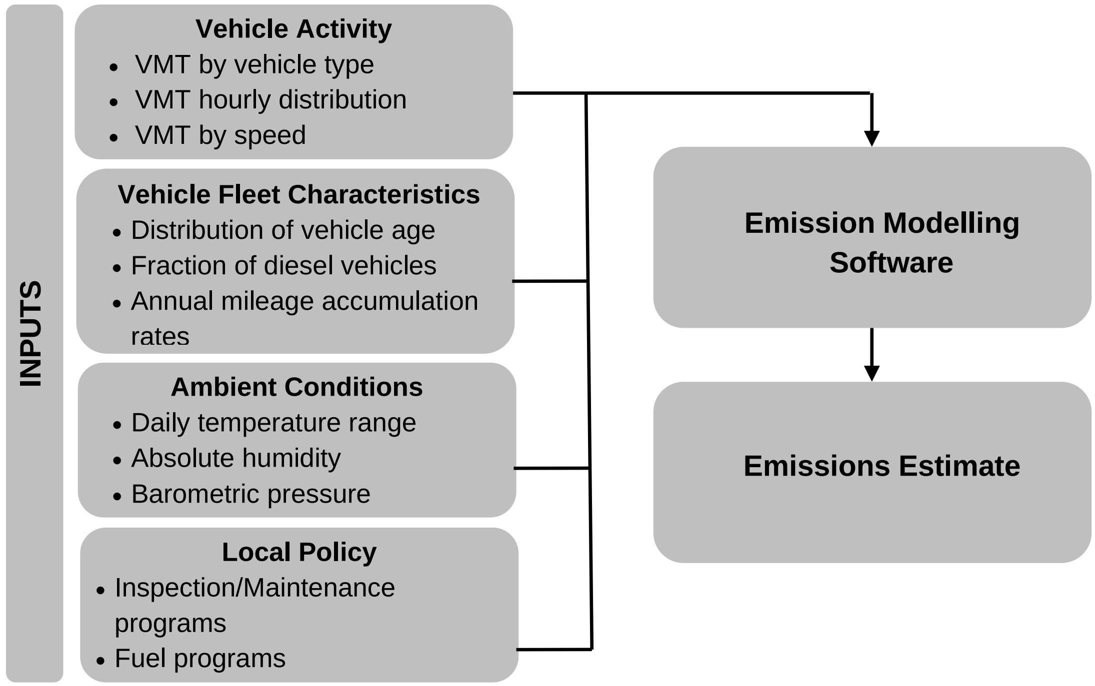


Figure 1: Inputs and process to produce emissions estimate.
Source: Developed in this research based on U.S. EPA (2004).

In this research vehicle activity data refers to on-road vehicle miles travelled and its characteristics, which are affected by the transportation network. It includes data for the distribution of VMT accumulated by vehicle class, the temporal distribution of VMT, and the distribution of speed experienced on the network. This data is often difficult to obtain and estimate; it requires input of local conditions and is critical for modelling on-road traffic emissions (Transportation Research Board, 2011a).

Vehicle fleet characteristics includes data such as the distribution of vehicle's ages, fraction of diesel vehicles in the fleet, and annual mileage accumulation rates for different age vehicles. The age distribution of the fleet also determines the fractions of the fleet that meet different emission standards. The relative fractions of gasoline and diesel-powered vehicles are important because gasoline and diesel engines have different emissions characteristics. This data can be obtained from sources such as inspection and maintenance programs, or insurance data (Heiken et al., 1996).

Ambient conditions have an impact on emissions, however they are external to the transportation network and vehicle fleet. This includes data such as hourly temperature and relative humidity. For example, data can be obtained from the National Climate Data and Information Archive (Environment Canada, 2011b).

Policy information is region specific and generally default data is provided. Inputs such as inspection/maintenance and fuel programs allow the user to model the effects of changes from programs, regulations, and technologies directed at mitigating air pollution effects (e.g., heavy duty vehicle engine standards).

These data feed into the emissions modelling software to produce an emissions estimate. Each new version of emission modelling software reflects the collection and analysis of new in-use vehicle emission test data. They also incorporate changes in vehicle, engine, and emission control system technologies; changes in applicable regulations, emission standards, and test procedures; and improved understanding of in-use emission levels and the factors that influence them (U.S. Environmental Protection Agency, 2003).

2.2.1. MOBILE6.2C

MOBILE6.2C is the current model used by Environment Canada to produce estimates for criteria air contaminants. It was developed in 2005 by Environment Canada after expanding and tailoring the adjustments applied to the basic emission rates calculated from the conditions present in the standard testing of U.S. EPA's MOBILE6.2 model (Environment Canada, 2005). "The Canadian model created was based on reviewing the underlying MOBILE6.2 method and documentation; reviewing current and past Canadian inventory methods, modelling documentation and other related studies; discussions with Environment Canada; and conversations with Canadian vehicle manufacturers to determine differences between U.S. and Canadian vehicle fleets" (Environment Canada, 2005, p. 1).

MOBILE6.2C estimates emission factors of hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), exhaust particulate matter (which consists of several components), tire wear particulate matter, brake wear particulate matter, sulfur dioxide (SO_2), ammonia (NH_3), six hazardous air pollutant (HAP), and carbon dioxide (CO_2) for gasoline, diesel, and natural-gas-fuelled vehicles. The model requires vehicle activity, vehicle fleet, ambient conditions, and local policy as inputs. MOBILE6.2C can model emission factors for the calendar years 1980 to 2030 inclusive.

MOBILE6.2C requires 11 data elements associated with vehicle activity commands for emissions modelling. Default values can be used for seven of the eleven data elements. For these data elements the EPA states that while the values will vary from area to area, this variation is negligible and the EPA will not expect states to develop local inputs (U.S. Environmental Protection Agency, 2004). Default vehicle activity data used to model emissions within MOBILE6.2C are:

- vehicle engine starts per day
- distribution of vehicle starts during the day
- vehicle soak time between engine starts
- vehicle hot soak time after engine shut down
- vehicle diurnal soak time[2]
- vehicle trip length distributions
- weekday and weekend day activity

[2] Soak time is defined as the time between when the engine is turned off to the next time it is started

The remaining four required elements are: VMT by facility type, VMT by vehicle class, VMT by hour, and VMT by speed. The MOBILE6.2C software requires special inputs based on these data elements.

VMT by road facility type –This input requires assigning VMT on the network to a facility type (described in Table 1) by the 28 vehicle classes described in Table 2 for each hour of the day. The input for this command contains 28 columns representing the 28 vehicle classes. In each column 96 fractions representing the fraction of travel on each roadway type (freeway, arterial/collector, local, freeway ramp) at each hour of the day for that vehicle type are entered (i.e., 4 x 24 = 96).

Table 1: MOBILE6.2C roadway classifications.

Roadway	Description
Freeway	Characterized by having limited access (via converging ramps), do not have traffic signals, and usually have free flow speeds greater than 50 miles per hour (80 kilometers per hour).
Arterial	Differ from freeways because they have traffic signals, but they may be divided, multiple lane, one-way, and have high free flow speeds. However, traffic is stopped periodically by traffic signals and flow is affected by access to the roadway by driveways and unsignalized intersections.
Local	Generally do not have traffic signals and rarely have more than one lane in each direction. They usually allow vehicle parking on the roadway and traffic control is handled via stop or yield signs.
Freeway Ramp	Access roadways for freeways which includes traffic entering and exiting the freeway. Traffic characterized by rapid acceleration from stop or low speeds to high speeds and decelerations from high speeds to low speeds or stop.

Source: U.S. Environmental Protection Agency (2003)

VMT by vehicle class – This input requires the proportion of network VMT accumulated by the 16 vehicle classes described in Table 3. This requires the assignment of network VMT to these 16 vehicle classes. The input for this command contains one column with 16 fractions each representing the distribution of total VMT by the 16 vehicle classes. These proportions are independent of road facility type, hour of day, and speed. These 16 classes are different than the 28 classes defined in Table 2 because they aggregate vehicles by fuel type.

Table 2: MOBILE6.2C 28 vehicle classification scheme.

Vehicle Class	Abbreviation	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs GVWR; 0-3,750 lbs LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs GVWR; 3,751-5,750 lbs LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs GVWR; 0-5750 lbs ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs GVWR; 5,751 lbs and greater ALVW)
6	HDGV2B	Class 2B Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs GVWR)
12	HDGV8A	Class 8A Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs GVWR)
13	HDGV8B	Class 8B Heavy-Duty Gasoline Vehicles (>60,000 lbs GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1 and 2 (0-6,000 lbs GVWR)
16	HDDV2B	Class 2B Heavy-Duty Diesel Vehicles (8,501-10,000 lbs GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs GVWR)
22	HDDV8A	Class 8A Heavy-Duty Diesel Vehicles (33,001-60,000 lbs GVWR)
23	HDDV8B	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs GVWR)

Source: U.S. Environmental Protection Agency (2003)

Loaded Vehicle Weight (LVW): The curb weight of the vehicle plus 300 pounds, representing the driver and incidental payload weight.

Gross Vehicle Weight Rating (GVWR): The maximum allowable total mass of a vehicle or vehicle and trailer when loaded.

Alternative Loaded Vehicle Weight (ALVW): The adjusted loaded vehicle weight is the numerical average of the vehicle curb weight and the gross vehicle weight rating.

Curb weight: The weight of the empty vehicle (without payload and driver) but including standard equipment (i.e. spare tire), and all necessary operating consumables (i.e. engine oil, fuel).

Table 3: MOBILE6.2C 16 vehicle classification scheme.

Vehicle Class	Abbreviation	Description
1	LDV	Light-Duty Vehicles (Passenger Cars)
2	LDT1	Light-Duty Trucks 1 (0-6,000 lbs GVWR; 0-3,750 lbs LVW)
3	LDT2	Light-Duty Trucks 2 (0-6,000 lbs GVWR; 3,751-5,750 lbs LVW)
4	LDT3	Light-Duty Trucks 3 (6,001-8,500 lbs GVWR; 0-5,750 lbs ALVW)
5	LDT4	Light-Duty Trucks 4 (6,001-8,500 lbs GVWR; 5,751 lbs and greater ALVW)
6	HDV2B	Class 2B Heavy-Duty Vehicles (8,501-10,000 lbs GVWR)
7	HDV3	Class 3 Heavy-Duty Vehicles (10,001-14,000 lbs GVWR)
8	HDV4	Class 4 Heavy-Duty Vehicles (14,001-16,000 lbs GVWR)
9	HDV5	Class 5 Heavy-Duty Vehicles (16,001-19,500 lbs GVWR)
10	HDV6	Class 6 Heavy-Duty Vehicles (19,501-26,000 lbs GVWR)
11	HDV7	Class 7 Heavy-Duty Vehicles (26,001-33,000 lbs GVWR)
12	HDV8A	Class 8A Heavy-Duty Vehicles (33,001-60,000 lbs GVWR)
13	HDV8B	Class 8B Heavy-Duty Vehicles (>60,000 lbs GVWR)
14	HDBS	School Buses
15	HDBT	Transit and Urban Buses
16	MC	Motorcycles (All)

Source: U.S. Environmental Protection Agency (2003)
Loaded Vehicle Weight (LVW): The curb weight of the vehicle plus 300 pounds, representing the driver and incidental payload weight.
Gross Vehicle Weight Rating (GVWR): The maximum allowable total mass of a vehicle or vehicle and trailer when loaded.
Alternative Loaded Vehicle Weight (ALVW): The adjusted loaded vehicle weight is the numerical average of the vehicle curb weight and the gross vehicle weight rating.
Curb weight: The weight of the empty vehicle (without payload and driver) but including standard equipment (i.e. spare tire), and all necessary operating consumables (i.e. engine oil, fuel).

VMT by hour – This requires the total VMT for each of the 24 hours of the day. This requires assigning total VMT on the network to each hour of the day. The input for this command requires one column with 24 values, containing the fraction of total VMT for each of the 24 hours of the day. These values are independent of vehicle class, facility type, and speed.

Speed VMT – This input requires the average speed on freeways and arterial/collector roadways. This requires determination of speed data for each hour of the day on freeways and arterial/collector roadways. MOBILE6.2C assigns a default speed to all local streets and freeway ramps. The input for this command requires 48 columns; the first 24 columns represent the 24 hours of the day and are used for freeway VMT. The remaining 24 columns represent the 24 hours of the day and are used for arterial/collector VMT. Each of the 24 columns contains 14 values representing the fraction of VMT in the corresponding MOBILE6.2C speed bin. Table 4 describes each of these 14 speed bins. These values are independent of vehicle class.

Table 4: Definition of MOBILE6.2C speed bins.

Bin Number	Description
1	VMT with average speed 0-2.5 mph
2	VMT with average speed 2.5-7.5 mph
3	VMT with average speed 7.5-12.5 mph
4	VMT with average speed 12.5-17.5 mph
5	VMT with average speed 17.5-22.5 mph
6	VMT with average speed 22.5-27.5 mph
7	VMT with average speed 27.5-32.5 mph
8	VMT with average speed 32.5-37.5 mph
9	VMT with average speed 37.5-42.5 mph
10	VMT with average speed 42.5-47.5 mph
11	VMT with average speed 47.5-52.5 mph
12	VMT with average speed 52.5-57.5 mph
13	VMT with average speed 57.5-62.5 mph
14	VMT with average speed >62.5 mph

2.2.2. MOVES

Upon publication of the United States Federal Register notice in December, 2009, MOVES became the EPA's approved motor vehicle emissions model (U.S. Environmental Protection Agency, 2009a). The Federal Register gives notice to a two-year transportation conformity grace period which ends on March 2, 2012, after which MOVES is required to be used for new regional emissions analyses for transportation conformity in the United States (U.S. Environmental Protection Agency, 2010).

Under the Clean Air Act, EPA is required to regularly update the way it calculates mobile source emissions. For this reason, EPA is continuously collecting data and conducting emissions studies to assess the air quality impacts of on-road vehicles. MOVES utilizes new in-use vehicle data collected and analyzed following the release of MOBILE6.2, particularly concerning emissions measurements from light-duty vehicles.

MOVES is the U.S. EPA's approved motor vehicle emissions factor model for estimating volatile organic compounds (VOCs), nitrogen oxides (NO_x), carbon monoxide (CO), direct particulate matter (PM_{10} and $PM_{2.5}$), air toxic, and greenhouse gas emissions from cars, trucks, buses, and motorcycles by state and local agencies for state implementation plans outside of California (U.S. Environmental Protection Agency, 2009a). The model requires vehicle activity, vehicle fleet, ambient conditions, and local policy as inputs. MOVES can model emission factors for the calendar years 1999 to 2050 inclusive.

MOVES has a database-centered design that allows practitioners greater flexibility in organizing input and output data. This structure also allows EPA to update emissions data incorporated in MOVES more easily (U.S. Environmental Protection Agency, 2010). MOVES is the first EPA model that can estimate emissions on a range of scales from national impacts down to the impacts of individual transportation projects. Another improvement is the ability to express output as either total mass (in tons, kilograms, or grams) or as emissions factors (grams per mile). MOVES is also currently the best tool the EPA has for estimating greenhouse gas emissions from the transportation sector and is a significant improvement over the greenhouse gas estimation from MOBILE6.2 (U.S. Environmental Protection Agency, 2009b).

2.2.3. Other

Table 5 describes the main inputs, outputs, and strengths and weaknesses of eleven other available tools which can be used to estimate emissions from transportation.

Table 5: Emission estimation tools.

Main Inputs	Main Outputs	Strengths	Weaknesses
Center for Clean Air Policy (CCAP) Guidebook Emissions Calculator			
Land use profile, transit improvements, road pricing, green policy levels, green taxes, emissions standards, fleet composition, driver education	Emission factors (g/veh-mile) for CO_2, CO, NO_x, SO_2, VOC, NH_3, CH_4, N_2O, PM_{10} and $PM_{2.5}$ for current and future years	Able to model wide range of policies, unique capabilities	Difficulty in quantifying effects of policy leads to inherent uncertainty in results
Canadian Mortgage and Housing Corporation Greenhouse Gas Emissions from Urban Transit			
Distance to CBD, Predicted vehicles/household, housing density, persons per household, local employment density, local retail levels, rapid transit and commuter rail provision	Weekday auto and transit VKT; CO_2e from auto and transit	Lack of detail	Ease of use, takes account of different transit modes
Comprehensive Modal Emissions Model (CMEM)			
Vehicle characteristics (including mass, engine size and power, torque information, idle speed and number of gears), operating environment (including road grade, accessory power, speed trace, soak time and humidity) and activity profile (velocity, acceleration, road grade and secondary power load by time period)	Tailpipe emissions (CO, CO_2, NO_x and hydrocarbons) and fuel consumption as a function of time	It can be used with both microscale and macroscale vehicle activity characteristics. It is easily validated and calibrated.	Hard to model future years; very specific purpose
Corridor Simulation (CORSIM)			
Transport network topology and geometry; demand by mode; emissions rate by pollutant	Transport network performance; emissions of CO, hydrocarbons and NO_x	High degree of precision in results	High price, limited number of vehicle classes
Emissions Factors Model (EMFAC)			
Geographic area, vehicle class (choice of 13), calendar year and season, fuel, year of manufacture, annual vehicle miles, annual trips, inspection/maintenance information	Running exhaust emissions, starting emissions, hot soak emissions, diurnal loss emissions, resting loss emissions, estimated travel fractions and evaporative running loss emissions of hydrocarbons, CO, NO_x, CO_2, PM_{10}, $PM_{2.5}$, SO_x and Pb	Ease of use, high level of detail	California-specific

Source: Transport Canada, 2009

Table 5 (cont'd): Emissions estimation tools.

Main Inputs	Main Outputs	Strengths	Weaknesses
Freight Logistics Environment and Energy Tracking (FLEET) Performance Models			
Current fleet characteristics (age, annual mileage, fuel consumption, idling information); existing and planned green strategies and technologies	Potential savings in fuel, emissions (CO_2, NO_x and particulate matter) and money from full range of green strategies and those to be implemented	Freight specific	Current model only goes up to 2003; unable to model changes in fuel mix
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation			
Vehicle and battery weight, vehicle component characteristics, vehicle lifetime, material composition of components, fuel economies, recycling information, material production characteristics	Consumption of total energy and of fossil fuels (petroleum, natural gas, and coal) and emissions (CO_2, CH_4, N_2O, NO_x, VOC, CO, PM_{10}, $PM_{2.5}$, SO_x) from well-to-pump, vehicle cycle and vehicle operation	Comprehensive in coverage; has very large range of fuel pathways	Complexity and amount of input required
Simulation and Assignment of Traffic to Urban Road Networks (SATURN)			
Road network, demand by vehicle type and origin/destination	Road usage statistics (including travel times and route choices); CO2, NOx, SOx, PM10, fuel consumption	High precision	Complexity of set-up and calibration
Urban Transport Emissions Calculator (UTEC)			
Vehicle-km for personal vehicles, commercial vehicles and buses; passenger-km for railed transit	CO2e emissions (upstream and in operation) by vehicle type; CO, NOx, SO2, VOC, TPM, PM10 and PM2.5 emissions by vehicle type	Ease of use, province-specific, able to model different fuel mixes	Only two road types (city and highway); cannot choose arbitrary future year
GHGenius			
Year of analysis, geographic area, VKT	The model can estimate CO2, CH4, N2O, NOx, SO2 and PM emissions from light duty trucks, medium duty trucks, heavy duty trucks and buses. It can also model a variety of different fuel types	The truck exhaust emissions are based on an algorithm from MOBILE6.2C	Relies heavily on MOBILE6.2C defaults because it does not allow the same flexibility with inputs
VISSIM			
Transport network topology and geometry; demand by mode; emissions characteristics by mode/vehicle type	Transport network performance; emissions by vehicle type, of benzene, CO, CO2, hydrocarbons, NOx, TPM, SO2 and soot	High degree of precision in results; user able to specify emissions profile	High price, large amount of set-up required

Source: Transport Canada, 2009

2.2.4. Comparison of MOBILE6.2C and MOVES

The Motor Vehicle Emissions Simulator (MOVES) is to replace MOBILE6.2C as the model of choice for the estimation of emissions from on-road vehicles in Canada, and in the future will inform the relevant portions of Environment Canada's Air Pollutant Emissions Inventory, trends and forecasts (Environment Canada, 2011c).

Koupal et al. (2010) discuss a three tiered approach for international customization of MOVES. The first tier is to input custom vehicle fleet and activity data. Using the methodology described in this research could produce the required inputs for MOVES for Canadian urban centres. The second tier focuses on developing vehicle emission rates reflecting the emission standards applicable to Canada. For example, Canada did not harmonize emission standards with the U.S. until after model year 1988 (for light duty gasoline vehicles and trucks), and these vehicles may be different in terms of the way they produce emissions. The third tier is described as more fundamental changes to the model such as adding vehicle types or road types. The paper describes that for many international applications, the second tier would likely provide the best trade-off between customization and resource allocation.

In order to make meaningful comparisons of emissions between Canada and the United States, and to harmonize emission regulations, the tools used to estimate emissions must be comparable. MOVES and its underlying databases (based on U.S. default data) must be modified to reflect Canadian conditions.

The underlying requirements for MOVES inputs are very similar to those required by MOBILE6.2C; however there are some differences. As described in Section 2.2.1, the main vehicle activity inputs for MOBILE6.2C are VMT by facility type, VMT by vehicle class, VMT by hour, and VMT by speed. MOVES requires these same basic inputs but in a different format. These inputs are road type distribution, vehicle type VMT, and average speed distribution.

Road type distribution – This input requires the distribution of VMT by road type for each of the 13 vehicle types used in MOVES. These distributions are independent of temporal characteristics and speed. Table 6 shows the five road types used by MOVES. These classes combine the “local” and “arterial/collector” roadway classes from MOBILE6.2C and allow the user to model both urban and rural VMT in the same model run.

Table 6: MOVES roadway classifications.

Abbreviation	Description
Off-network	All locations where the predominant activity is vehicle starts, parking and idling (truck stops, rest areas, freight or bus terminals)
Rural restricted access	Rural highways that can only be accessed by an on-ramp
Rural unrestricted access	All other rural roads (arterials, connectors, and local streets)
Urban restricted access	Urban highways that can only be accessed by an on-ramp
Urban unrestricted access	All other urban roads (arterials, connectors, and local streets)

Source: U.S. Environmental Protection Agency (2010)

Vehicle type VMT: This input requires data for total annual VMT, monthly VMT fraction, VMT fraction by day, and hourly VMT fraction. There are no default values for the total annual VMT because this is dependent on the size of the network being modelled. The MOVES default hourly inputs assign different hourly distributions to different roadway classifications; however, the same distribution is used for every vehicle type. The vehicle types required by MOBILE6.2C are difficult to obtain from standard traffic data collection so the classes have been changed to vehicle types more compatible with those used by

U.S. states when reporting to the Highway Performance Monitoring System. Table 7 shows the vehicle types employed by MOVES.

Table 7: MOVES source types and HPMS vehicle types.

Source Type ID	MOVES Source Type	HPMS Vehicle Type ID	HPMS Vehicle Type
11	Motorcycle	10	Motorcycle
21	Passenger car	20	Passenger car
31	Passenger truck	30	Other 2 axle-4 tire vehicle
32	Light commercial truck	30	Other 2 axle-4 tire vehicle
41	Intercity bus	40	Bus
42	Transit bus	40	Bus
43	School bus	40	Bus
51	Refuse truck	50	Single unit trucks
52	Single unit short-haul truck	50	Single unit trucks
53	Single unit long-haul truck	50	Single unit trucks
54	Motorhome	50	Single unit trucks
61	Combination short-haul truck	60	Combination trucks
62	Combination long-haul truck	60	Combination trucks

Source: U.S. Environmental Protection Agency (2010)

Average speed distribution – This input requires the user to assign the fraction of hourly VMT to one of the MOVES 16 speed bins. MOBILE6.2C utilizes 14 speed bins with the highest having an average speed of 65 mph. The 2 new bins in MOVES are for 70 and 75mph. MOBILE6.2C only allows the user to enter two different speed profiles, one for freeways and one for arterial/collector roadway segments while MOVES allows the user to enter a speed profile for each type of vehicle on each roadway classification.

Table 9 provides a more general comparison of all the capabilities of the MOBILE6.2C and MOVES models and their differences. To aid in the transition from MOBILE6.2 to MOVES, EPA has developed spread sheet tools to take MOBILE6.2 input files and convert them to MOVES format. Each of the developed spreadsheets contains detailed instructions and a complete description of the capabilities of the spreadsheet.

Table 8: Definition of MOVES speed bins.

Speed Bin ID	Average Bin Speed (mph)	Speed Bin Range (mph)
1	2.5	VMT with average speed < 2.5
2	5	2.5 <= speed <7.5
3	10	7.5 <= speed <12.5
4	15	12.5 <= speed <17.5
5	20	17.5 <= speed <22.5
6	25	22.5 <= speed <27.5
7	30	27.5 <= speed <32.5
8	35	32.5 <= speed <37.5
9	40	37.5 <= speed <42.5
10	45	42.5 <= speed <47.5
11	50	47.5 <= speed <52.5
12	55	52.5 <= speed <57.5
13	60	57.5 <= speed <62.5
14	65	62.5 <= speed <67.5
15	70	67.5 <= speed <72.5
16	75	72.5 <= speed

Source: U.S. Environmental Protection Agency (2010)

2.3. DATA ACQUISITION METHODOLOGIES FOR EMISSIONS MODELLING

Region-specific vehicle activity data are typically supplied by travel demand models (TDMs) or traffic counts. In the absence of these, default data are used. Constructing demand models or establishing traffic count programs dedicated to acquiring this data exclusively for emissions modelling can be onerous. Existing and readily-available data sources maintained by provincial or local agencies can provide data needed for vehicle activity inputs. Often these data are collected by different government departments for purposes other than emissions modelling, therefore data-sharing is critical. Further, the strengths, weaknesses, assumptions, and limitations associated with multiple datasets must be understood prior to integrating and calculating vehicle activity inputs.

Table 9: Comparison of MOBILE6.2C and MOVES

Criteria	MOBILE6.2C	MOVES
Model Methodology	• Emissions by speed characterized by set of driving cycles • Lacks flexibility to analyse different driving patterns	• Emissions stored by unique combination of source and operating mode bins • Any driving pattern can be analysed as a sum of appropriate modes
Software Interface	• Model embedded calculation	• Graphical User Interface allows easier use • Relational database structure with all inputs, outputs, default activities, and base modal emission rates stored and managed in MySQL database
Emission sources	• On-road	• On-road and Off-road
Spatial Scale	• Single large regional scale	• Macroscopic, mesoscopic, and microscopic
Pollutants	• Criteria Pollutants, Hydrocarbons, Particulate Matter, Air Toxics, Carbon Dioxide, Methane	• All pollutants estimated by MOBILE6.2 plus new pollutants: Sulfur dioxide, Ammonia, Nitrogen dioxides, energy consumption
Roadway Classification	• Freeway • Arterial and Collector Roads • Local • Freeway on and off ramps	• Off Network • Rural Restricted access • Rural Unrestricted access • Urban Restricted access • Urban Unrestricted access
Vehicle Classification	• 16 and 28 vehicle classes • Vehicle types match historical emission standards classifying vehicles according to weight and fuel type	• 13 vehicle classes • Vehicle types more compatible with HPMS data collection
Temporal Scale	• Analysis years 1980 through 2050	• Analysis years 1999 through 2050
Speed	• Single speed for ramps and local roads	• Speed distribution for all roadway types by area type
Emission Estimation	• Trip-based vehicle average speed	• Distributes total activity into source and operating mode bins
Meteorology Data	• User supplied	• Default county specific temperature and humidity values; users can overwrite the default data with local data
Fuel Supply	• User Supplied	• Default county specific fuel supply values; users can overwrite the default data with local data
Inspection/ Maintenance Program	• User Supplied	• Default county specific I/M program values; users can overwrite the default data with local data
Age Distribution	• User supplied – registration distribution	• Default National age distribution for years 1999 to 2050
Output	• Emission Factors	• Emission Inventories or Emission Factors, Total Energy Consumption

Source: Vallamsundar and Lin (2011)

2.3.1. Vehicle Activity Based on Default Data

Default input values are included with both the MOBILE6.2C and MOVES emissions models to assist practitioners in the application of these models. While this type of data allows practitioners to calculate VMT based on U.S. national average values, it assumes that vehicle activity is the same across all jurisdictions. It is insensitive to local traffic conditions and is not necessarily representative of the most current or best information available for a particular location (U.S. Environmental Protection Agency, 2010). This limits its ability to capture unique traffic characteristics influenced by regional policies, economic conditions (e.g., agricultural versus manufacturing economies), seasonality, and others.

Default data are the least expensive and quickest method to obtain inputs for emissions models.

2.3.2. Vehicle Activity Based on Travel Demand Models

Travel demand models assign trips (defined by an origin and a destination within the roadway network) to roadway segments (Systems Application International, Inc., 2001). The most commonly used approach is the four-step (trip generation, trip distribution, mode choice, and trip assignment) analysis process (Institute of Transportation Engineers, 2009). This process estimates the number of trips generated and attracted by a zone; distributes the generations and attractions to origins and destinations; predicts the number of trips that will use each of the available modes for the origin-destination pairs; and produces the estimated traffic volume on each of the network links (Institute of Transportation Engineers, 2009).

Travel demand models are a popular option for obtaining vehicle activity data because they are endorsed by researchers and practitioners and most metropolitan planning organizations maintain a calibrated model capable of estimating VMT on their network (Institute of Transportation Engineers, 2009; Decker, Brooks and Dickson, 1996). Continuous efforts by practitioners to refine and improve the functional performance of these models are strengthening the case to use travel demand models for emissions estimates.

New models require data collection to develop and validate the model against existing traffic volumes. In this case, traffic volumes are derived from data sources such as household surveys and census data, not actual traffic counts. City and state travel demand models may not provide accurate estimates for emissions models in cases:

- regarding volume fluctuation by time of day and vehicle type (Systems Applications International, Inc., 2001).
- involving “intrazonal” travel (trips whose origin and destination are within the same zone of the TDM) and other travel on local roads which is not directly assigned to the network (Systems Application International, Inc., 2001).
- involving goods movement (Spear, Giaimo, Curlee, & Neels, 2008).

Most travel demand models are not designed to disaggregate traffic volumes by vehicle class and can have particular problems estimating truck volumes. “Methods of forecasting future truck traffic are still fairly primitive compared to the sophisticated modelling procedures applied in forecasting person travel in urban areas” (Douglas, 1999, p. 79). Travel demand models typically assume that vehicle trips can be modelled with data sources such as travel surveys, land use and the road network characteristics (Institute of Transportation Engineers, 2009). This data can be biased by the survey questions and the selection of the observation set from the population (Barton-Aschman Associates, Inc. and Cambridge Systematics, Inc. , 1997).

The City of Winnipeg and City of Saskatoon do not have existing travel demand models that can estimate vehicle volumes by class and for the temporal specificity required by MOBILE6.2C.

2.3.3. Vehicle Activity Based on Traffic Counts

Traffic counts involve the collection of vehicle data from roadways under existing conditions. Traffic count data sources include permanent count stations (PCS), coverage count stations, manual turning movement and classification counts, intersection turning movement, and manual video classification counts. Permanent traffic count stations typically use in-pavement technologies to provide continuous traffic information on a year-round basis. These stations often have the capability to classify vehicle types and measure speeds. Coverage counts are usually short-duration counts conducted with pneumatic road tubes or inductive loops. Turning movement counts and manual video classification counts manually classify and quantify vehicles. The key to a successful traffic count program is not only the source of the data, but the ability to routinely obtain it, verify its validity, summarize it into useable formats, report it in a manner that is useful to data users, and manage the process efficiently (Federal Highway Administration, 2001).

A strength associated with traffic-count data is the ability to provide an understanding of freight transportation in both urban and rural areas (Spear, Giaimo, Curlee, & Neels, 2008). Understanding freight is important because trucks comprise 7.5 percent of U.S. VMT nationally (Federal Highway Administration, 2008), yet they produce approximately

25 percent of on-road vehicle CO_2 emissions (U.S. Environmental Protection Agency, 2009a).

However, when it comes to traffic count data collection in urban areas, there are difficulties for the operation of data collection equipment (Federal Highway Administration, 2001). Traffic counting technologies are known to misclassify vehicles in conditions of non-uniform speed, short headways, or frequent vehicle starts and stops. Traffic-count data quality can be an issue due to non-calibrated equipment, sensor failures, improper installation, variation in the portion of multi-axle vehicles and mechanical count failure (National Cooperative Highway Research Program, 2005). The type of data collection is also important to consider as manual counts are more prone to errors than automatic data collection methods. Additionally, short-duration counts can produce traffic volumes that do not represent average conditions due to abnormal events including weather, construction, and traffic accidents. Published documents such as the Federal Highway Administration Traffic Monitoring Guide and Guidelines for Traffic Data Programs provide detailed and standard procedures for proper manipulation of traffic count data in different environments (FHWA, 2001; AASHTO, 2009).

3. VEHICLE ACTIVITY DATA FOR WINNIPEG AND SASKATOON

This chapter presents the general methodology to obtain the vehicle activity data required by MOBILE6.2C. The data collection process is then illustrated by applying the methodology to Winnipeg and Saskatoon.

3.1. GENERAL METHODOLOGY

The methodology developed by this research to estimate VMT by vehicle class, facility type, hour, and speed requires six steps as shown in Figure 2. Each of these steps is described in the following sections.

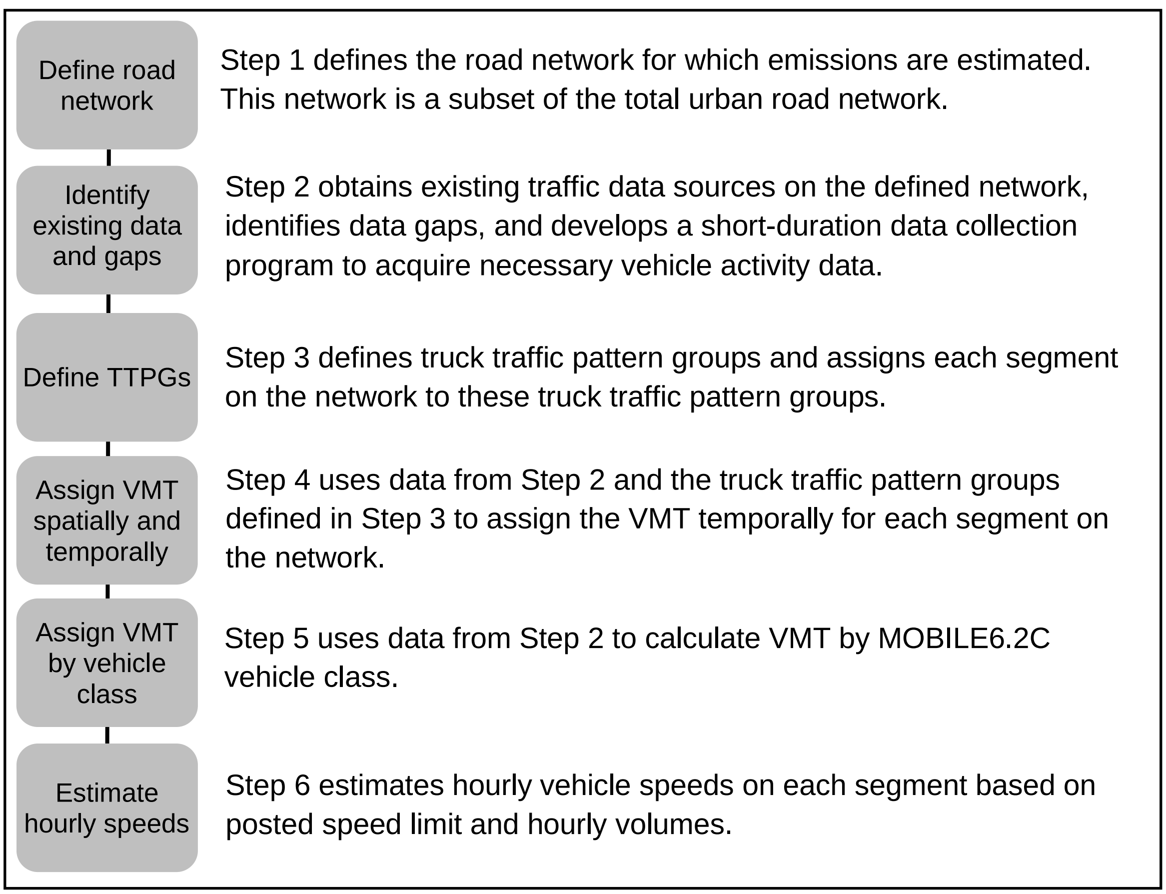
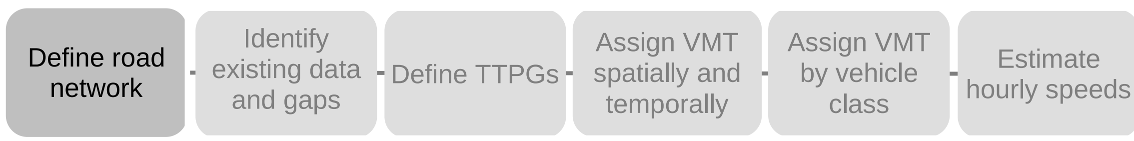


Figure 2: Methodology to estimate VMT by facility type, vehicle type, hour, and speed.

Most urban centres can provide average daily traffic volumes and length for road segments on their network. This may be accomplished through traffic monitoring programs or the use of travel demand models. Since VMT for MOBILE6.2C is the product of ADT and road segment length, total VMT is readily available. However, MOBILE6.2C vehicle activity inputs require total VMT to be disaggregated by vehicle class, road facility type, hour, and speed.

3.1.1. Define the Road Network

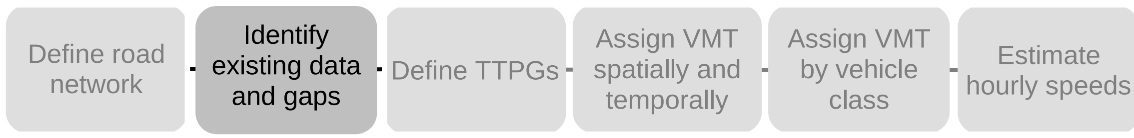


MOBILE6.2C enables the modelling of vehicle emissions with a high-level of spatial and temporal specificity. However, as specificity increases the complexity and cost of the data collection and modelling task also increases. Available empirical evidence indicates that incorporating more refined highway networks in the modelling task (i.e., increasing the highway network density to include all arterials, collectors, and local roads) may not always capture a substantially higher proportion of an urban area's VMT. For example, technical documentation for MOBILE6.2 estimates that on average local roads comprise only 13 percent of urban VMT (U.S. Environmental Protection Agency, 1999) although they represent a much higher percentage of total network length.

A sequential application of urban road network inclusion criteria is developed in consultation with local engineers. These criteria are tailored for each urban centre and developed and applied to balance the relative importance of different types of urban facilities, the level of effort required to collect and analyze data on a dense urban network, and the desire for spatial specificity of vehicle emissions modelling.

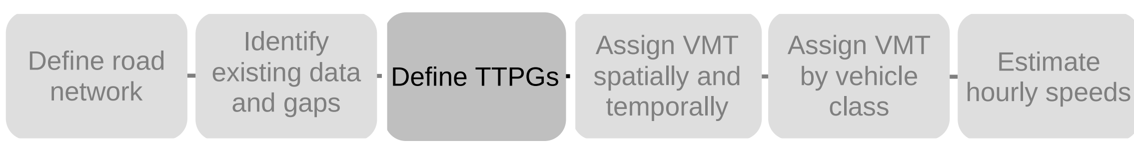
MOBILE6.2C characterizes roadways as freeways, arterials/collectors, freeway ramps, and local roadways. These roadways are described in Table 1.

3.1.2. Identify Existing Data and Gaps



Some urban centres use a combination of weigh-in-motion, permanent count stations, and coverage count stations to develop traffic volume estimates. The methodology developed in this research uses this data and develops a short-duration data collection program to collect hourly traffic distribution by vehicle class. The short-duration data collection comprises video cameras installed to collect 24-hours of traffic data that is used to generate hourly vehicle distributions by vehicle class for each location.

3.1.3. Define TTPGs

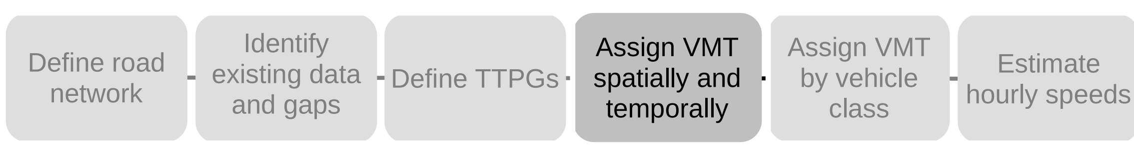


As previously discussed, some urban centres can provide traffic volume estimates for segments on their network; however, classification data are less common. Trucks have the greatest impact on emissions of all vehicle types (based on MOBILE6.2C analysis); therefore trucks are the most important vehicle type to estimate as accurately as possible. Truck traffic pattern groups (TTPGs) are developed to aggregate roadways that exhibit similar operational characteristics in terms of the hourly distribution and volume of single unit and articulated truck traffic.

The purpose of TTPGs is to create a more accurate hourly estimate of truck volumes, (and by extension, all vehicle classes) than applying a network average of vehicle classes by hour to each road segment. Roads are assigned to a TTPG through consultation with the urban centre engineering staff and engineering judgment a considering the hourly traffic volume distributions of single unit trucks and articulated trucks, percent trucks of total vehicles, types of truck activity (e.g. regional or local), and land use zones serviced by these vehicles (e.g., commercial or industrial).

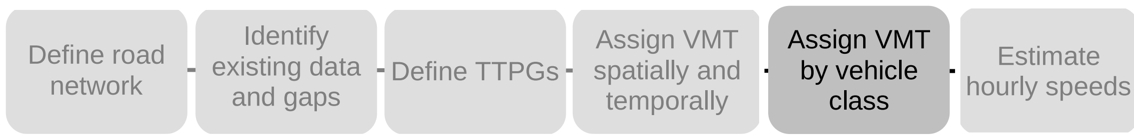
Truck traffic pattern groups are generally created after analyzing data and observing differences in volume distributions. This is a limitation of this research methodology because there is generally not a sufficient amount of existing data in urban centres. This research hypothesizes truck traffic pattern groups and uses video traffic count data from Step 2 to develop the hourly traffic distributions for each of the TTPGs and verify their uniqueness.

3.1.4. Assign VMT Spatially and Temporally



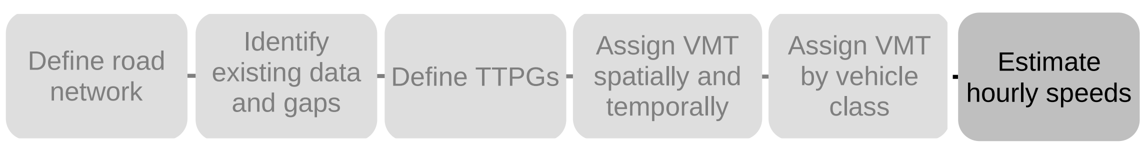
Once TTPGs are developed, it is possible to estimate VMT temporally and spatially on the road network developed for the research. The general methodology to estimate vehicle miles travelled (VMT) uses truck traffic pattern groups (TTPGs) to expand short-term traffic counts into average weekday daily traffic volumes.

3.1.5. Assign VMT by Vehicle Class



Traffic data sources available from traffic count programs classify vehicles differently than MOBILE6.2C, and therefore require conversion prior to generating VMT inputs. MOBILE6.2C categorizes vehicles into 16 classes or 28 classes depending on the vehicle activity input based on gross vehicle weight rating and the type of fuel used. Table 2 shows the 28 vehicle classification scheme and Table 3 shows the 16 vehicle classification scheme. Most traffic count programs use manual or electronic classification based on number of axles and classify vehicles to fewer, more general categories.

3.1.6. Estimate Hourly Speeds



The Bureau of Public Roads method is used to estimate travel speed by hour for each segment on the network. The previous steps estimate VMT by segment and hour for each segment. Therefore, summing the VMT for all segments with the same speed produces VMT by speed by hour.

VMT by speed requires the average traffic speed for each hour of the day by facility type. MOBILE6.2C categorizes speeds into one of the 14 speed bins defined in Table 4. The BPR procedure is recommended by EPA for estimating speed because of its practicality for typical urban areas (U.S. Environmental Protection Agency, 1999).

The BPR procedure estimates the average speed by hour using the following equation:

$$s = s_f / (1 + a * (v/c)^b)$$

where: s = predicted mean speed
s_f = free flow speed
v = traffic volume, (i.e., hourly volume)
c = practical capacity
a = 0.05 for signalized facilities (arterials, collectors, and local roads) or 0.20 for unsignalized facilities (freeways)
b = 10

For freeways the U.S. Environmental Protection Agency (1999) provides the following equations to calculate free flow speeds (s_f) for facilities with posted speed limits above and below 50 mph.

Facilities with posted speed limits > 50 mph (80 km/h):

Free flow speed (mph) = 0.88 x (posted speed limit in mph) + 14

Facilities with posted speed limits <= 50 mph (80km/h):

*Free flow speed (mph) = 0.79 * (posted speed limit in mph) + 12*

For arterials/collectors the free flow speed (S_f) required for the BPR procedure is calculated using the following equation:

$$S_f = \frac{L}{L/S_{mb} + N * (D/3600)}$$

where: S_f = free-flow speed for urban interrupted facilities (mph)
L = length of facility (mi)
S_{mb} = midblock free-flow speed (mph)
= 0.79 (posted speed limit in mph) + 12 for posted limits <= 50 mph
= 0.88 (posted speed limit in mph) + 14 for posted limits > 50 mph
N = number of signalized intersections on length (L) of the facility
D = average delay per signal (sec)

The average delay per signal is calculated using the following equation:

$$D = DF * 0.5 * C(1 - g/C)^2$$

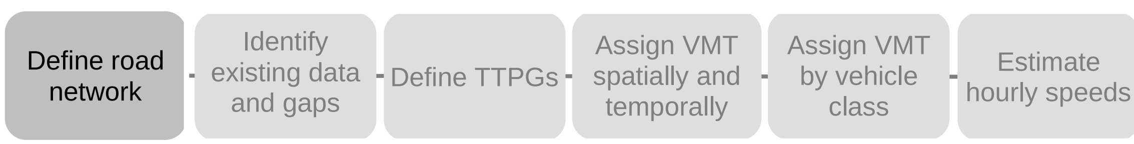
where: D = average delay per signal (sec)
DF = delay adjustment factor
= 1.0 for uncoordinated fixed time signals
C = cycle length (sec)
g/C = effective green ratio

Sections 3.2 and 3.3 illustrate the application of this methodology to Winnipeg and Saskatoon respectively.

3.2. APPLICATION OF METHODOLOGY TO WINNIPEG

This section describes the application of the general methodology to Winnipeg, Manitoba.

3.2.1. Define the Road Network



This section defines the road network in Winnipeg for which vehicle activity data are collected and prepared. The section describes the criteria for defining this network, [referred to as the Winnipeg Emissions Modelling Network (WEMN)], calculates the total network length by facility type, provides a map of this network, and describes the development of truck segments.

Sequential application of the following criteria defines the urban road network:

1. Roads located beyond Winnipeg's Perimeter Highway are excluded from the urban network.

2. All provincial roads located within the Perimeter Highway are included in the urban network regardless of data availability. These roads include the Perimeter Highway itself (Provincial Trunk Highway (PTH) 100 and PTH 101) and roads that provide connectivity between the Perimeter Highway and principal urban arterials.

3. All municipal roads that are designated as part of Winnipeg's truck route network are included in the urban network regardless of data availability. The truck route network includes all arterials that provide intra-urban connectivity (e.g., major cross-town roads and roads leading into the central business district), roads servicing industrial zones, all roads in the central business district and all roads on the regional street system in the city boundaries.

Table 10 provides the total number of centreline miles in Winnipeg by facility type. This table also shows centreline miles for local roads and freeway ramps (which include ramps on the truck route network) that are not considered in this research. The WEMN measures 333 centreline miles and is shown in Figure 3.

Table 10: Centreline miles of road by facility type for Winnipeg.

Facility Type	Centreline Miles	Percent of Total	Percent of WEMN
Freeway	56	3	17
Arterial/Collector	277	16	83
WEMN	***333***	***19***	***100***
Freeway Ramp	34	2	-
Local	1406	79	-
Total	**1773**	**100**	**-**

Source: Created using GIS data obtained from the City of Winnipeg
WEMN – Winnipeg Emissions Modelling Network

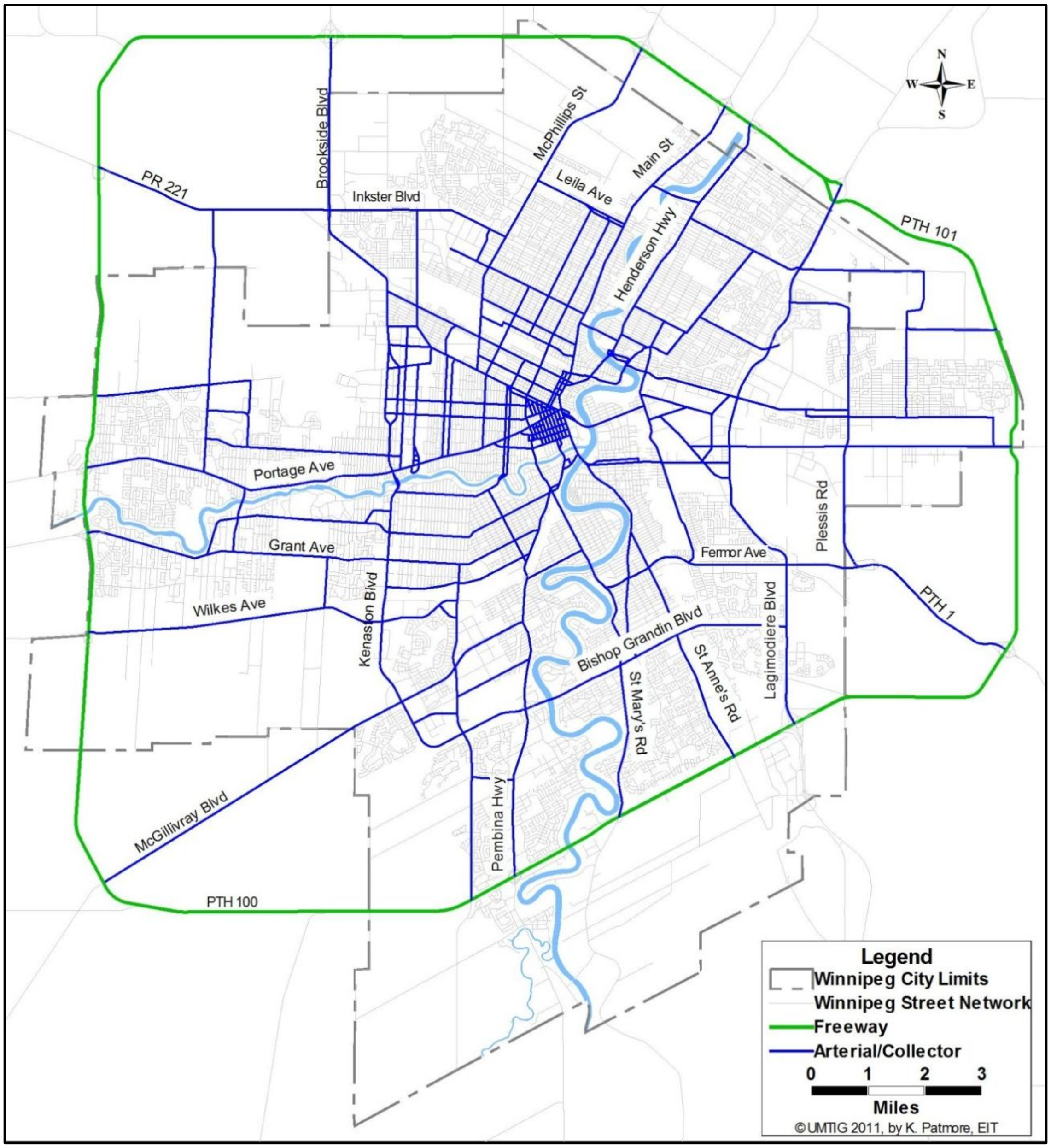
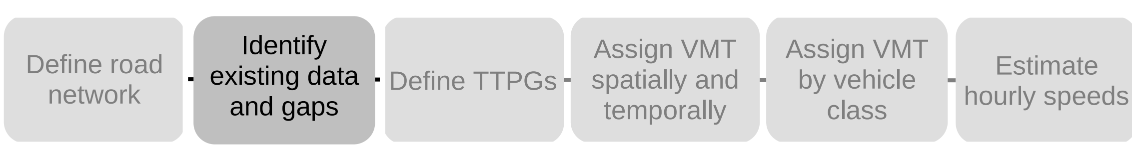


Figure 3: Winnipeg emissions modelling network.

3.2.2. Identify Existing Data and Gaps



This section describes the second step in the methodology application which is to identify existing data and gaps on the defined road network. This research produces

VMT estimates using three sources of traffic count data: (1) the Manitoba Highway Traffic Information System (MHTIS), (2) the City of Winnipeg Public Works Department, and (3) data collected from this research. Data from the City of Winnipeg and MHTIS are publicly available and updated continuously throughout the year. The traffic data collected by this research is developed by conducting video counts at key locations in Winnipeg. Each data source uses different types of traffic data collection equipment which results in different data types. Table 11 summarizes the characteristics of traffic data used in this research by data collection equipment and type of data collected for each road facility. Figure 4 shows the traffic count data collection locations.

Table 11: Data types and characteristics for Winnipeg.

Data Collection Equipment	Number of Count Types	Data Source	Data Type collected			
			Vehicle Class	Vehicle Volume	Distribution by Hour	Speed
Road Facility Type: Freeway						
AVC/WIM	3	MHTIS	✓	✓	✓	✓
Titan	16	MHTIS	✓	✓	✓	
PCS	1	MHTIS		✓	✓	
CCS	26	MHTIS		✓		
Road Facility Type: Arterial/Collector						
Video Count	4	research	✓	✓	✓	
TMC	167	C of W	✓	✓	✓	
Control Road Tube	95	C of W		✓		
Coverage Road Tube	5007	C of W		✓		

✓ represents that data is collected by the given data collection equipment
MHTIS - Manitoba Highway Traffic Information System
AVC - Automatic vehicle classifier
WIM - Weigh-in-motion
PCS - Permanent count station
CCS - Coverage count station
TMC - Turning movement count
Titan – Manual turning movement and classification count

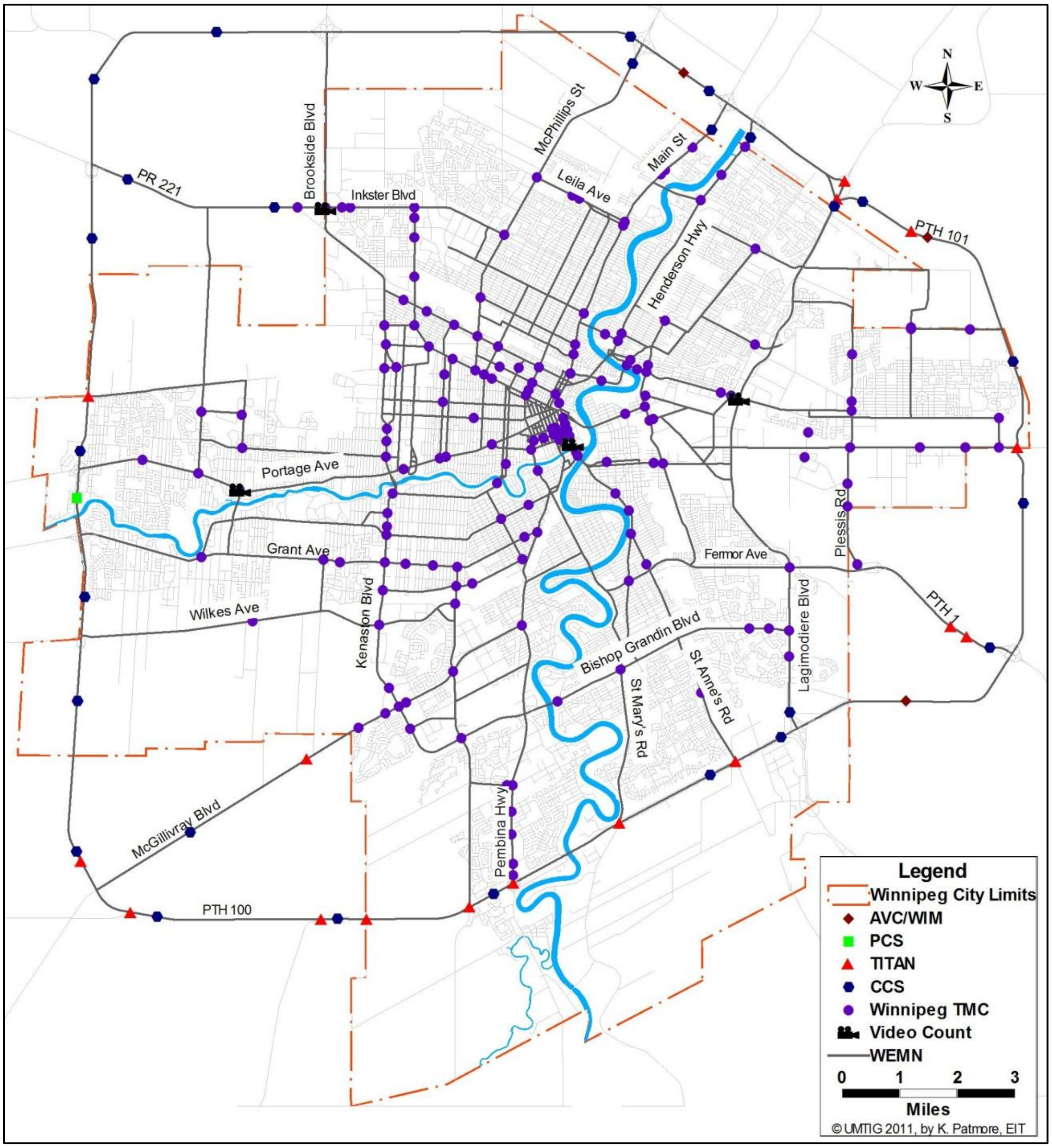


Figure 4: Traffic count locations in Winnipeg.

Although the scope of traffic volumes for this research is 2006, traffic data from each source are from different years. There are two reasons why it is acceptable to use data from other years: (1) it reduces the dependence on using expansion factors to estimate VMT, and (2) traffic volume growth rates are small. Table 12 shows Perimeter Highway traffic volume estimates using three AVC/WIM stations for the year 2006 and 2008. As the table shows, the difference in weighted average are less than 2 percent. Therefore the VMT estimates produced by this research are assumed to accurately represent 2006 traffic conditions.

Table 12: Manitoba Highway Traffic Information System AADT volumes on the perimeter highway.

AVC/WIM Station	2006 AADT	2008 AADT	Percent Growth
20	20440	20300	-0.7
64	7500	7960	5.8
86	5420	5680	4.6
Weighted average			**1.7**

AVC - Automatic vehicle classifier
WIM - Weigh-in-motion
Source: University of Manitoba Transport Information Group (2011)

The Manitoba Highway Traffic Information System (MHTIS) produces annual average daily traffic (AADT) estimates on provincial roads using permanent traffic count stations, coverage count stations, and manual turning movement and classification (Titan) counts (University of Manitoba Transport Information Group, 2011). This research uses these three data collection equipment types to calculate VMT estimates on the Perimeter Highway.

Permanent traffic count stations (PCSs) provide continuous traffic data on a year-round basis, except when data collection is interrupted due to equipment failure, construction, road closures, or other issues. Following are descriptions of each type of permanent traffic count station in Manitoba.

- Automatic Vehicle Classifiers (AVCs): These stations collect speed, volume, vehicle classification, and axle spacing data. This research uses data from two AVC stations.

- Weigh-in-Motion (WIM): These stations collect speed, volume, vehicle classification, axle spacing, and weight data. This research uses data from one WIM station.

- Permanent Count Station (PCS): These stations count total number of vehicles. No weight or classification data is collected. This research uses data from one PCS station.

Manual turning movement and vehicle classification counts are conducted using electronic Titan counting boards. This research uses data from 16 FHWA Titan counts.

Coverage count stations (CCS) are short-term traffic count stations that are scheduled to be surveyed once every two years. The survey typically consists of two 48-hour counts, either using induction loops or pneumatic road tubes, at each station (University of Manitoba Transport Information Group, 2011). Induction loops detect the passage of a vehicle and road tubes count the number of vehicle axles. This research uses data from 26 CCSs.

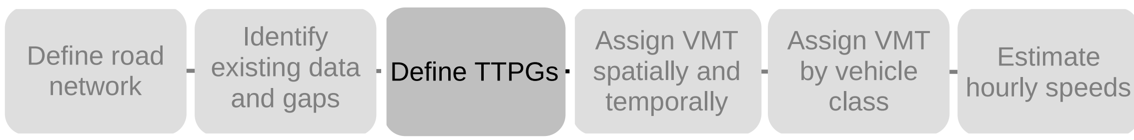
The City of Winnipeg traffic counting program produces average weekday traffic (AWDT) estimates on arterials/collectors using intersection turning movement counts and pneumatic road tube counters. The City of Winnipeg has an annual data collection program that collects three types of traffic data: intersection turning movement counts by vehicle class, automatic link counts without vehicle classification, and local street counts without vehicle classification. This research uses intersection and link counts to calculate VMT; local street counts are not used in this research because they are not part of the annual data collection program and are conducted for special requests only. Speed limit and lane data are also provided by the City for calculating VMT by speed.

Data from 167 City of Winnipeg intersection turning movement counts (TMCs) are used to obtain vehicle class data and traffic volumes on the truck route network. There are five classes of vehicles for these counts: passenger vehicles, single unit trucks, single trailer trucks, and multi trailer trucks. In 2009 a fifth classification was introduced by the City for buses. Prior to 2009 buses were included in the single unit trucks class. There are five standard count durations used by the City: 6, 8, 11, 12 and 15 hours. All counts used in this research are conducted during weekdays and begin at 07:00. All counts end at 17:00, except for the 12 and 15-hour counts, which end at 18:00 and 21:00, respectively.

Automatic link counts use pneumatic road tube counters connected to an automatic recording device to obtain traffic volume data. The devices are programmed with an algorithm that converts the number of axles to vehicles. Because the counters are typically used on urban streets with non-uniform traffic speeds, the algorithm divides the number of axle counts by two to estimate the number of vehicles counted. This normalizes all vehicles that pass the machine to the equivalent number of two-axle vehicles. However, this overestimates the number of vehicles (e.g., a single four-axle truck is counted as two two-axle vehicles).

The data collected by this research uses video camera traffic recordings to produce 24-hour volumes by vehicle class. The selection of the video count locations reflects different types of vehicle operating characteristics based on road class and geographic location. Video count data are available for roads within and adjacent to the central business district, roads that support truck traffic and connect industrial and commercial land use zones, and roads that support commuter traffic. City of Winnipeg traffic engineers provided direct input for selecting the locations where video cameras were installed. Vehicles from these counts are manually classified as passenger cars, light duty trucks, single unit trucks, articulated trucks, buses, and motorcycles.

3.2.3. Define TTPGs



This section describes the process of defining truck traffic pattern groups and assigning each segment on the network to one of these TTPG's. Most of the data collection equipment used in this research does not have the ability to collect 24-hour vehicle volumes by vehicle type. In order to determine 24-hour vehicle volumes by vehicle type from these counts it is necessary to assign them to traffic counts which do have 24-hour vehicle volumes by vehicle type. The counts can then be expanded using the process described in Section 3.2.4. Creating TTPGs combines roadways with similar characteristics so that expansion estimates are more accurate.

This research developed four TTPGs (described in Table 13), each with expansion factors to expand short-term counts into hourly traffic volume estimates by vehicle type for each hour of the day. These pattern groups are defined using hourly traffic volume distributions of single unit trucks and articulated trucks (aggregation of single trailer and multi trailer trucks) and percent trucks of total traffic. Roads are assigned to a TTPG through consultation with City of Winnipeg traffic engineers and using engineering judgement which considered the hourly traffic volume distributions of single unit trucks and articulated trucks, types of truck activity (e.g., regional or local), and land use zones serviced by these vehicles (e.g., commercial or industrial).

AVC/WIM data are used to develop the TTPG on the Perimeter Highway and video count data are used to develop the other TTPGs on the arterial/collector network. Video cameras are installed along segments on Main St. (near Stradbrook Ave), Lagimodiere Blvd (near Regent Ave), Route 90 (near Inkster Blvd), and Portage Ave (near Moray St.). Figure 5 shows the locations of the AVC/WIM stations and video cameras. Figure 6 to Figure 9 illustrate the temporal distributions by vehicle class and the total vehicle class distribution for each TTPG resulting from the data collection and analysis conducted by this research.

Table 13: Truck traffic pattern group description for Winnipeg.

TTPG	Data Type	Description
TTPG1-YWG	AVC/WIM	Road segments under provincial jurisdiction (the Perimeter Highway and roads that provide connectivity to principal urban arterials).
TTPG2-YWG	Video count	Road segments on the inner ring system or serving major industrial zones or intermodal terminals.
TTPG3-YWG	Video count	Road segments in the central business district (CBD) or road segments within a 5 km radius of the intersection of Main St and Portage Ave serving local commercial purposes. These road segments service high density mixed land use areas.
TTPG4-YWG	Video count	Road segments providing regional service primarily for passenger and light duty or single unit truck traffic.

TTPG-YWG - Truck traffic pattern group for Winnipeg

There are two video counts conducted on TTPG2 because it was originally hypothesized that these locations would exhibit distinct operating characteristics. Upon analyzing the collected data it was determined that these locations exhibited similar vehicle class distributions and hourly distributions and were grouped into a single TTPG.

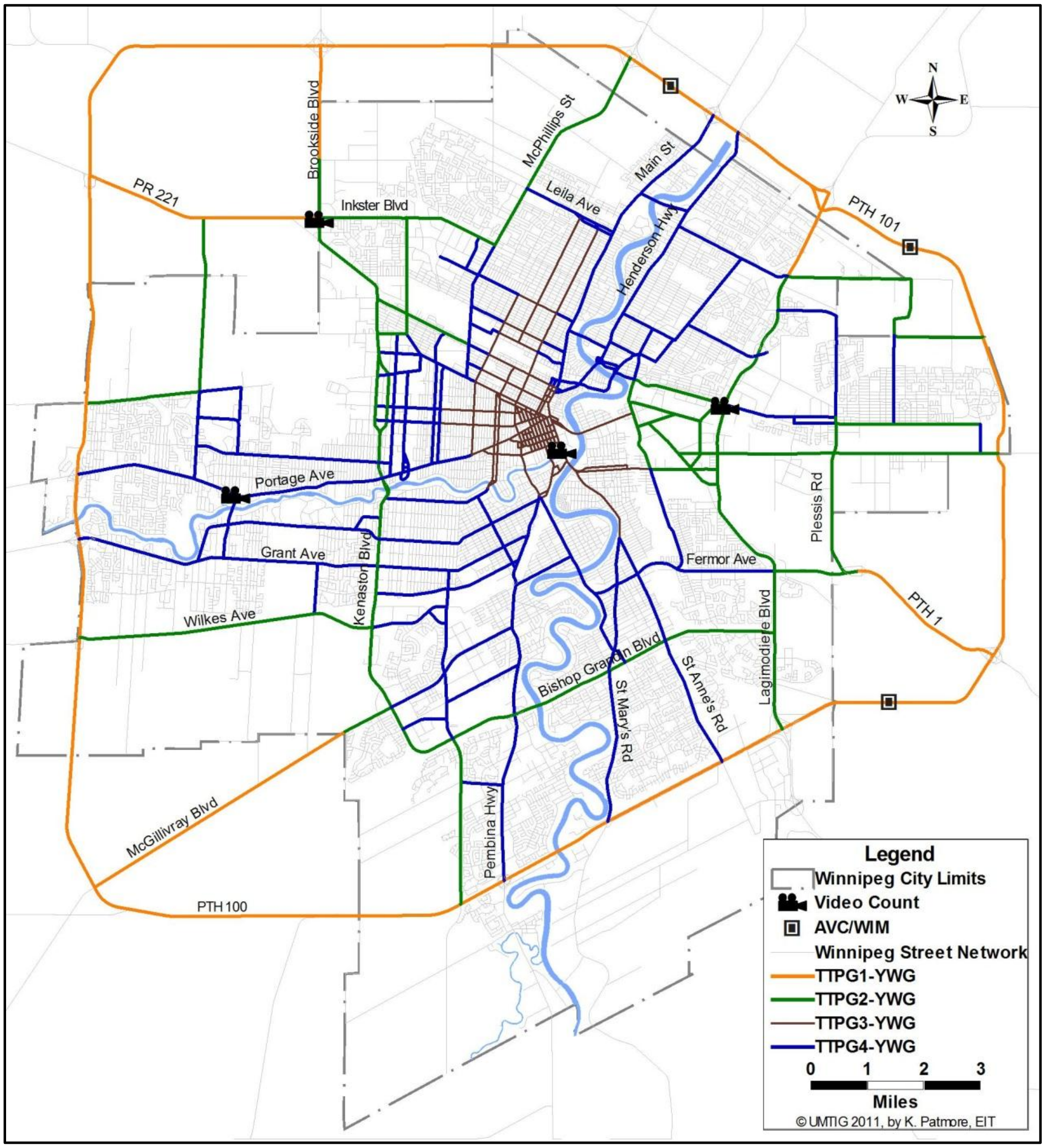
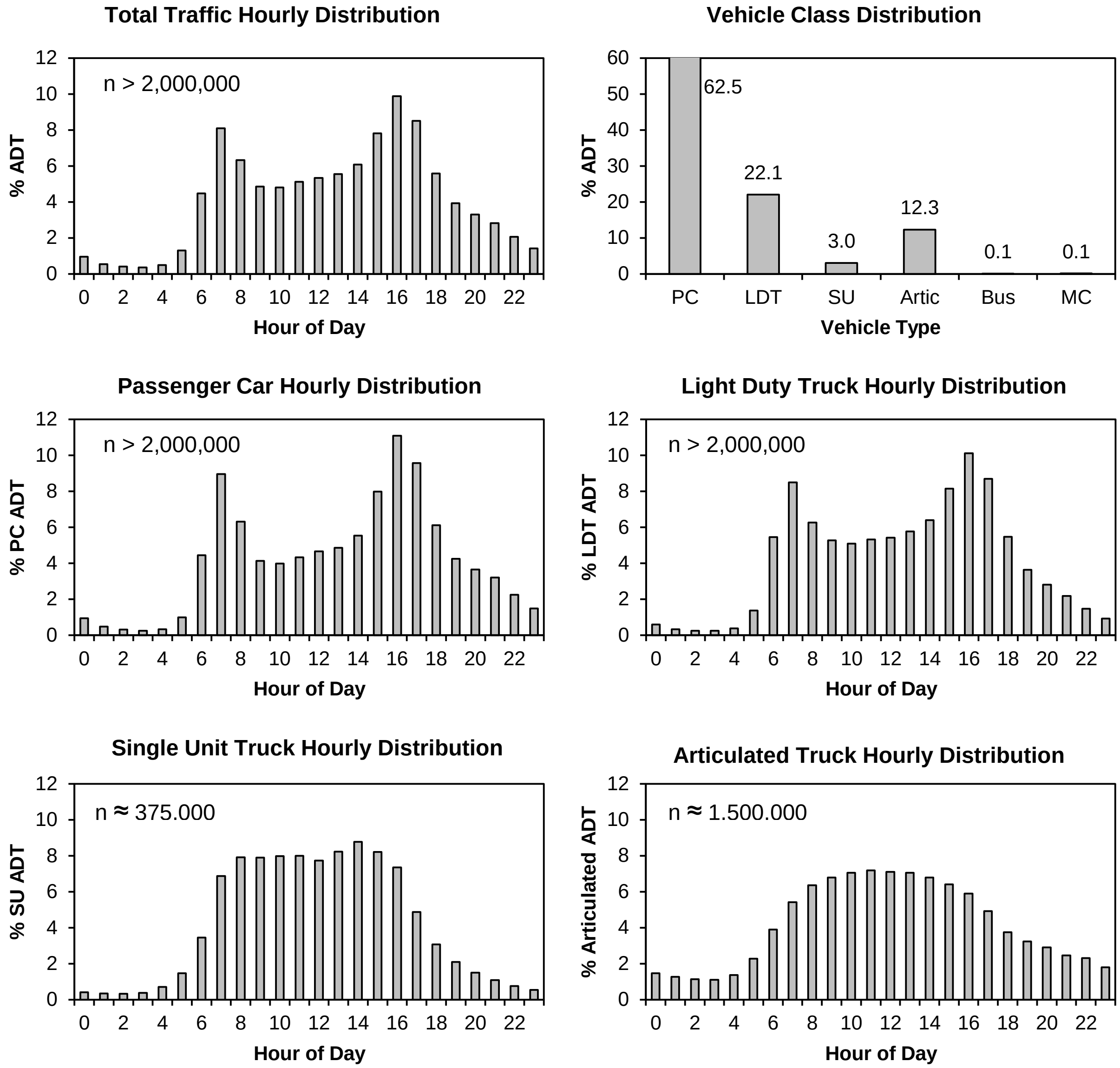
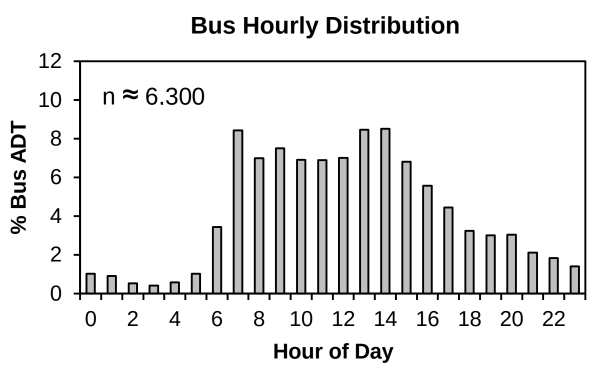


Figure 5: Segment assignment and data source location.

WEMN -	Winnipeg Emissions Modelling Network
TTPG-YWG -	Truck traffic pattern group for Winnipeg
AVC -	Automatic vehicle classifier
WIM -	Weigh-in-motion

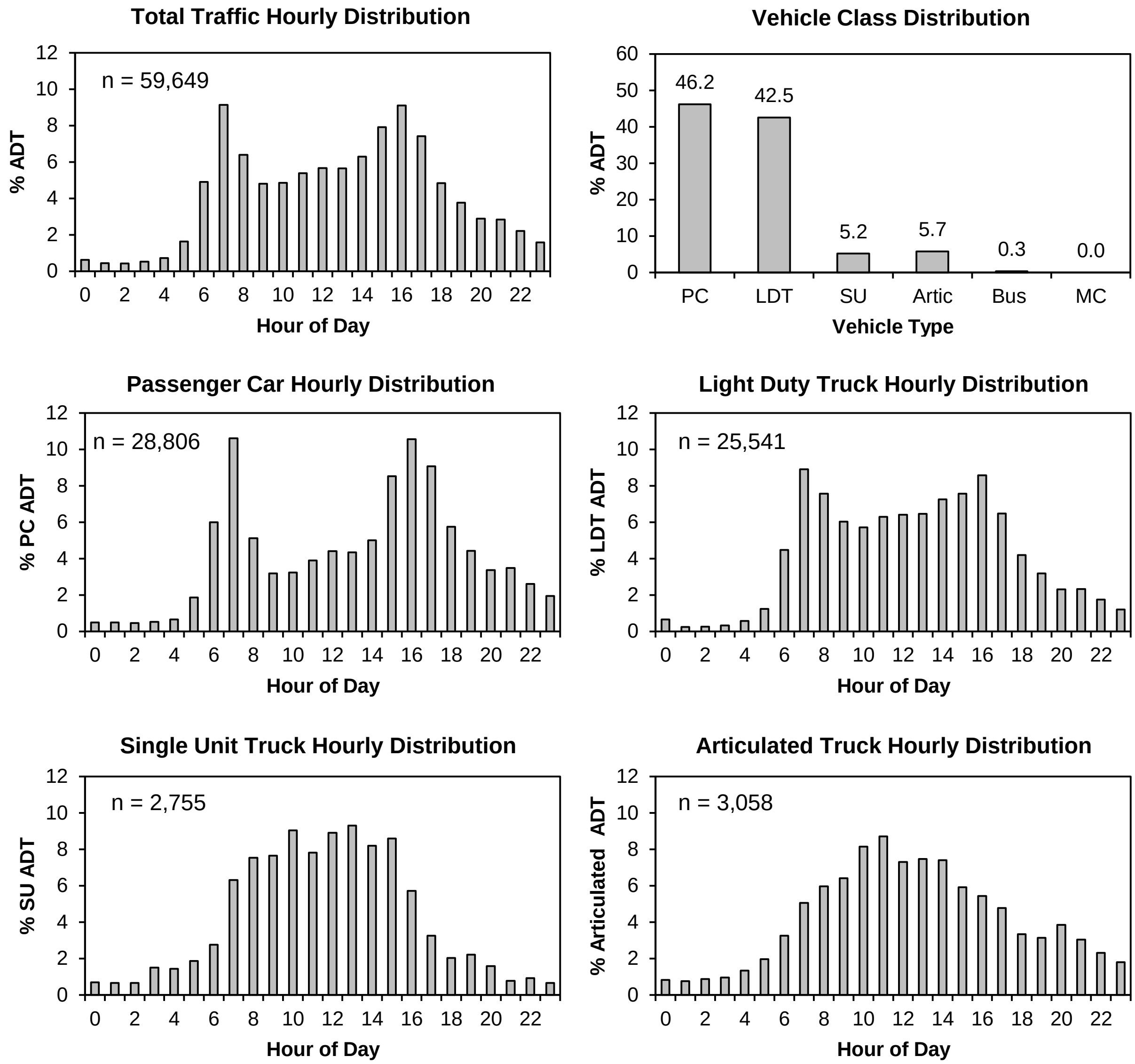


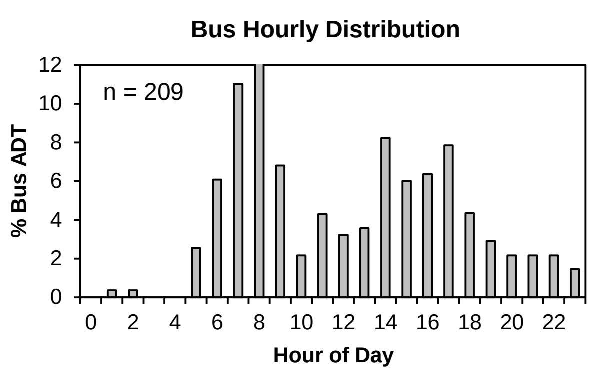


Truck traffic pattern group 1 (TTPG1-YWG) characteristics are derived from AVC/WIM data on the Perimeter Highway.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 6: TTPG1-YWG characteristics.

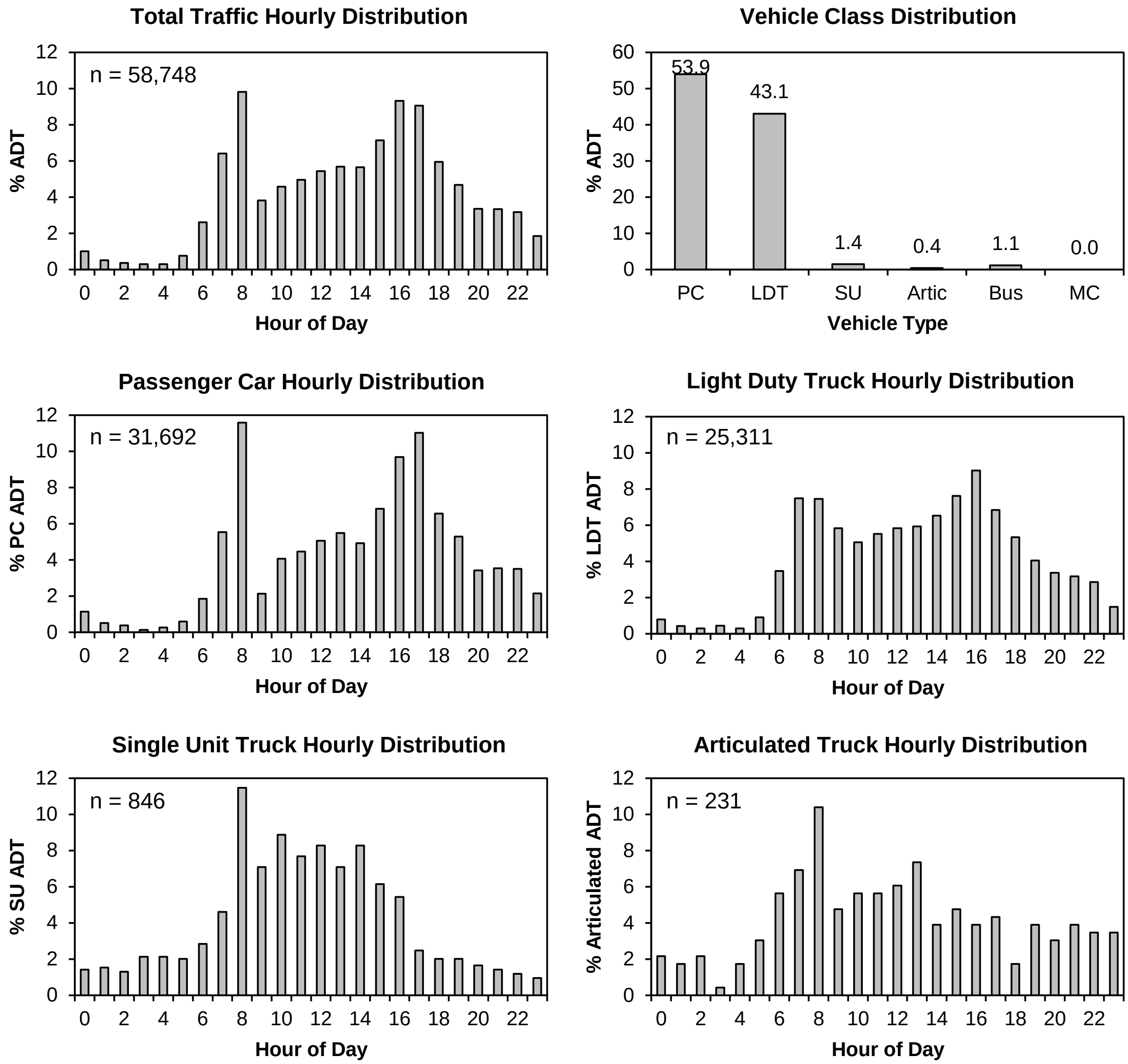


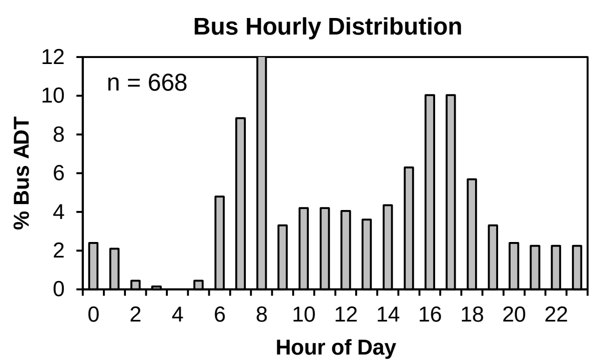


Truck traffic pattern group 2 (TTPG2-YWG) characteristics are derived from a 24-hour video count on Lagimodiere Blvd (near Regent Ave) and Route 90 (near Inkster Blvd).

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 7: TTPG2-YWG characteristics.

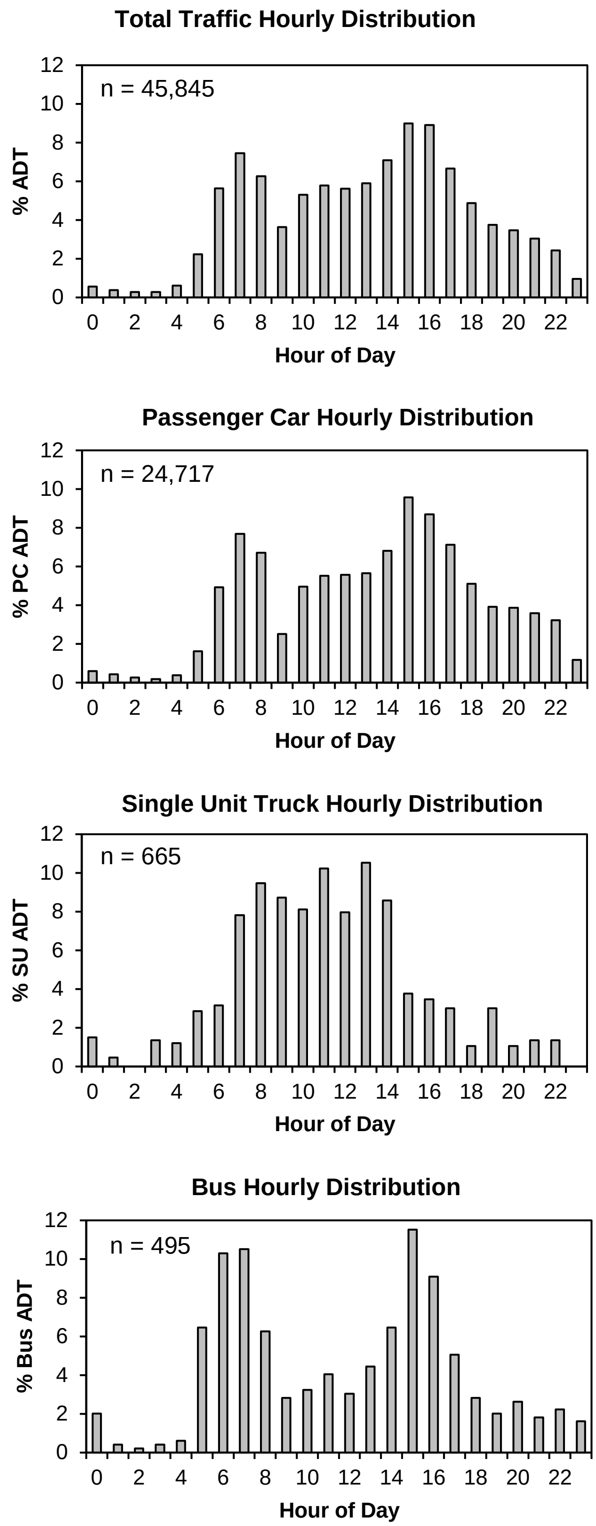




Truck traffic pattern group 3 (TTPG3-YWG) characteristics are derived from a 24-hour video count on the Main St Bridge.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 8: TTPG3-YWG characteristics.

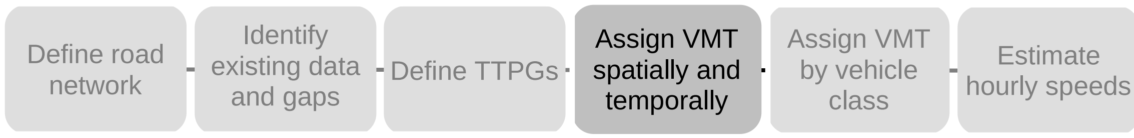


Truck traffic pattern group 4 (TTPG4-YWG) characteristics are derived from a 24-hour video count on Portage Ave (near Moray St).

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 9: TTPG4-YWG characteristics.

3.2.4. Assign VMT Spatially and Temporally



Once the network is segmented, VMT is assigned spatially and temporally to the network. The methodology to estimate VMT on freeways and arterials/collectors follows a standard approach. However, since different data is used for each road facility type, the details of calculating VMT differ. Data from the Manitoba Highway Traffic Information System (MHTIS) is used to estimate VMT for the Perimeter Highway (the only freeway in this research). Principal data sources for calculating arterial/collector VMT are provided by the City of Winnipeg traffic monitoring program and video counts performed as part of this research. Data from MHTIS are also used for provincial roads that provide connectivity between the Perimeter Highway and principal urban arterials.

The MHTIS and the City of Winnipeg provide annual average daily traffic (AADT) and average weekday daily traffic (AWDT), respectively, along with the length for each road segment on the network. Because VMT is the product of traffic volume and road segment length, total VMT for the freeway and arterial/collector network are readily available, provided that axle-correction factors are applied to City of Winnipeg traffic data. However, different data types are used for each road facility type to disaggregate total VMT to the necessary VMT estimates required by MOBILE6.2C.

AADT is defined as the number of vehicles passing a point in both directions on an average day of the year. AWDT is defined as the number of vehicles passing a point in both directions on an average weekday (Monday through Friday). While there is a difference between AADT and AWDT, data collection limitations in the City of Winnipeg preclude the calculation of AADTs. This is because sample counts are generally not conducted during weekends. This results in AWDT volumes typically being higher than AADT volumes. For the purpose of this research the AADT and AWDT are regarded as equivalent and are hereby referred to as average daily traffic (ADT).

VMT estimates on Winnipeg Emissions Modelling Network segments are produced by this research using the different data types shown previously in Table 11, each with different degrees of certainty. Figure 10 shows the level of confidence of the VMT estimate for the WEMN using a scale of 1 to 3, where 1 is the highest level of certainty and 3 is the lowest.

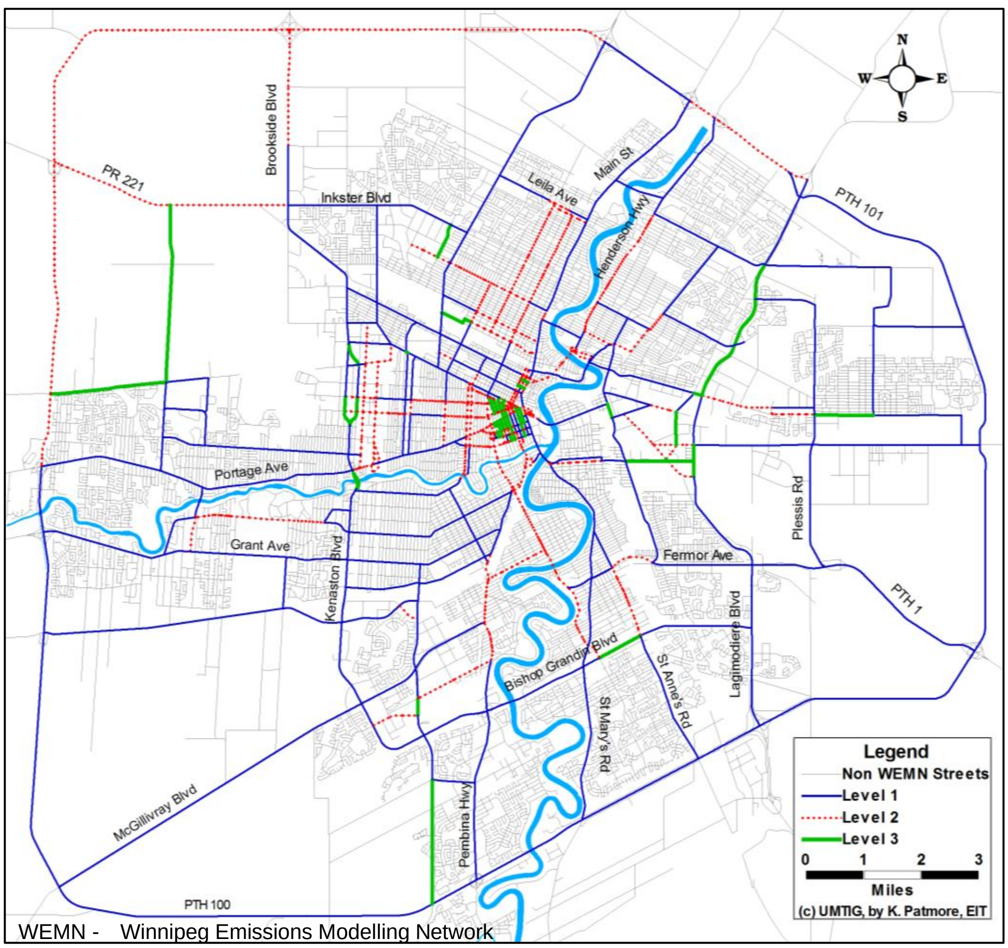


Figure 10: Data levels.

Level 1 segments are those with vehicle class data by hour (i.e., TMC, AVC/WIM, or Titan data). Level 2 segments are those with traffic data, but not by vehicle class (i.e., PCS, CCS, or road tube data). Level 3 segments are those without any traffic data or with data that is disregarded due to insufficient accuracy. Table 14 describes the process and data used in this research to estimate the VMT by hour of day and type of vehicle for each data level.

Table 14: Description of Winnipeg data levels.

Road type	Data Used	Process
Level 1 segments – possess data for volume with temporal, and vehicle-class specificity		
Freeway	MHTIS • AVC/WIM • Titan	1. Calculate daily truck volumes on each segment 2. Calculate daily passenger vehicle volumes on each segment 3. Disaggregate daily volumes by class to hourly volumes by class
Arterial/collector	City of Winnipeg • Turning movement counts Collected by research • Video counts	1. Calculate daily truck volumes on each segment 2. Calculate daily passenger vehicle volumes on each segment 3. Disaggregate daily volumes by class to hourly volumes by class
Level 2 segments – possess traffic volumes but no temporal or vehicle class specificity		
Freeway	MHTIS • AVC/WIM • PCS, CCS	1. Disaggregate daily volumes to hourly volumes by class
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Calculate total traffic volume on each segment from passenger car equivalent volume 2. Disaggregate daily volumes to hourly volumes by class
Level 3 segments – no traffic data		
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Use engineering judgement to transfer ADT volumes from adjacent segments 2. Disaggregate daily volumes to hourly volumes by class
Level 3 segments – inaccurate data		
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Use engineering judgement to assign vehicle class fractions from adjacent segments 2. Calculate total traffic volume on each segment 3. Disaggregate daily volumes by class to hourly volumes by class

The following sections discuss the process developed and used in this research to estimate VMT for each type of road segment (i.e., data level 1, 2, and 3 segments).

3.3.4.1. VMT on Level 1 Segments

Level 1 segments are those that have data for spatial, temporal, and vehicle-specific factors (i.e., turning movement count, AVC/WIM, or Titan data). VMT is calculated differently for freeway and arterial/collector Level 1 segments since MHTIS and City of Winnipeg data are used, respectively. Table 15 describes this process.

Table 15: Description of Winnipeg data level 1 segments.

Road type	Data	Process
Level 1 segments – possess data for volume with temporal, and vehicle-class specificity		
Freeway	MHTIS • AVC/WIM • Titan	1. Calculate daily truck volumes on each segment 2. Calculate daily passenger vehicle volumes on each segment 3. Disaggregate daily volumes by class to hourly volumes by class
Arterial/collector	City of Winnipeg • Turning movement counts Collected by research • Video counts	1. Calculate daily truck volumes on each segment 2. Calculate daily passenger vehicle volumes on each segment 3. Disaggregate daily volumes by class to hourly volumes by class

Freeway VMT estimation using MHTIS data (19 road segments)

Freeway VMT for road segments with AVC/WIM data are calculated by summing hourly volumes for each FHWA vehicle class for the entire year and multiplying by the road segment length. For freeway road segments that have Titan truck volumes, three steps are required to calculate VMT.

STEP 1. Calculate daily truck volumes on each segment

Expand Titan truck volumes to a total 24-hr traffic volume (ADT) using TTPG temporal expansion factors. These values are provided by MHTIS and the methodology used to produce them is described by the University of Manitoba Transport Information Group (2010). This methodology is based on Traffic Monitoring Guide (Federal Highway Administration, 2001) procedures. The short-term counts are expanded by directly comparing the short-term observed volume with the hourly data from the station's volume control station or TTPG.

STEP 2. Calculate daily passenger vehicle volumes on each segment

The Manitoba Highway Traffic Information System estimates total traffic ADT on each segment each year. To calculate the passenger vehicle volumes the 24-hour truck volume is subtracted from the total traffic ADT.

$$Passenger\ vehicle_{24} = ADT - total\ trucks_{24}$$

Where $Passenger\ vehicle_{24}$ = 24-hour passenger vehicle volume

$all\ trucks_{24}$= 24-hour total truck volume

STEP 3. Disaggregate daily volumes by class to hourly volumes by class

Apply TTPG1-YWG hourly vehicle class distribution factors (see Figure 6) to 24-hour ADT data by class. The following shows a sample calculation to determine the hourly volume of single unit trucks at 08:00.

$$SU_8 = ADT\ x\ Vehicle\ Class\ Distribution\ factor_{SU}\ x\ SU\ hourly\ distribution\ factor_8$$
$$SU_8 = 10{,}000\ x\ 0.03\ x\ 0.08$$
$$SU_8 = 24$$

Where SU_8 = Single unit truck volume during the hour 08:00

Arterial/collector VMT estimations using City of Winnipeg data (246 road segments)

STEP 1. Calculate daily truck volumes on each segment

Turning movement count data are used to calculate sample hourly traffic volumes on each road segment by three truck classes (single unit, single trailer, and multi trailer). Single trailer and multi trailer volumes are summed to create a single articulated truck volume. The sample volumes from the two truck classes (single unit and articulated) are expanded to a 24-hour truck volume by applying TTPG temporal expansion factors.

The following example uses data from the turning movement count conducted at Inkster Boulevard and McPhillips Street to show how single unit traffic volume on a segment is calculated. Table 16 shows data from a 2009 City of Winnipeg turning movement count. This portion of the count shows volumes for the five City of Winnipeg classes by hour for the 8-hour duration of the count.

Table 16: Sample data analyzed from turning movement count.

Inkster Blvd west of McPhillips St						
Hour	**Passenger**	**Single Unit**	**Single Trailer**	**Multi Trailer**	**Articulated Trucks**	**Bus**
7	1409	18	24	0	25	8
8	1419	32	25	1	26	8
9	1070	40	35	0	35	3
10	958	43	31	1	32	4
14	1384	47	27	1	28	11
15	1715	29	28	0	28	8
16	1878	18	19	1	20	5
17	1857	17	12	0	12	4

Source: City of Winnipeg
Note: Only hours when data is collected are shown.

This road segment is assigned to TTPG2-YWG based on its hourly truck traffic distribution and functional classification. The single unit vehicle hourly distribution from this TTPG is used to expand the short-term count to a 24-hour count. Table 17 shows the single unit volume by hour from the turning movement count and the corresponding percentage of ADT for that hour from the TTPG (refer to the Single Unit Hourly

Distribution chart in Figure 7). Applying the expansion factors to the sample count data produces a single unit truck ADT of 434 for this segment.

Table 17: Turning movement count expansion data.

Hour	Single Unit Hourly Volume	% Single Unit ADT
7	18	6.30
8	32	7.54
9	40	7.65
10	43	9.04
14	47	8.20
15	29	8.59
16	18	5.72
17	17	3.25
Total	**244**	**56.28**

Source: Adapted from City of Winnipeg turning movement count data

$$SU_{24} = \frac{sum\ of\ single\ unit\ trucks\ counted}{sum\ of\ \%\ single\ unit\ ADT\ during\ counted\ hours}$$

$$SU_{24} = \frac{244}{0.5628} = 434$$

STEP 2. Calculate daily passenger volumes on each segment

City of Winnipeg ADT volumes are provided in passenger car equivalents (PCEs). This is because volume estimates are produced using data from pneumatic road tube counters that only count the number of axles without axle spacing or axle weight data. The devices are programmed with an algorithm that divides the number of axle counts by two to estimate the passenger car equivalent volume. However, this overestimates the number of vehicles (e.g., a single four-axle truck is counted as two 2-axle vehicles). This research develops axle correction factors for single unit trucks, single trailer trucks, and multi trailer trucks to convert PCE volumes to total traffic volumes. Passenger vehicles and buses are both defined as 2-axle vehicles in this research. The average number of axles for single unit trucks, single trailer trucks, and multi trailer trucks is calculated from AVC/WIM stations on the Perimeter Highway. The number of axles for articulated trucks is the weighted average (by volume) of single and multi trailer trucks. Passenger vehicle volumes are calculated by subtracting PCE truck traffic volumes from the corresponding ADT_{PCE}. The ADT_{PCE} is the count provided by the City which counts every two axles as one vehicle.

Table 18: Axle correction factors.

Vehicle Type	Average Axles	Passenger Car Equivalents
Passenger	2	1
Single Unit	2.68	1.34
Articulated	5.50	2.75
Bus	2	1

Note: average axles for passenger vehicles and buses is assumed to be 2. Average axles for the other vehicles are calculated from AVC/WIM data.

The Inkster Boulevard segment from the previous step is used to illustrate how passenger vehicle volumes are calculated. The 24-hour truck volume distribution consists of 434 single unit trucks, 418 articulated trucks, and 63 buses. The ADT_{PCE} is 23,520. This research develops the following equation to calculate a passenger vehicle volume of 21,727.

$$\textit{Passenger vehicle volume} = ADT_{PCE} - (\textit{single unit truck volume} * 1.34\ PCE) - (\textit{articulated truck volume} * 2.75\ PCE) - (\textit{bus volume} * 1\ PCE)$$

$$\textit{Passenger vehicle volume} = 23{,}520 - (434 * 1.34) - (418 * 2.75) - (63 * 1)$$

$$\textit{Passenger vehicle volume} = 21{,}727$$

STEP 3. Disaggregate daily volumes by class to hourly volumes by class

Apply the corresponding TTPG (TTPG2-YWG, TTPG3-YWG, or TTPG4-YWG) hourly distribution factors to the 24-hour ADT data by class for each segment.

3.3.4.2. VMT on Level 2 Segments

Level 2 data segments are those with traffic volumes, but without spatial, temporal, or vehicle class specificity (i.e., those with PCS, CCS, or road tube data). VMT is calculated differently for freeway and arterial/collector Level 2 segments since MHTIS and City of Winnipeg data are used, respectively. Table 19 describes this process.

Table 19: Description of Winnipeg data level 2 segments.

Road type	Data Used	Process
Level 2 segments – possess traffic volumes but no temporal or vehicle class specificity		
Freeway	MHTIS • AVC/WIM • PCS • CCS	1. Disaggregate daily volumes to hourly volumes by class
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Calculate total traffic volume on each segment from passenger car equivalent volume 2. Disaggregate daily volumes to hourly volumes by class

Freeway VMT estimation using MHTIS data (11 road segments)

This requires only one step: *Disaggregate daily volumes to hourly volumes by class*

Apply TTPG1-YWG hourly vehicle class distribution factors to 24-hour ADT data by class. The 24-hour ADT values are provided by MHTIS and the methodology used to produce them is described by the University of Manitoba Transport Information Group (2010). This methodology is based on Traffic Monitoring Guide (FHWA, 2001) procedures. The short-term counts are expanded by directly comparing the short-term observed volume with the hourly data from the station's volume control station or TTPG.

Arterial/collector VMT estimations using City of Winnipeg data (241 road segments)

STEP 1. Calculate total traffic volume on each segment from passenger car equivalent volume

Total traffic volume on each segment is calculated by applying a vehicle correction factor to the ADT_{PCE}. The calculation requires the fraction of vehicle class (from Figure 7, Figure 8, and Figure 9) and axle correction factors from Table 18. TTPG2-YWG comprises 88.7 percent passenger vehicles, 5.2 percent single unit trucks, 5.1 percent single trailer trucks, 0.7 percent multi trailer trucks, and 0.3 percent buses (Figure 7). This research developed the equation below to calculate the vehicle correction factors for each TTPG.

$$ADT_{PCE} = (\textit{vehicle correction factor} * \textit{fraction of passenger vehicles} * 1.00\ PCE) + (\textit{vehicle correction factor} * \textit{fraction of single unit trucks} * 1.34\ PCE) + (\textit{vehicle correction factor} * \textit{fraction of single trailer trucks} * 2.62\ PCE) + (\textit{vehicle correction factor} * \textit{fraction of multi trailer trucks} * 3.78\ PCE) + (\textit{vehicle correction factor} * \textit{fraction of buses} * 1.00\ PCE)$$

$$ADT_{PCE} = (\textit{vehicle correction factor} * 0.887 * 1.00) + (\textit{vehicle correction factor} * 0.052 * 1.34) + (\textit{vehicle correction factor} * 0.051 * 2.62) + (\textit{vehicle correction factor} * 0.007 * 3.78) + (\textit{vehicle correction factor} * 0.003 * 1.00)$$

The vehicle correction factor is found by setting ADT_{PCE} to one and solving the equation. Therefore the vehicle correction factor for TTPG2-YWG is equal to 89.4 percent of ADT_{PCE}. Dawson Rd (a road segment assigned to TTPG2-YWG), for example, has a ADT_{PCE} of 6646; however, the $ADT_{corrected}$ is 5941 after applying the vehicle correction factor (6646 x 0.894 = 5941).

STEP 2. Disaggregate daily volumes to hourly volumes by class

Apply the corresponding TTPG (TTPG2-YWG, TTPG3-YWG, TTPG4-YWG) hourly vehicle class distribution factors to 24-hour ADT data by class. To illustrate this process Dawson Rd is used as an example. Dawson Rd is a TTPG2-YWG road segment that has an $ADT_{corrected}$ of 5941. Passenger vehicles comprise 88.7 percent of the total traffic and 9.1 percent of the total passenger vehicle volume is at 07:00. Using the following equation, the passenger vehicle volume on this segment at 07:00 is 480.

$$Class\ volume\ by\ hour = ADTcorrected * vehicle\ class\ fraction * hourly\ class\ fraction$$

$$Class\ volume\ by\ hour = = 5941 * 0.887 * 0.091$$

$$Class\ volume\ by\ hour = 480$$

3.3.4.3. VMT on Level 3 Segments

Level 3 segments are those without any traffic data or with data that are disregarded due to insufficient accuracy. Table 20 describes the process.

Table 20: Description of Winnipeg data level 3 segments.

Road type	Data	Process
Level 3 segments – no traffic data		
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Use engineering judgement to assign ADT volumes based on ADT from adjacent segments 2. Disaggregate daily volumes to hourly volumes by class
Level 3 segments – unreliable data		
Arterial/collector	City of Winnipeg • Road tubes Collected by research • Video counts	1. Use engineering judgement to assign vehicle class fractions based on vehicle class fractions from adjacent segments 2. Calculate total traffic volume on each segment 3. Disaggregate daily volumes by class to hourly volumes by class

For these segments, engineering judgement is applied to assign a traffic volume estimate. This judgement is based on extensive knowledge and understanding of the road network and its characteristics. VMT is calculated differently for segments with no data and for segments with unreliable data.

VMT estimation for segments with no traffic data (44 road segments)

STEP 1. Assign ADT volumes to segments with no data

ADT volumes were assigned to arterial/collector road segments without ADT estimates from the City of Winnipeg. The assignment of ADT volumes considers the ADT on surrounding road segments and was completed in consultation with the City of Winnipeg planning engineer.

STEP 2. Disaggregate daily volumes to hourly volumes by class

Apply the corresponding TTPG (TTPG2-YWG, TTPG3-YWG, or TTPG4-YWG) hourly vehicle class distribution factors to the assigned 24-hour ADT data. This step is identical to Step 2 for calculating VMT on Level 2 arterial/collector road segments.

VMT estimation for segments with unreliable data (24 road segments)

Based on engineering judgement and analysis of Level 1 road segment data ADT estimates on 21 level 2 segments and three level 1 segments were rejected. Engineering judgement and analysis involved comparing ADT estimates to surrounding road segments and using knowledge about the transportation system to decide if the ADT on a segment was reasonable. Segments with unreliable ADT estimates are provided with an ADT by transferring vehicle class fractions from adjacent road segments and applying appropriate TTPG expansion factors.

STEP 1. Transfer vehicle class fractions

Transfer vehicle class fractions from adjacent or surrounding Level 1 road segments to road segments with unreliable data.

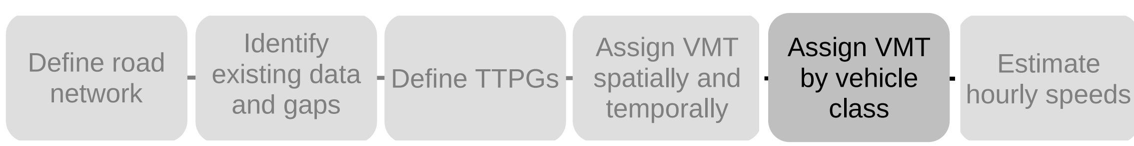
STEP 2. Calculate total traffic volume on each segment with transferred vehicle class fractions

Once class distribution fractions are transferred from an adjacent segment, the total traffic volume is calculated in the same manner as City of Winnipeg Level 2 sites. The total traffic volume is calculated by applying the vehicle correction factor from the corresponding TTPG to the PCE ADT. Upon completing this step, an ADT is produced for total traffic only.

STEP 3. Disaggregate daily volumes from Step 2 to hourly volumes by class

Apply the corresponding TTPG (TTPG2-YWG, TTPG3-YWG, TTPG4-YWG) hourly vehicle class distribution factors to 24-hour ADT data by class for each segment calculated in Step 2.

3.2.5. Assign VMT by Vehicle Class



This section describes the process of calculating VMT for each of the vehicle classes required by MOBILE6.2C. Traffic data sources available for this research classify vehicles differently than MOBILE6.2C, and therefore require conversion prior to generating VMT inputs. The data collected from video cameras in this research uses six vehicle classes (Figure 11 illustrates examples of each of these vehicle classes), and MOBILE6.2C uses either 16 or 28 vehicle classes depending on the specific input.

	Motorcycle
	Passenger car
	Light duty truck
	Single unit truck
	Articulated truck
	Bus

Figure 11: Winnipeg classification scheme.

Environment Canada provided VMT distribution tables for the MOBILE6.2C vehicle classes. These tables are produced using vehicle registration data from the province of Manitoba and mileage accumulation rates for each of these vehicles to properly weight the percentage that each vehicle type contributes to the entire Manitoba VMT. Table 21 shows the fractions of Manitoba VMT by vehicle class for 16 vehicle classes, the percentage of VMT for the individual vehicle classes sum to 100 percent.

Table 21: Manitoba VMT percentages by vehicle class using the MOBILE6.2C 16 classes.

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
41.84	2.40	22.90	9.74	8.88	2.40	0.81	0.21
Class 9	**Class 10**	**Class 11**	**Class 12**	**Class 13**	**Class 14**	**Class 15**	**Class 16**
0.11	1.03	0.92	1.17	6.16	0.20	0.75	0.49

Sum = 100 %
Source: Environment Canada

Prior to this research, it was necessary to use the data in Table 21 to disaggregate Winnipeg's total traffic VMT to MOBILE6.2C vehicle classes. This assumes that the vehicle fleet mix in Winnipeg is identical to that in Manitoba as a whole. The vehicle activity data produced by this research demonstrates that this assumption is incorrect and can lead to erroneous fleet mix estimates. For example, traffic data obtained through this research indicates that Class 1 vehicles represent 47 percent of the fleet as opposed to 42 percent as shown in Table 21.

This research considers the jurisdictionally-specific vehicle classes (i.e., Winnipeg vehicle fleet mix) by collecting hourly traffic data for six classes, however it is not possible to properly classify vehicles to the specificity required by MOBILE6.2C. The methodology developed in this research disaggregates total traffic VMT to six vehicle types and matches MOBILE6.2C classes to these vehicle types (as shown in Table 22).

The percentages of MOBILE6.2C in Table 21 are used to disaggregate each of the vehicle classes used in this research to the corresponding MOBILE6.2C 16 classes. To illustrate the conversion process, an example of converting visually classified light duty trucks to MOBILE6.2C classes is provided. Consider an hourly count with 200 single unit trucks. Single unit trucks correspond to MOBILE6.2C classes 7 through 12 (as shown in Table 22). MOBILE6.2C classes 2 through 6 sum to 4.25 percent of Manitoba VMT (as shown in Table 23). Each MOBILE6.2C vehicle class fraction is divided by the sum of the corresponding classes (4.25 percent) and then multiplied by the single unit truck volume (200 veh/day).

Table 22: MOBILE6.2C vehicle class equivalents for Winnipeg.

Winnipeg Research Classes	MOBILE6.2C Vehicles Class Number	Abbreviation	Description
Passenger cars	1	LDV	Light-Duty Vehicles
Light Duty Trucks	2	LDT1	Light-Duty Trucks 1
	3	LDT2	Light-Duty Trucks 2
	4	LDT3	Light-Duty Trucks 3
	5	LDT4	Light-Duty Trucks 4
	6	HDV2B	Class 2B Heavy-Duty Vehicles
Single Unit Trucks	7	HDV3	Class 3 Heavy-Duty Vehicles
	8	HDV4	Class 4 Heavy-Duty Vehicles
	9	HDV5	Class 5 Heavy-Duty Vehicles
	10	HDV6	Class 6 Heavy-Duty Vehicles
	11	HDV7	Class 7 Heavy-Duty Vehicles
	12	HDV8A	Class 8A Heavy-Duty Vehicles
Articulated Trucks	13	HDV8B	Class 8B Heavy-Duty Vehicles
Buses	14	HDBS	School Buses
	15	HDBT	Transit and Urban Buses
Motorcycles	16	MC	Motorcycles

Table 23: Example class conversion calculations for classes in this research to MOBILE6.2C classes.

Wpg Research		MOBILE6.2C			
Vehicle Class	**Volume (veh/day)**	**Vehicle Class**	**Percent of Manitoba VMT**	**Percent of single unit truck VMT**	**Volume (veh/day)**
Single Unit Truck	200	HDV3	0.81	19*	38
		HDV4	0.21	5	10
		HDV5	0.11	3	6
		HDV6	1.03	24	48
		HDV7	0.92	22	44
		HDV8A	1.17	27	54
Total	**200**		**4.25**	**100**	**200**

* 19 percent = 0.81/4.25

$$\text{MOBILE6.2C HDV3 volume} = \frac{\mathit{MOBILE6.2C\ HDV3\ fraction}}{\mathit{Sum\ of\ MOBILE6.2\ Fractions\ within\ Vehicle\ Class}} \text{ x SU truck volume}$$

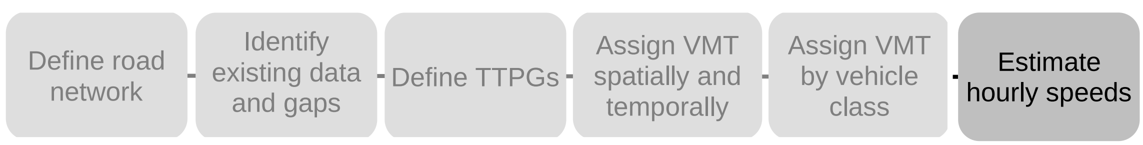
$$\text{MOBILE6.2C HDV3 volume} = \frac{0.81}{4.25} \text{ x } 200 = 38 \text{ HDV3 vehicles per day}$$

Table 24 shows that the single unit truck classification is disaggregated into 19 percent HDV3, 5 percent HDV4, 3 percent HDV5, 24 percent HDV6, 22 percent HDV7, and 27 percent HDV8A. Table 24 is a conversion table that illustrates the relationships between the Winnipeg research classes and MOBILE6.2C vehicle classification schemes.

Table 24: Conversion to MOBILE classification scheme for Winnipeg.

MOBILE Vehicle Type		Winnipeg Research Vehicle Type Percent					
Vehicle Class	Abbreviation	LDV	LDT	SU Truck	Articulated Truck	Bus	Motorcycle
1	LDV	100					
2	LDT1		5.18				
3	LDT2		49.44				
4	LDT3		21.03				
5	LDT4		19.17				
6	HDV2B		5.18				
7	HDV3			19.06			
8	HDV4			4.94			
9	HDV5			2.59			
10	HDV6			24.24			
11	HDV7			21.65			
12	HDV8A			27.53			
13	HDV8B				100		
14	HDBS					21.00	
15	HDBT					79.00	
16	MC						100
	All	100	100	100	100	100	100

3.2.6. Estimate Hourly Speeds



This section describes the process to estimate hourly speeds on the Winnipeg Emissions Modelling Network. The Bureau of Public Roads method is used to estimate travel speed by hour for each segment. The procedure described in Section 3.2.4 (Assign VMT Spatially and Temporally) estimates VMT by segment and hour. Summing the VMT for all segments with the same speed produces VMT by speed by hour.

Each TTPG on the network is assigned to a road class as defined by the Highway Capacity Manual (Transportation Research Board, 2000). The road classes in the Highway Capacity Manual (HCM) are defined using 14 road characteristics (e.g., number of lanes, signal density, and posted speed limit). For each of the TTPGs, default values for practical capacity (practical capacity is defined as 80 percent of the maximum capacity), signal density, average signal cycle length, and effective green ratio (average per signal) are selected from the HCM and used in the BPR speed equations. These default values are shown in Table 25 and Table 26. Attribute data provided by the City of Winnipeg for each Road Segment is used for the posted speed limit, and length.

Table 25: Highway capacity manual default values to estimate free flow speed.

		TTPG1-YWG*	TTPG2-YWG	TTPG3-YWG	TTPG4-YWG
Signal Density (sig/mi)	SD	-	.8	9.6	3.2
Cycle Length (seconds)	C	-	110	70	90
Free-flow Speed (mph)	FFS	-	50	30	40
Effective green ratio	g/C	-	0.45	0.45	0.45

Source: Transportation Research Board (2000)
TTPG-YWG - Truck traffic pattern group for Winnipeg
* this TTPG is a freeway and does not require these default values to estimate free flow speed

This research calculates the average speed for each hour on each segment using the BPR equations and HCM default values. A MOBILE6.2C speed bin is assigned to each hour of each road segment based on the average speed calculated using the BPR procedure. VMT estimates are aggregated by speed bin and by hour to produce a VMT by speed for each hour.

Table 26: Maximum and practical capacity volumes.

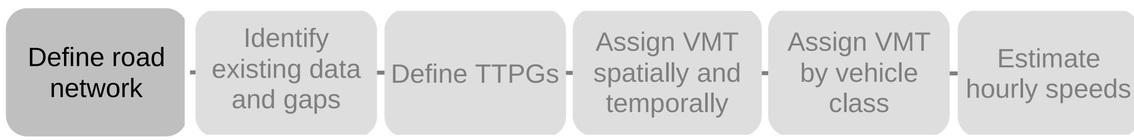
Number of Lanes	Maximum Capacity (veh/h) [Practical Capacity]			
	TTPG1-YWG	TTPG2-YWG	TTPG3-YWG	TTPG4-YWG
1	1110 [890]	1110 [890]	790 [630]	860 [690]
2	2120 [1700]	2120 [1700]	1520 [1220]	1650 [1320]
3	3040 [2430]	3040 [2430]	2180 [1740]	2370 [1900]
4	4060 [3250]	4060 [3250]	2900 [2320]	3190 [2250]

Source: Transportation Research Board (2000)
TTPG-YWG - Truck traffic pattern group for Winnipeg

3.3. APPLICATION OF METHODOLOGY TO SASKATOON

This section describes the application of the general methodology to Saskatoon, Saskatchewan. This method is very similar to what was conducted in Winnipeg but refined to consider the unique characteristics and data availability of Saskatoon.

3.3.1. Define the Road Network



Similar to the work done for Winnipeg, this section defines the road network in Saskatoon for which vehicle activity data is collected and prepared. The section describes the criteria for defining this network, referred to as the Emissions Modelling Network for Saskatoon (EMNS), calculates the total network length by facility type, provides a map of this network, and describes the development of truck segments.

Sequential application of the following criteria defines the urban road network:

1. Roads located beyond City of Saskatoon City Limits are excluded from the urban network.

2. Provincial roads within Saskatoon City Limits (including the portions of Circle Drive under provincial jurisdiction and major provincial highways such as Highways 11, 16, and 14 that connect rural areas with Circle Drive) are included in the urban road network.

3. Roads that are designated as primary truck routes, secondary truck routes, and arterials by the Schedule No.8 Saskatoon Truck Route Map (City of Saskatoon, 2011) are included in the urban road network. The truck route network includes all

arterials that provide intra-urban connectivity (e.g., major cross-town roads and roads leading into the central business district), and roads servicing industrial zones.

4. Ramps that provide access to Circle Drive and Provincial roads which have available traffic volume data are included in the network.

Table 27 provides the total number of centreline miles in Saskatoon by road facility type. Road facility types used in this research are freeways, arterials/collectors, freeway ramps, and local roads, as defined and required by MOBILE6.2C. This table shows centreline miles for local roads; however the emissions from these roads are not estimated. The EMNS measures 150 centreline miles and is shown in Figure 12.

Table 27: Centreline miles of road by facility type for Saskatoon.

Facility Type	Centreline Miles	Percent of Total	Percent of EMNS
Freeway	33	4.6	22.0
Arterial/Collector	96	13.4	64.0
Freeway Ramp	21	3.0	14.0
EMNS	***150***	***21***	***100***
Local	570	79.0	-
Total	**720**	**100**	**-**

Source: Created using GIS data obtained from the City of Saskatoon
EMNS - Emissions Modelling Network for Saskatoon

Geographic Information System (GIS) data provided by City of Saskatoon (COS) contains a unique Road ID with the segment length and ADT for each road segment. Road segments are defined by COS to provide a systematic way to identify and analyze conditions and characteristics of the roadway network for transportation engineering, planning, management, and traffic monitoring purposes.

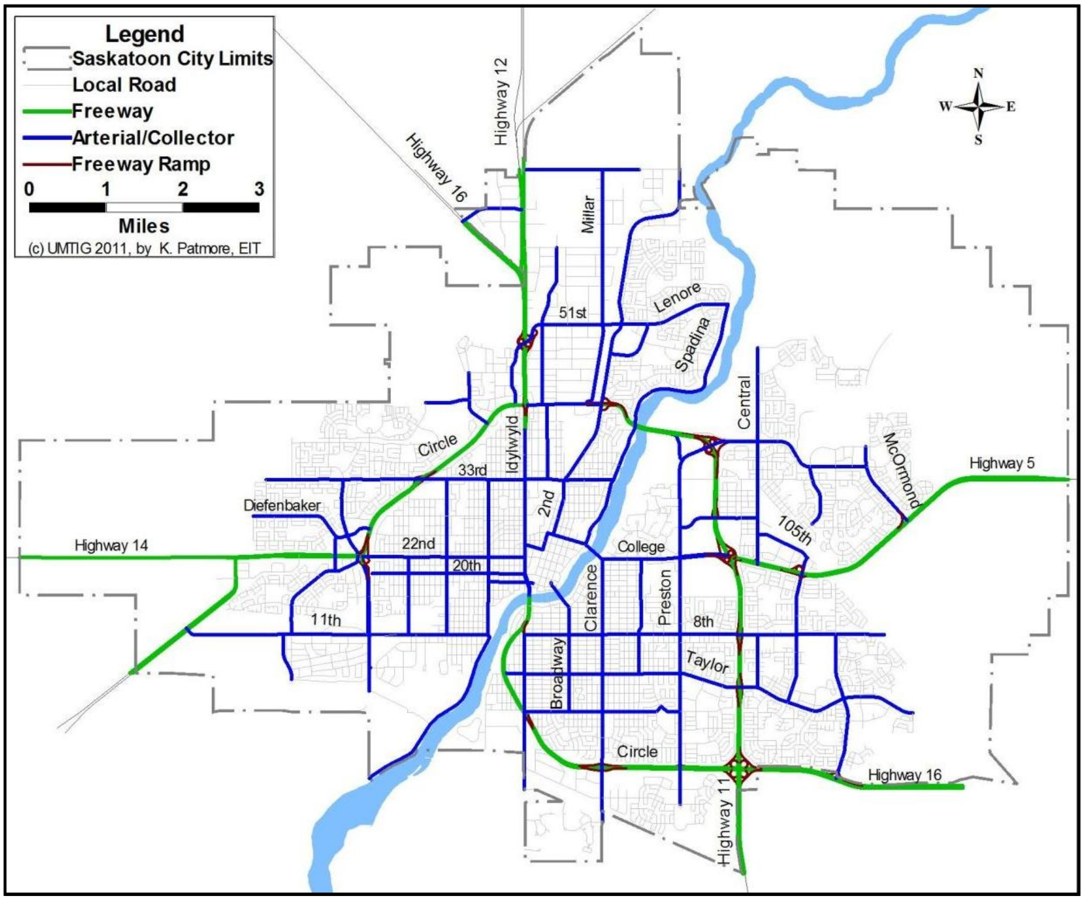
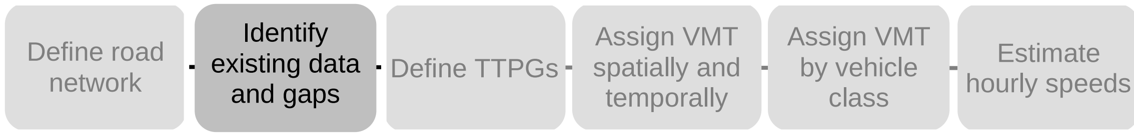


Figure 12: Emissions modelling network for Saskatoon.

This research develops truck segments to assign truck volumes to roadway segments. Truck segments are the amalgamation of Road Segments between intersections on the EMNS. Each Truck Segment is assigned a unique Truck ID and is assumed to exhibit homogeneous truck traffic characteristics (e.g., volumes, vehicle type, temporal distribution).

A Truck ID is assigned to each freeway, arterial/collector, and freeway ramp road segment on the EMNS. Local roads which are included in the City of Saskatoon GIS data are not included as part of the EMNS because they generally do not have ADT estimates.

3.3.2. Identify Existing Data and Gaps



This section describes the second step in the methodology application which is to identify existing data and gaps on the defined road network, similar to the Winnipeg application. This part of the research uses ADT volumes and segment length provided by the City of Saskatoon Infrastructure Services Department and develops a short-duration data collection program to collect hourly traffic distribution by vehicle class.

Data from the City of Saskatoon is publicly available and updated throughout the year. The short-duration data collection developed by this research utilizes video counts at four locations. Each data source uses different types of traffic data collection equipment which results in different data types (and defines vehicle classes differently). Figure 13 shows the traffic count data locations. Table 28 summarizes the characteristics of traffic data used in this research by source and type for each road facility.

The City of Saskatoon Infrastructure Services Department provided traffic volume, geospatial, and roadway attribute data for this research. The City of Saskatoon traffic counting program produces average daily traffic (ADT) estimates using permanent count stations, weigh-in-motion devices, and coverage count stations. ADT is not disaggregated by vehicle class, it is produced as a total for all vehicle types. The 2009 Traffic Characteristics (City of Saskatoon, 2010a) report outlines the complete traffic count program.

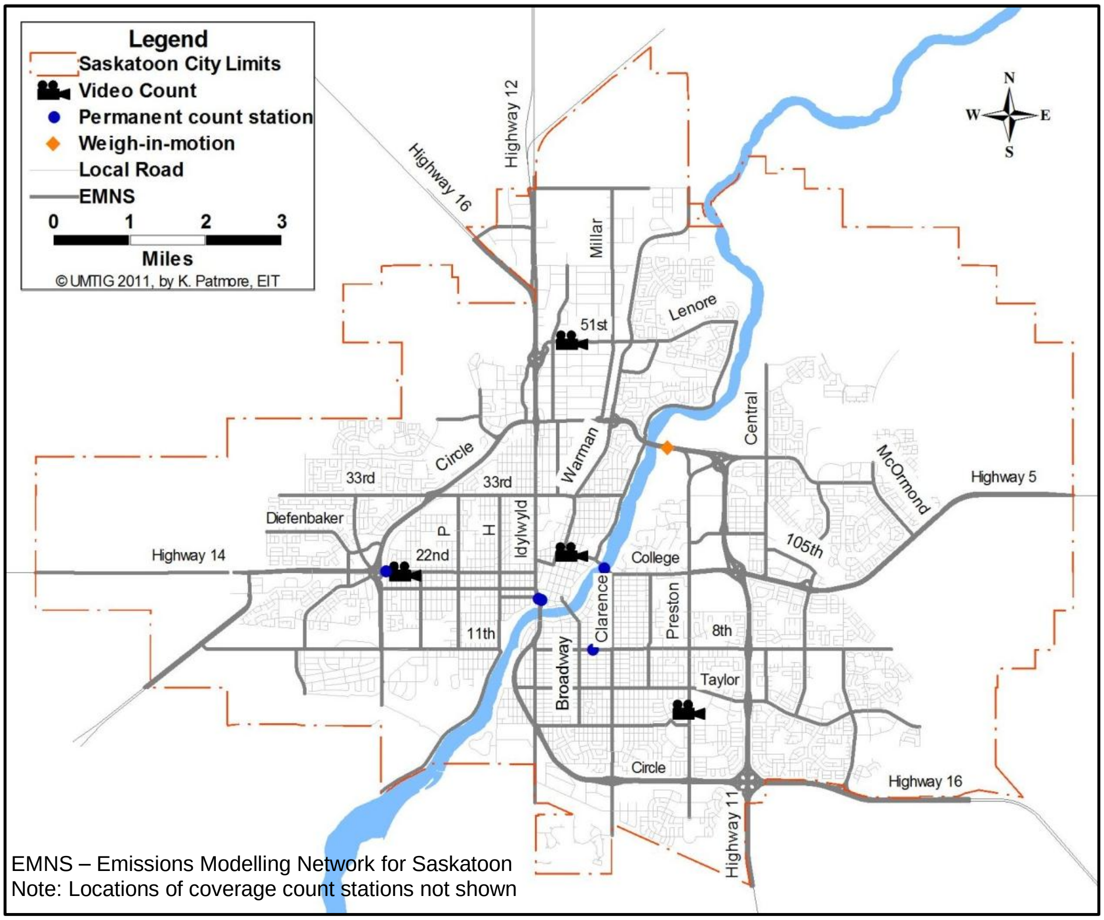


Figure 13: Traffic count locations in Saskatoon.

Table 28: Data types and characteristics for Saskatoon.

Data Collection Equipment	Number of Count Types	Data Source	Data Type Collected			
			Vehicle Class	24-hr Volume	Distribution by Hour	Speed
Road Facility Type: Freeway						
WIM	1	COS	✓	✓	✓	✓
CCS	52	COS		✓		
Road Facility Type: Arterial/Collector						
Video Count	4	research	✓	✓	✓	
PCS	5	COS		✓	✓	
CCS	267	COS		✓		
Road Facility Type: Freeway ramp						
CCS	65	COS		✓		

✓ represents that data is collected by the given equipment source
PCS – Permanent count station
CCS – Coverage count station
WIM – Weigh-in-motion
COS – City of Saskatoon

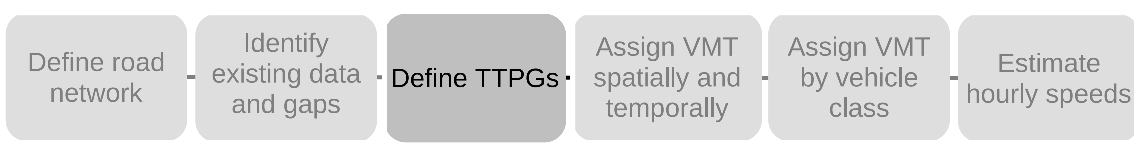
Permanent count stations (PCSs) provide continuous traffic data on a year-round basis, except when data collection is interrupted due to equipment failure, construction, road closures, or other issues. The year round traffic counts from the PCSs are used to calculate weekly expansion factors for the short term coverage count station (CCS) data. Data from the PCS on 22nd Street is used to calculate weekly expansion factors which are applied to the seven day CCS volumes to produce an ADT estimate for each segment.

There is one weigh-in-motion (WIM) device used in this research. WIM stations collect speed, volume, vehicle classification, axle spacing, and weight data. The WIM classifies vehicles using a 19 vehicle classification scheme based on an axle spacing and axle weight developed by Saskatchewan Ministry of Highways and Infrastructure (MHI). WIM data from a seven day period in September is used to produce expansion factors for the freeway traffic pattern group.

Coverage count stations (CCSs) use pneumatic road tube counters connected to an automatic recording device to obtain traffic volume data. The devices are programmed with an algorithm that converts the number of axles to vehicles. The collection typically consists of a seven day count conducted by a pneumatic road tube counter between April and October. The City of Saskatoon provided geospatial data of their road network complete with attribute information for each road segment. Attribute information relevant to this research include posted speed, number of lanes, and segment length.

Four 24-hour video traffic counts were conducted during the course of this research to develop hourly traffic volumes by vehicle class (Figure 13 shows the location of these counts). These counts are necessary because although the COS provides ADT for each road segment, there is no existing data for temporal distribution or vehicle class mix. The selection of the video count locations reflects different types of vehicle operating characteristics based on facility type and geographic location. Video count data is obtained for roads within and adjacent to the central business district, roads that support truck traffic and connect industrial and commercial land use zones, and roads that support commuter traffic. Engineers from the Transportation Branch of City of Saskatoon Infrastructure Services Department provided direct input for selecting the locations where video cameras were installed. Traffic data obtained from these counts are used to develop hourly volume by vehicle class and create the vehicle specific temporal factors for each truck traffic pattern group described in Section 3.3.4. Vehicles from these counts are manually classified as Passenger cars, light duty trucks, single unit trucks, articulated trucks, buses, and motorcycles (also referred to as Saskatoon research vehicle classes).

3.3.3. Define TTPGs



This section describes the process of segmenting the defined road network into truck traffic pattern groups. Most of the data collection equipment used in this research does not have the ability to collect 24-hour vehicle volumes by vehicle type. In order to determine 24-hour vehicle volumes by vehicle type from these counts it is necessary to assign them to traffic counts which do have 24-hour vehicle volumes by vehicle type. The counts can then be expanded using the process described in Section 3.4.4. Creating TTPGs combines roadways with similar characteristics so that expansion estimates are more accurate.

Video traffic count data is used to develop the hourly traffic distributions for the TTPGs on the arterial/collector network and WIM data is used for the freeway network. Table 29 provides a description of the TTPGs and Figure 14 shows the segment assignment to each TTPG and the location of the data source (WIM and video recorders) used to calculate the traffic characteristics of each TTPG.

Table 29: Truck traffic pattern group description for Saskatoon.

TTPG	Data Type	Description
TTPG1-YXE	WIM	Road segments on Circle Drive that exhibit freeway characteristics and provincial roads within Saskatoon city limits.
TTPG2-YXE	Video count	Road segments serving major industrial zones or intermodal terminals.
TTPG3-YXE	Video count	Road segments in the central business district (CBD) or road segments serving local commercial purposes. These road segments service high density mixed land use areas.
TTPG4-YXE	Video count	Road segments providing regional service primarily for passenger and light duty or single unit truck traffic.
TTPG5-YXE	Video count	Road segments primarily for local passenger and light duty truck traffic.

TTPG-YXE - Truck traffic pattern group for Saskatoon (YXE is the airport code for Saskatoon)

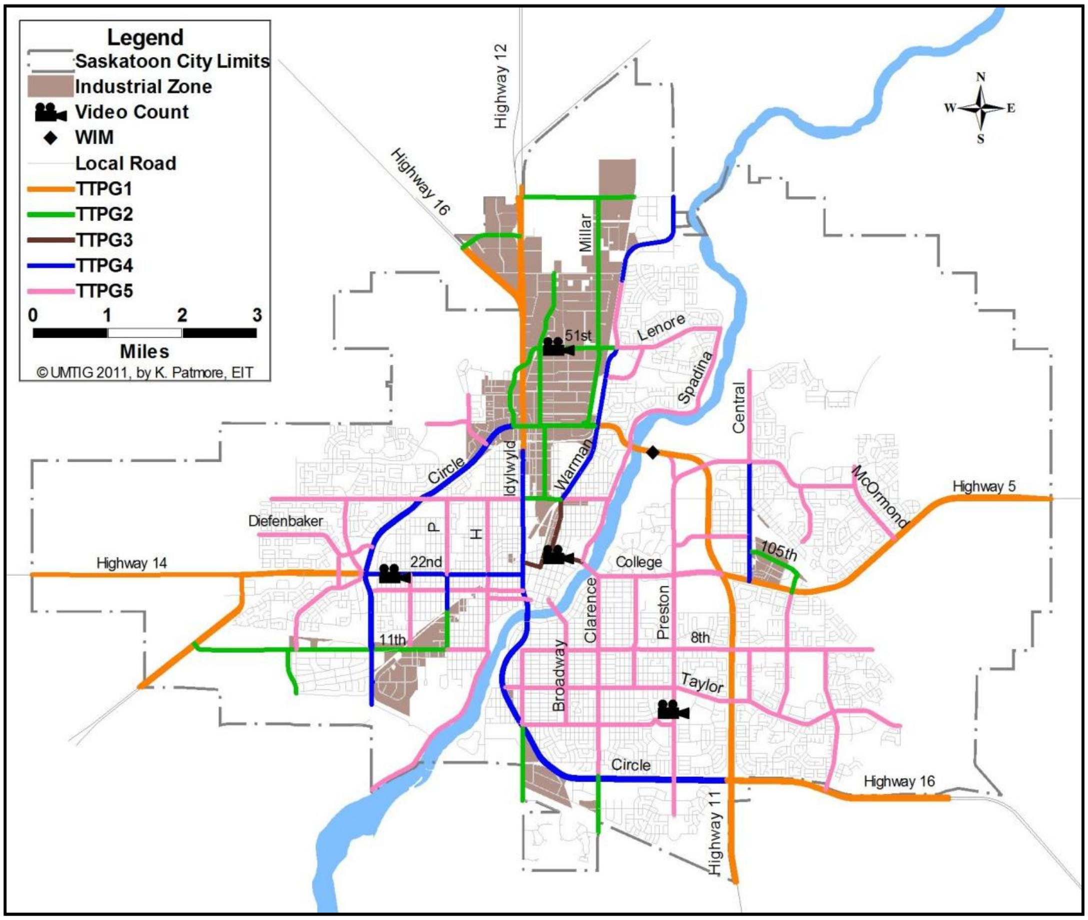
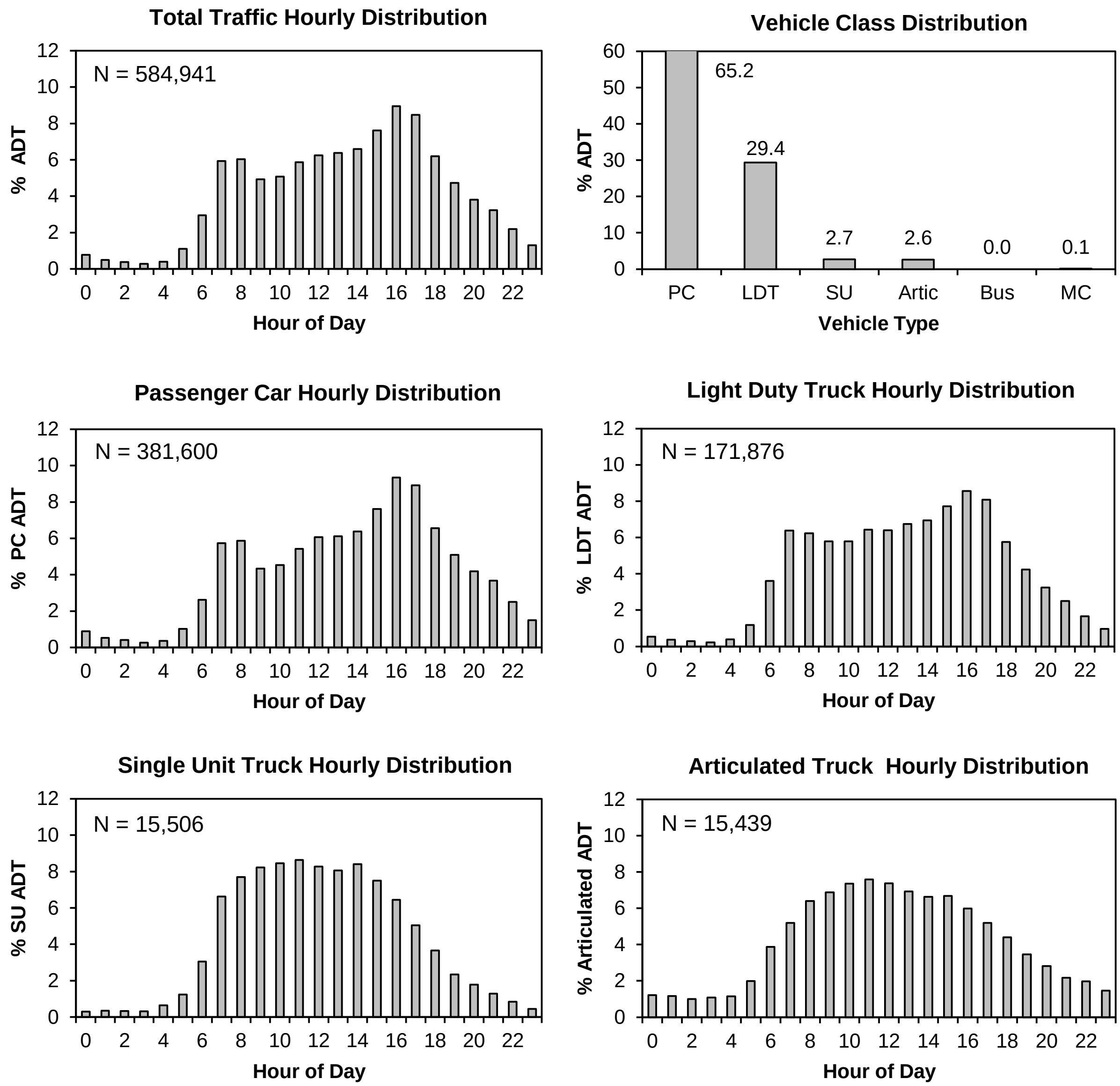
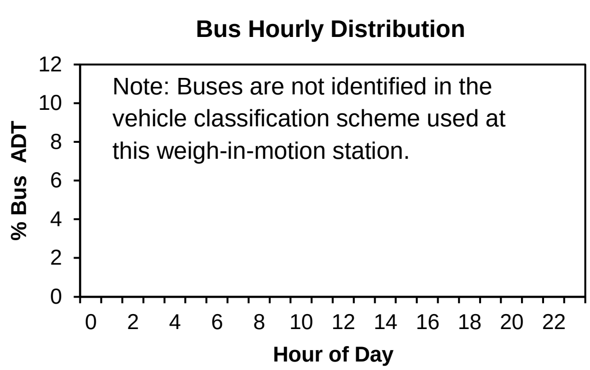


Figure 14: Truck traffic pattern group assignment and data source location.

Figure 15 to Figure 19 illustrate the temporal distributions by vehicle class and the total vehicle class distribution for each TTPG resulting from the data collection and analysis conducted in this research. The volume of observed articulated trucks for TTPG3 and TTPG5 were less than one per hour with an observed count of zero for many hours. This exemplifies the limitation of short-term counts on capturing average daily conditions since articulated trucks are expected to operate at these locations during all hours of the day. Therefore a uniform hourly distribution across all hours is used to replace the observed distribution. For TTPG3 and TTPG5, it is assumed that 0.1 and 0.2 percent, respectively, of the total traffic will be articulated trucks and that the distribution for each hour is equal.

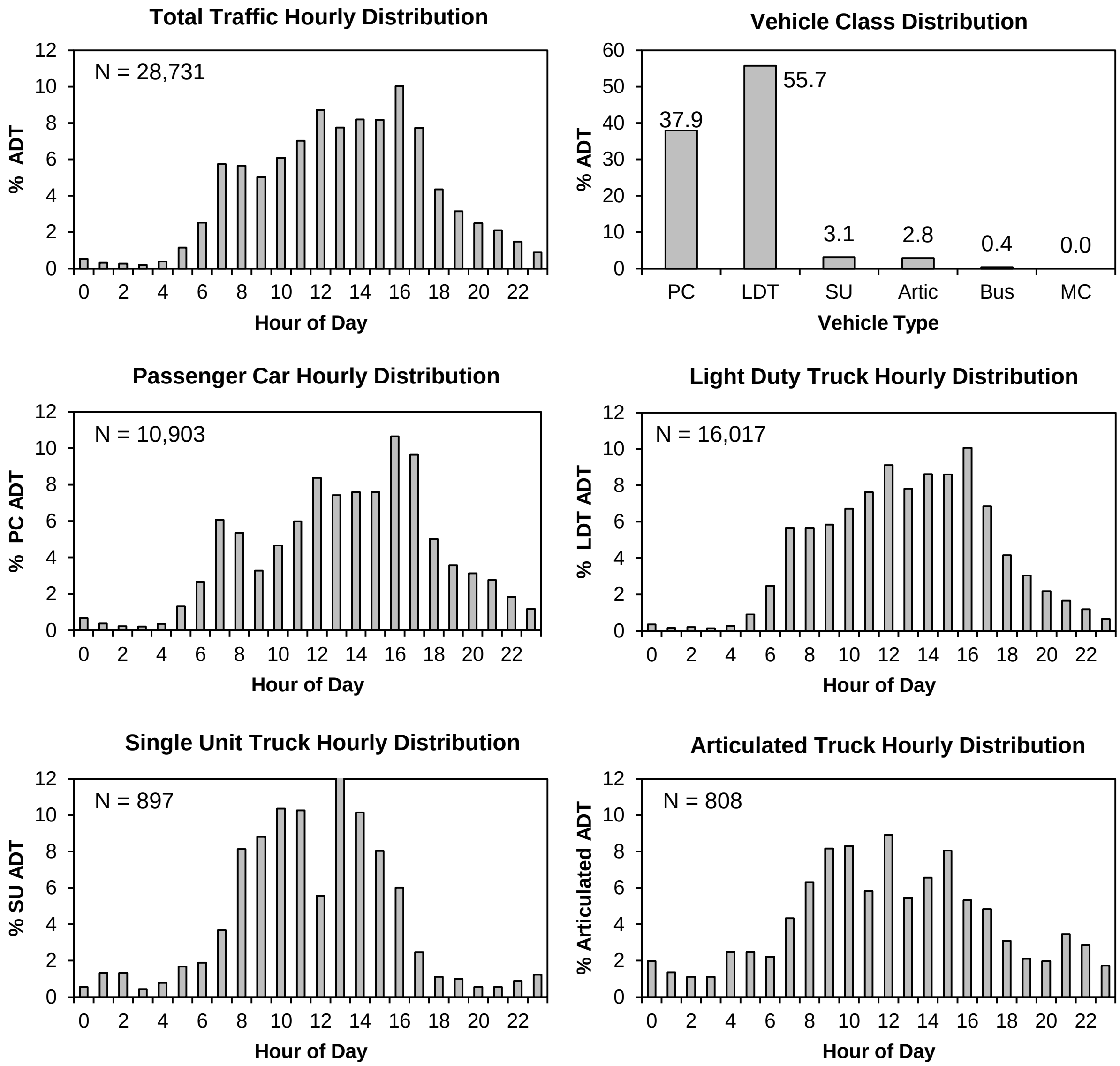


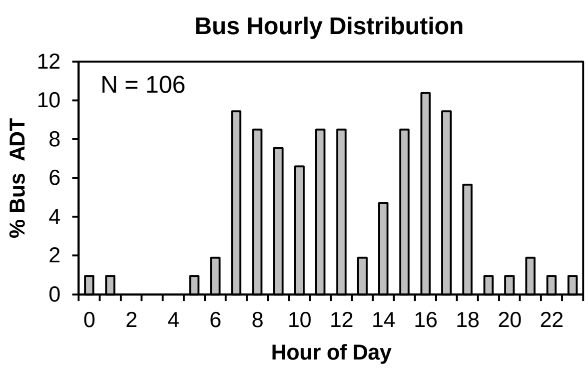


Truck traffic pattern group 1 (TTPG1-YXE) characteristics are derived from 7 days of weigh-in-motion data on Circle Drive Bridge.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 15: TTPG1-YXE characteristics.

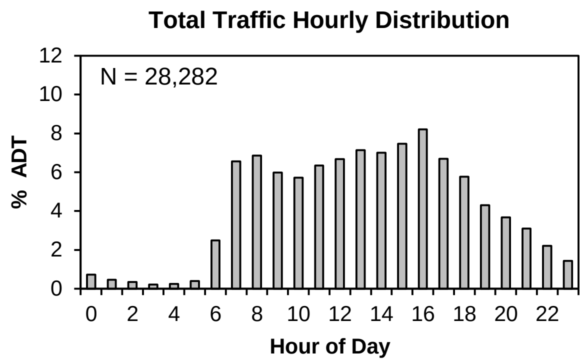


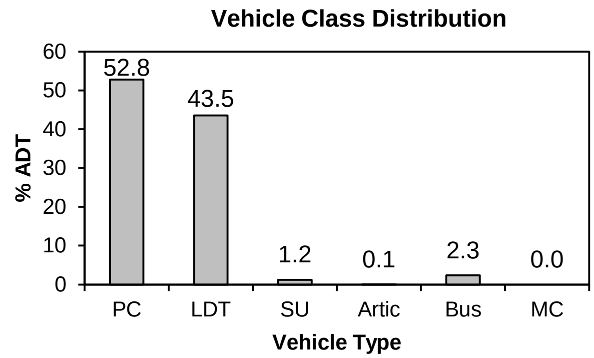


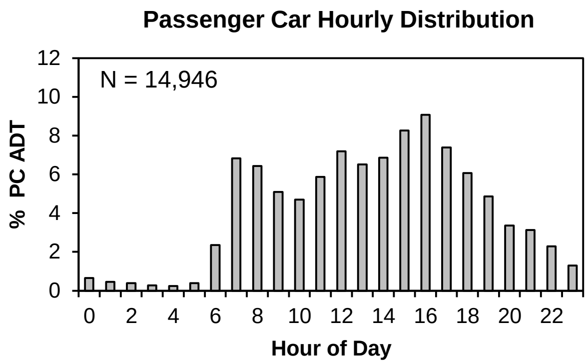
Truck traffic pattern group 2 (TTPG2-YXE) characteristics are derived from a 24-hour video traffic count on 51st Street.

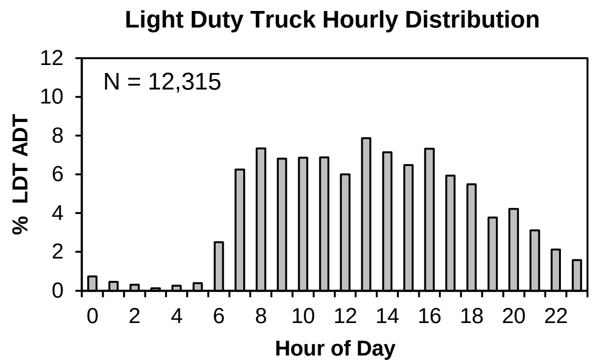
ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

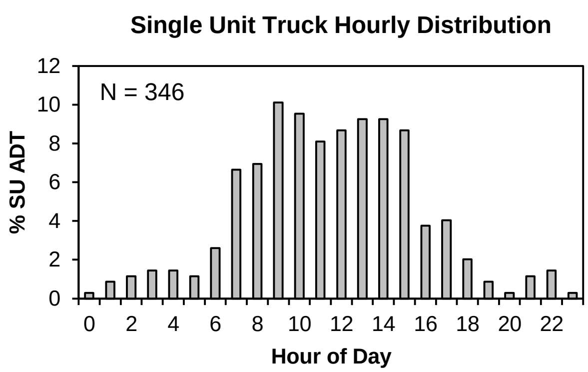
Figure 16: TTPG2-YXE characteristics.

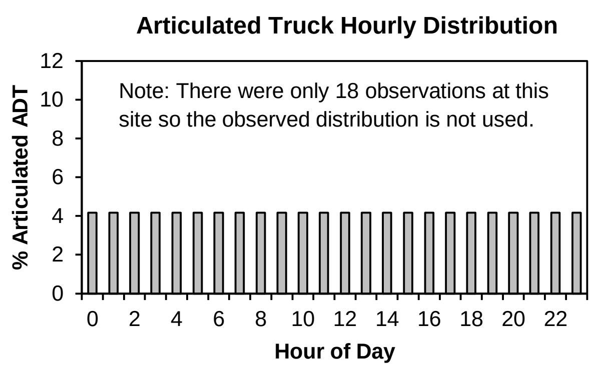


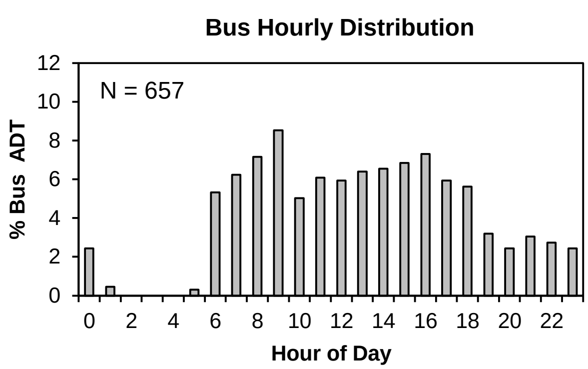








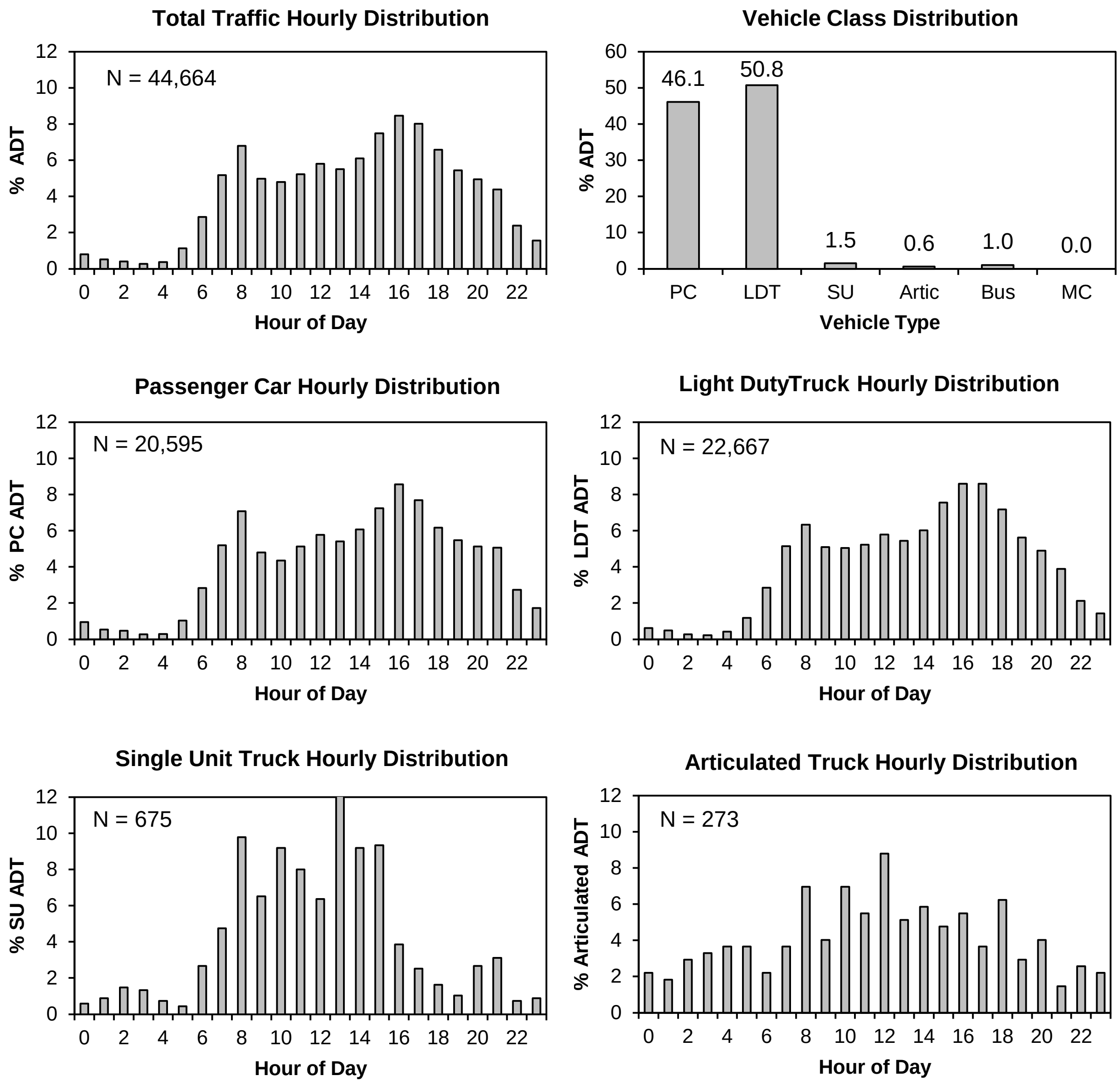


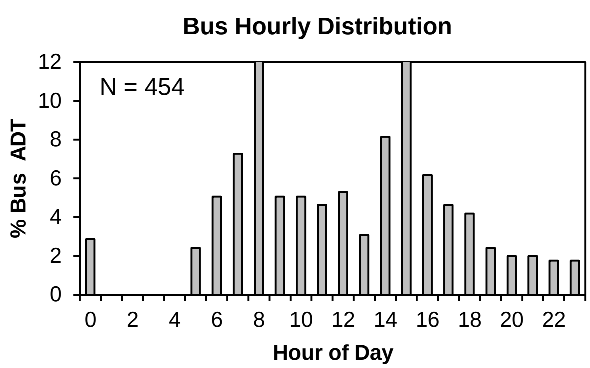


Truck traffic pattern group 3 (TTPG3-YXE) characteristics are derived from a 24-hour video traffic count on 25th Street.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 17: TTPG3-YXE characteristics.

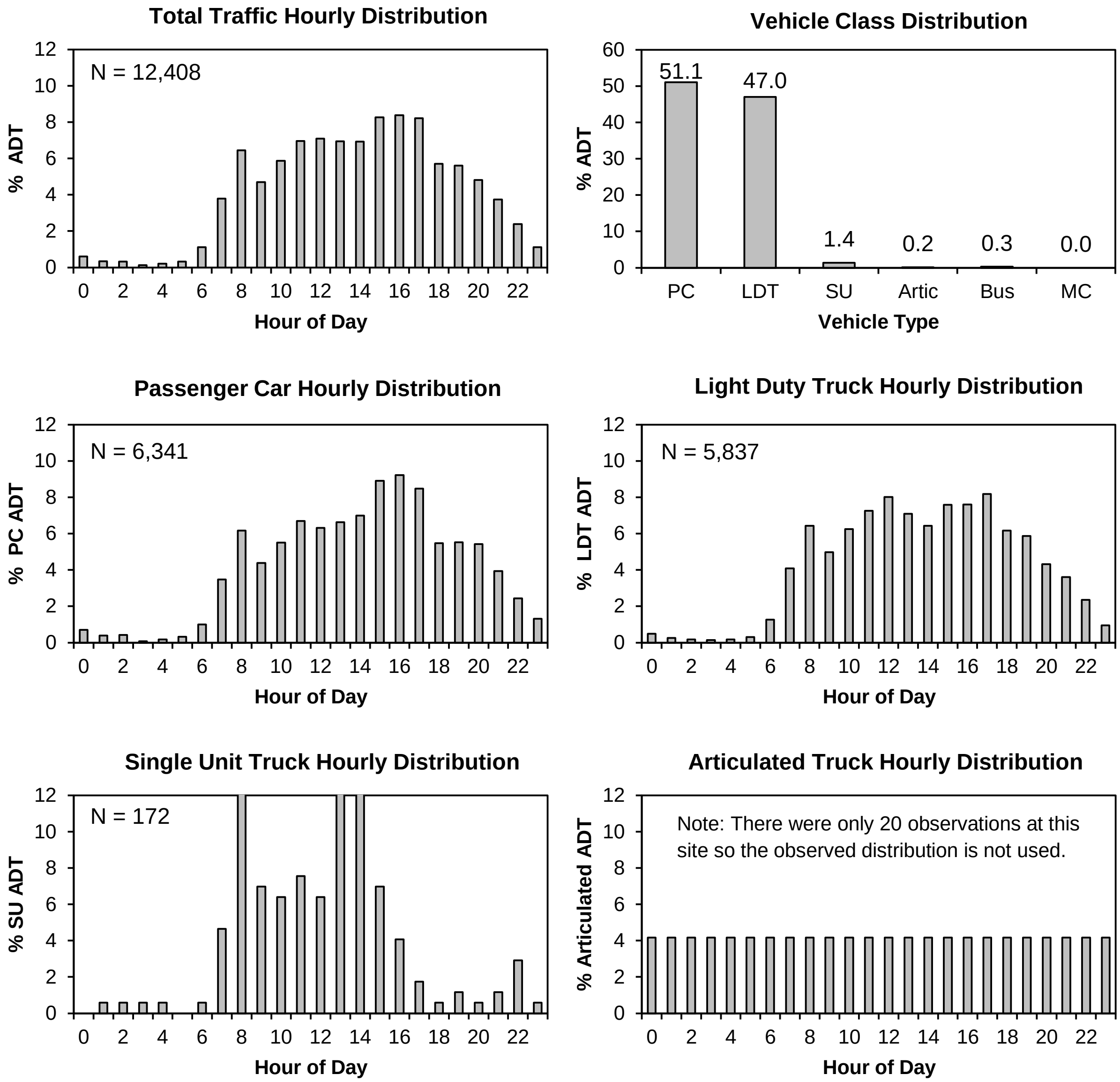


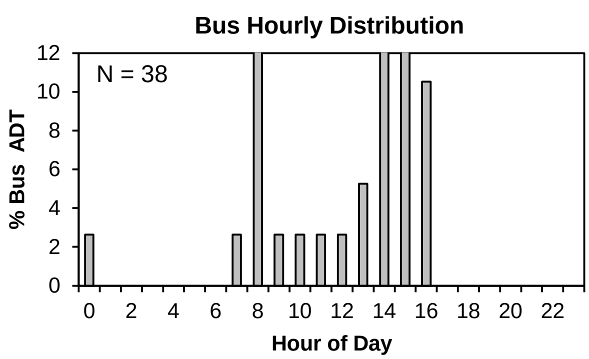


Truck traffic pattern group 4 (TTPG4-YXE) characteristics are derived from a 24-hour video traffic count on 22nd Street.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 18: TTPG4-YXE characteristics.



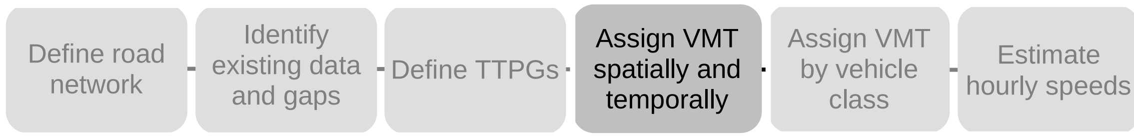


Truck traffic pattern group 5 (TTPG5-YXE) characteristics are derived from a 24-hour video traffic count on Preston Avenue.

ADT – average daily traffic
MC – motorcycle
PC – passenger car
LDT – light duty truck
SU – single unit truck
Artic – articulated truck

Figure 19: TTPG5-YXE characteristics.

3.3.4. Assign VMT Spatially and Temporally



This section describes how VMT is assigned spatially and temporally to the segmented network. VMT estimates on the Emissions Modelling Network for Saskatoon segments are produced using the different data types shown in Table 28, each with different degrees of certainty. VMT is estimated on the EMNS using a scale of 1 to 3, where 1 is the highest level of confidence and 3 is the lowest (the same scale as used for Winnipeg). Level 1 segments are those with vehicle class data by hour (i.e., turning movement count, AVC, or Titan data), there is no such data for Saskatoon. Level 2 segments are those with traffic data, but not by vehicle class (i.e., PCS, CCS, or road tube data). Level 3 segments are those without any traffic data or with data that is disregarded due to insufficient accuracy. For these segments, engineering judgment is applied to assign a traffic volume estimate. Table 30 describes the process and data used in this research to estimate the VMT by hour of day and type of vehicle.

Table 30: Description of Saskatoon data levels.

Road type	Data	Process
Level 1 segments – possess data for volume with temporal, and vehicle-class specificity		
No such data exists for Saskatoon		
Level 2 segments – possess traffic volumes but no temporal or vehicle class specificity		
Freeway Arterial/collector	City of Saskatoon • WIM • PCS • CCS • Road tubes Collected by research • Video counts	1. Calculate total traffic volume on each segment from passenger car equivalent volume 2. Disaggregate daily volumes to hourly volumes by class
Level 3 segments – no traffic data		
Arterial/collector	City of Winnipeg • Road tubes • PM peak model Collected by research • Video counts	1a. Volume Transfer from Adjacent Road Segments 1b. Expand 2009 PM peak traffic volume to total daily volume

3.4.4.1. VMT on Level 2 Segments

Level 2 data segments are those with traffic volumes, but without, temporal, or vehicle class specificity (i.e., those with PCS, CCS, or road tube data). The vehicle class distribution for each TTPG is used to calculate an ADT for each road segment on the EMNS. This is accomplished using four steps: (1) estimating the truck ADT (i.e., single unit, and articulated truck ADT) on each segment, (2) developing and applying axle correction factors to the ADT on each segment to produce an axle corrected ADT, (3) subtracting the truck ADT (calculated in Step 1) from the axle corrected ADT (calculated in Step 2) to produce a non-truck ADT, and (4) estimating the ADT by passenger car, light duty truck, bus, and motorcycle by applying a factor to the non-truck ADT (calculated in Step 3). The result is an ADT estimate for six vehicle classes: passenger car, light duty truck, single unit truck, articulated truck, bus, and motorcycle.

STEP 1: Estimate the truck ADT on each segment

The single unit and articulated truck traffic is assumed to be homogenous across each truck segment on the EMNS. The following example describes the two step process of calculating truck traffic volumes and VMT by vehicle type for each Truck Segment on the Saskatoon network.

Table 31 shows the Road IDs that comprise Truck ID 20100 complete with each Road IDs ADT, length, and daily VMT. The summation of daily VMT is divided by the summation of segment length to arrive at the ADT for the Truck ID. In this example, the ADT for Truck ID 20100 is calculated as follows:

ADT = 23,793 / 0.77 miles = 30,900 vehicles per day.

Table 31: Average daily traffic volume estimation.

Truck ID	Road ID	Average daily traffic	Length (miles)	Daily vehicle miles travelled
20100	11904	26,400	0.18	4,752
	11903	26,400	0.14	3,696
	11895	34,100	0.05	1,705
	11894	34,100	0.21	7,161
	11893	34,100	0.19	6,479
Summation	**-**	**-**	**0.77**	**23,793**

Truck ID 20100 is located on TTPG2. As shown in Figure 16 the vehicle class distribution of TTPG2 is characterized as being 37.9 percent passenger cars, 55.7 percent light duty trucks, 3.1 percent single unit trucks, 2.8 percent articulated trucks, and 0.4 percent buses. Therefore across the entire Truck ID the single unit and articulated truck volumes are:

*Single unit truck ADT = ADT on Truck Segment * percent single unit truck volume*

*= 30,900 * 0.031*

= 958 single unit trucks per day

*Articulated truck ADT = ADT on Truck Segment * percent articulated truck volume*

*= 30,900 * 0.028*

= 865 articulated trucks per day

The summation of these two values is the ADT_{truck}.

STEP 2: Develop and Apply Axle Correction Factors

Axle correction factors are then applied to City of Saskatoon ADT volumes. This is because volume estimates are produced using data from pneumatic road tube counters that only count the number of axles without axle spacing or axle weight data. The devices are programmed with an algorithm that divides the number of axle counts by two to estimate the passenger car equivalent (PCE) volume. However, this overestimates the number of vehicles (e.g., a single four-axle truck is counted as two 2-axle vehicles). This research defines axle correction factors for single unit trucks and articulated trucks to convert PCE volumes to total traffic volumes. Passenger cars, light duty trucks, and buses are defined as 2-axle vehicles in this research. The average number of axles for single unit trucks and articulated trucks is calculated from the WIM station on Circle Drive (as shown in Table 32). Total vehicle volumes are calculated by subtracting PCE truck traffic volumes from the corresponding PCE total traffic volume.

Table 32: Axle correction factors.

Vehicle Type	Average Axles	Passenger Car Equivalents
Passenger car	2	1
Light duty truck	2	1
Single unit truck	2.42	1.21
Articulated truck	5.22	2.61
Bus	2	1
Motorcycle	2	1

Note: average axles for passenger cars, light duty trucks and buses is assumed to be 2. Average axles for the other vehicles are calculated from WIM data on Circle Drive.

Road ID 11904 from 51st Street is used to illustrate how the axle corrected total traffic volumes are calculated. As shown earlier, the total daily truck traffic for this Road ID consists of 958 single unit trucks and 865 articulated trucks. Using the following equation, the $ADT_{corrected}$ is 24,806 (instead of 26,400 as estimated by pneumatic counters).

$$ADT_{PCE} = ADT_{corrected} - (\text{single unit truck volume} * 1.21\ PCE) - (\text{articulated truck volume} * 2.61\ PCE) + \text{single unit truck volume} + \text{articulated truck volume}$$

$$ADT_{corrected} = 26{,}400 - (958 * 1.21) - (865 * 2.61) + 958 + 865$$

$$ADT_{corrected} = 24{,}806$$

STEP 3: Calculate Non-Truck ADT

The $ADT_{non\text{-}truck}$ is the ADT_{PCE} minus the ADT_{truck}. Continuing with the example, the sample calculations are as follows:

$$ADT_{non-truck} = ADT_{PCE} - ADT_{truck}$$

$$= 24{,}806 - 958 - 865$$

$$= 22{,}983$$

STEP 4: Calculate Passenger Car, Light Duty Truck, Bus, and Motorcycle ADT

The passenger car, light duty truck, bus, and motorcycles ADT is assumed to be homogenous across each road segment on the EMNS. As shown earlier, the non-truck traffic for Road ID 11904 is 22,983. Table 33 shows the percent of non-truck ADT for TTPG2.

Table 33: TTPG2 non-truck percent of ADT.

Vehicle Type	TTPG2 Percent of total TTPG ADT	TTPG2 Percent of non-truck ADT
Passenger car	37.90	40.32
Light duty truck	55.70	59.25
Bus	0.40	0.43
Motorcycle	0.00	0.00
TOTAL	**94.00**	**100.00**

TTPG – truck traffic pattern group
ADT – average daily traffic

Using the following equation, the $ADT_{passenger\ car}$ is 9,267. Similar calculations are completed for light duty trucks, buses, and motorcycles.

$$ADT_{Passenger\ car} = ADT_{non-truck} * \text{passenger car percent of non-truck ADT}$$

$$= 22{,}983 * 0.4032$$

$$= 9{,}267$$

3.4.4.2. *VMT on Level 3 Segments*

Level 3 segments are those without any traffic data or those with solely peak flow estimates. For these segments, engineering judgement is applied to assign a traffic volume estimate. Two methods are used to assign traffic volumes to segments without a volume so that all segments on the EMNS have an ADT estimate: (1) volume transfer from adjacent Road IDs, and (2) total daily volume expansion from the 2009 PM Peak Flow Volumes via Matrix Correction Map (City of Saskatoon, 2010b)

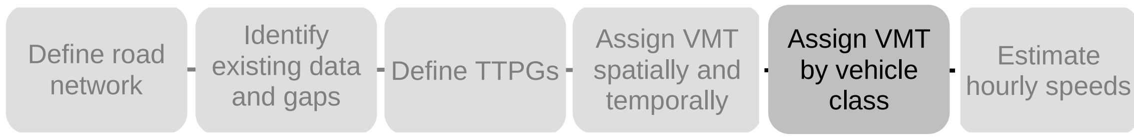
Volume Transfer from Adjacent Road Segments

A truck segment comprises several consecutive Road Segments. If one of these Road Segments does not have an ADT, then the ADT from an adjacent Road Segment within the same truck segment is transferred. For this research, there are 45 road segments (a total of 8.4 centreline miles) that have an ADT assigned using this method.

Total Daily Volume Expansion from the 2009 PM Peak Traffic Volume Map

The City of Saskatoon has developed the 2009 PM Peak Traffic Volume Map (City of Saskatoon, 2010b) which provides the PM peak flows on the Saskatoon roadway network. This research estimates ADT on 17 Road IDs (a total of 4.2 centreline miles) on the EMNS by expanding the PM peak flow to produce an average daily traffic volume. For instance, if a road segment exhibits a volume of 2,000 during the PM peak period, and nine percent of the ADT on this segment occurs during this period, then the ADT is calculated to be 22,222 (2000/0.09). The proportion of ADT occurring during the PM peak period is derived from the Saskatoon truck traffic pattern group characteristics.

3.3.5. Assign VMT by Vehicle Class



This section describes the process of calculating VMT for each of the vehicle classes required by MOBILE6.2C. Traffic data sources available for this research classify vehicles differently than MOBILE6.2C, and therefore require conversion prior to generating VMT inputs. The data collected from video cameras in this research uses six vehicle classes (Figure 20 illustrates examples of each of these vehicle classes), and MOBILE6.2C uses either 16 or 28 vehicle classes depending on the specific input.

	Motorcycle
	Passenger car
	Light duty truck
	Single unit truck
	Articulated truck
	Bus

Figure 20: Saskatoon classification scheme.

Environment Canada provided VMT distribution tables for the MOBILE6.2C vehicle classes. These tables are produced using vehicle registration data from the province of Saskatchewan and mileage accumulation rates for each of these vehicles to properly weight the percentage that each vehicle type contributes to the entire Saskatchewan VMT. Table 34 shows the fractions of Saskatchewan VMT by vehicle class for 16 vehicle classes, the percentage of VMT for the individual vehicle classes sum to 100 percent.

Table 34: Saskatchewan VMT percentages by vehicle class using the MOBILE6.2C 16 classes.

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
35.24	2.08	19.03	11.84	12.49	4.68	1.38	0.27
Class 9	**Class 10**	**Class 11**	**Class 12**	**Class 13**	**Class 14**	**Class 15**	**Class 16**
0.10	01.34	0.96	1.48	7.96	0.10	0.66	0.39

Sum = 100 %
Source: Environment Canada

Prior to this research, it was necessary to use Table 34 to disaggregate Saskatoon's total traffic VMT to MOBILE6.2C vehicle classes. This assumes that the vehicle fleet mix in Saskatoon is identical to that in Saskatchewan as a whole. The vehicle activity data produced by this research demonstrates that this assumption is incorrect and can lead to erroneous fleet mix estimates and consequently different emissions estimates. For example, traffic data obtained through this research indicates that Class 1 vehicles represent 52 percent of the fleet as opposed to 35 percent as shown in Table 34.

This research considers the jurisdictionally-specific vehicle classes (i.e., Saskatoon vehicle fleet mix) by collecting hourly traffic data for six vehicle classes, however it is not possible to properly classify vehicles to the specificity required by MOBILE6.2C. The methodology developed in this research disaggregates total traffic VMT to six classes and matches MOBILE6.2C classes to these (as shown in Table 35).

Table 35: MOBILE6.2C vehicle class equivalents for Saskatoon.

Saskatoon Research Classes	MOBILE6.2C Vehicles Class Number	Abbreviation	Description
Passenger car	1	LDV	Light-Duty Vehicles
Light Duty Trucks	2	LDT1	Light-Duty Trucks 1
	3	LDT2	Light-Duty Trucks 2
	4	LDT3	Light-Duty Trucks 3
	5	LDT4	Light-Duty Trucks 4
	6	HDV2B	Class 2B Heavy-Duty Vehicles
Single Unit Trucks	7	HDV3	Class 3 Heavy-Duty Vehicles
	8	HDV4	Class 4 Heavy-Duty Vehicles
	9	HDV5	Class 5 Heavy-Duty Vehicles
	10	HDV6	Class 6 Heavy-Duty Vehicles
	11	HDV7	Class 7 Heavy-Duty Vehicles
	12	HDV8A	Class 8A Heavy-Duty Vehicles
Articulated Trucks	13	HDV8B	Class 8B Heavy-Duty Vehicles
Buses	14	HDBS	School Buses
	15	HDBT	Transit and Urban Buses
Motorcycles	16	MC	Motorcycles

The percentages of MOBILE6.2C in Table 34 are used to disaggregate the six vehicle classes to the corresponding MOBILE6.2C 16 classes. To illustrate the conversion process, an example of converting light duty trucks to MOBILE6.2C classes is provided. Consider an hourly count with 200 light duty trucks. Light duty trucks correspond to MOBILE6.2C classes 2 through 6 (as shown in Table 35). MOBILE6.2C classes 2 through 6 sum to 50.12 percent of Saskatchewan VMT (as shown in Table 34). Each MOBILE6.2C vehicle class fraction is divided by the sum of the corresponding classes (50.12 percent) and then multiplied by the light duty truck volume (200 veh/day). Table 36 shows the calculations needed for this hypothetical example.

Table 36: Example class conversion calculation to MOBILE6.2C classes.

Saskatoon Research Vehicle Class	Volume (veh/day)	MOBILE6.2C Vehicle Class	Fraction of Saskatchewan VMT	Percent of light duty truck VMT	Volume (veh/day)
Light Duty Truck	200	LDT1	0.0208	*4	8
		LDT2	0.1903	38	76
		LDT3	0.1184	24	48
		LDT4	0.1249	25	50
		HDV2B	0.0468	9	18
Total	**200**		**0.5012**	**100**	**200**

* 4 percent = 0.0208/0.5012

$$\text{MOBILE6.2C LDT1 volume} = \frac{MOBILE6.2C\ LDT1\ fraction}{Sum\ of\ MOBILE6.2\ Fractions\ within\ Vehicle\ Class} \text{ x light duty truck volume}$$

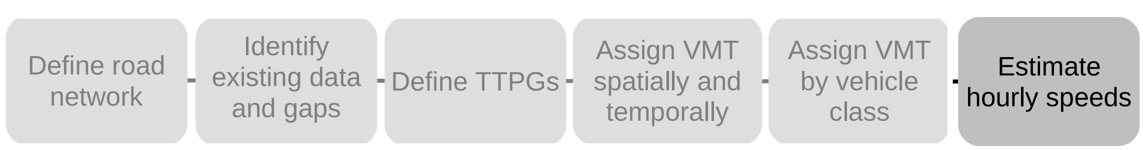
$$\text{MOBILE6.2C LDT1 volume} = \frac{0.0208}{0.5012} \text{ x } 200 = 8 \text{ LDT1 vehicles per day}$$

As Table 36 shows, the light duty truck classification is disaggregated into 4 percent LDT1, 38 percent LDT2, 24 percent LDT3, 25 percent LDT4, and 9 percent HDV2B. Table 37 is a conversion table that illustrates the relationships between the Saskatoon research classes and MOBILE6.2C vehicle classification schemes.

Table 37: Conversion to MOBILE classification scheme for Saskatoon.

MOBILE Vehicle Type		Saskatoon Research Vehicle Type Percent					
Vehicle Class	Abbreviation	LDV	LDT	SU Truck	Articulated Truck	Bus	Motorcycle
1	LDV	100					
2	LDT1		4.16				
3	LDT2		37.97				
4	LDT3		23.62				
5	LDT4		24.91				
6	HDV2B		9.34				
7	HDV3			24.92			
8	HDV4			4.86			
9	HDV5			1.75			
10	HDV6			24.21			
11	HDV7			17.47			
12	HDV8A			26.79			
13	HDV8B				100		
14	HDBS					13.66	
15	HDBT					86.34	
16	MC						100
	All	100	100	100	100	100	100

3.3.6. Estimate Hourly Speeds



This section describes the process to estimate hourly speeds on the Emissions Modelling Network for Saskatoon. The Bureau of Public Roads method is used to estimate travel speed by hour for each segment. The procedure described in Section 3.3.4 (Assign VMT Spatially and Temporally) estimate VMT by segment and hour. Summing the VMT for all segments with the same speed produces VMT by speed by hour.

Each TTPG on the network is assigned to a road class as defined by the Highway Capacity Manual (Transportation Research Board, 2000). The road classes in the Highway Capacity Manual (HCM) are defined using 14 road characteristics (e.g., number of lanes, signal density, and posted speed limit). For each of the TTPGs, default values for practical capacity (practical capacity is defined as 80 percent of the maximum capacity), signal density, average signal cycle length, and effective green ratio (average per signal) are selected from the HCM and used in the BPR speed equations. These default values are shown in Table 38 and Table 39. Attribute data provided by COS for each Road ID is used for the, posted speed limit, and segment length.

Table 38: Highway capacity manual default values to estimate free flow speed.

	TTPG1-YXE*	TTPG2-YXE	TTPG3-YXE	TTPG4-YXE	TTPG5-YXE
Signal Density (sig/mi)	-	3.2	9.6	.8	6.4
Cycle Length (seconds)	-	90	70	110	80
Effective green ratio	-	0.45	0.45	0.45	0.45

Source: Transportation Research Board (2000)
TTPG-YXE - Truck traffic pattern group for Saskatoon
* this TTPG is a freeway and does not require these default values to estimate free flow speed

Table 39: Maximum and practical capacity volumes.

Number of Lanes	Maximum Capacity (veh/h) [Practical Capacity]				
	TTPG1-YXE	TTPG2-YXE	TTPG3-YXE	TTPG4-YXE	TTPG5-YXE
1	1110 [890]	860 [690]	790 [630]	1110 [890]	840 [670]
2	2120 [1700]	1650 [1320]	1520 [1220]	2120 [1700]	1610 [1290]
3	3040 [2430]	2370 [1900]	2180 [1740]	3040 [2430]	2310 [1850]
4	4060 [3250]	3190 [2550]	2900 [2320]	4060 [3250]	3080 [2460]

Source: Transportation Research Board (2000)
TTPG-YXE - Truck traffic pattern group for Saskatoon

This research calculates the average speed for each hour on each segment using the BPR equations and HCM default values. A MOBILE6.2C speed bin is assigned to each hour of each road segment based on the average speed calculated using the BPR procedure. VMT estimates are aggregated by speed bin and by hour to produce a VMT by speed for each hour.

4. DATA ANALYSIS AND RESULTS

This chapter provides VMT estimates by vehicle class, VMT by hour, and example tables of VMT by road facility type and VMT by speed. A comparison is provided between the emissions estimates using locally developed vehicle activity inputs and the MOBILE6.2C (U.S. based) default inputs. This chapter then provides the results of the emissions estimate for the Winnipeg and Saskatoon using the MOBILE6.2C model and provides a comparison to an estimate produced using default vehicle activity inputs.

4.1. VMT ESTIMATES FOR EMISSIONS MODELLING

This section provides the vehicle miles travelled (VMT) estimates produced by this research and compares them to MOBILE6.2C defaults. Specifically, this section provides VMT estimates by vehicle class, VMT by hour, VMT by road facility type, and VMT by speed.

4.1.1. VMT by Vehicle Class

The VMT fractions command in MOBILE6.2C requires the proportion of network VMT accumulated by each of the MOBILE6.2C 16 vehicle classes. These proportions are independent of road facility type, hour of day, and speed. Table 40 illustrates the differences between the default values used by MOBILE6.2C and the fraction of total vehicle class VMT developed in this research.

Figure 21 groups the 16 vehicle classes in Table 40 into five more encompassing vehicle classes identified in this research (passenger cars, light duty trucks, single unit trucks, articulated trucks, and buses).

Table 40: VMT by vehicle class.

Vehicle Class	Abbreviation	Winnipeg Fraction of Total VMT	Saskatoon Fraction of Total VMT	MOBILE6.2C Default Fraction
1	LDV	0.5421	0.5188	0.4096
2	LDT1	0.0213	0.0185	0.0797
3	LDT2	0.2029	0.1688	0.2654
4	LDT3	0.0863	0.1050	0.0818
5	LDT4	0.0787	0.1107	0.0376
6	HDV2B	0.0213	0.0415	0.0387
7	HDV3	0.0036	0.0049	0.0038
8	HDV4	0.0009	0.0010	0.0031
9	HDV5	0.0005	0.0003	0.0023
10	HDV6	0.0046	0.0048	0.0086
11	HDV7	0.0041	0.0035	0.0102
12	HDV8A	0.0068	0.0053	0.0111
13	HDV8B	0.0220	0.0123	0.0396
14	HDBS	0.0006	0.0006	0.0020
15	HDBT	0.0041	0.0038	0.0009
16	MC	0.0002	0.0002	0.0056
	Total	1.0000	1.0000	1.0000

Source of default values: U.S. Environmental Protection Agency (2004)
Winnipeg values: developed in this research
Saskatoon values: developed in this research

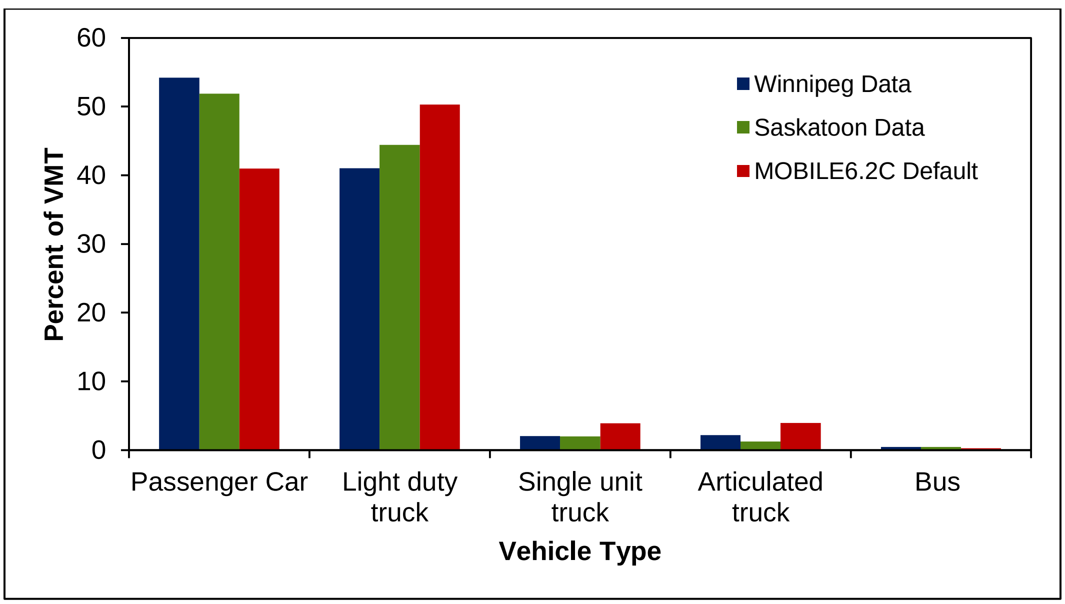


Figure 21: Percent of VMT by vehicle type.

Note: Passenger car includes: Vehicle class 1 from Table 40
Light duty truck includes: Vehicle classes 2, 3, 4, and 5 from Table 40
Single unit truck includes: Vehicle classes 6 through 12 from Table 40
Articulated truck includes: Vehicle class 13 from Table 40
Bus includes: Vehicle classes 14 and 15 from Table 40

The Winnipeg Emissions Modelling Network and Emissions Modelling Network for Saskatoon experience a higher percentage of passenger car volumes than the default values (54 and 52 percent in Winnipeg and Saskatoon respectively, versus 41 percent in MOBILE6.2C) and a lower percentage of light duty trucks (LDT1, LDT2, LDT3, and LDT4, and HDV2B) than the default values (41 and 44 percent in Winnipeg and Saskatoon respectively, versus 50 percent in MOBILE6.2C). The research shows differences in VMT by class between MOBILE6.2C defaults and those calculated for Winnipeg and Saskatoon. Consequently, emissions estimates using defaults or VMT from this research are also different.

For passenger cars and light duty trucks the Transportation Research Board (2011b) discusses increasing energy efficiency of vehicles and diversifying fuel supplies as likely opportunities to reduce emissions. For single unit and articulated trucks the Transportation Research Board (2011b) discusses accelerating the development and introduction of fuel saving truck designs and technologies, diversifying the fuel supply to reduce diesel consumption, increasing energy efficiency in engine standards. To measure the effects of these emission reduction strategies it is critical to have accurate estimates of the VMT contributed by each of these vehicle types.

The method developed in this research provides spatially detailed traffic volumes by vehicle type. This resulted in the first-ever single unit and articulated truck traffic volume maps for Winnipeg, and Saskatoon. Examples illustrating the single unit truck and articulated truck traffic flow map for Winnipeg are shown in Figure 22 and Figure 23, respectively. Examples illustrating the single unit truck and articulated truck traffic flow map for Saskatoon are shown in Figure 24 and Figure 25, respectively. This information can be used by engineers to evaluate environmental impacts, traffic growth patterns, the performance of a transportation system, and to design geometry and pavement (AASHTO, 2009).

These maps were produced for total traffic volumes and volume for each vehicle type. The maps were used as a system wide reasonableness check to ensure the methodology produced realistic volumes.

4.1.2. VMT by Road Facility Type

VMT by road facility type requires the fraction of total VMT on each facility type by hour of the day and vehicle class. This requires assigning VMT on the network to a facility type by the 28 vehicle classes for each hour of the day. This research considers three road facility types: freeway, arterial/collector, and freeway ramps (only for Saskatoon). These VMT estimates are independent of speed.

For each hour the proportion of VMT occurring on each road type is a function of the network definition. Including varying amounts of freeways or arterials in the defined network varies the total proportion of VMT occurring on each of these facility types. Differences in these figures from the default values do not necessarily represent a difference in traffic patterns, rather they represent a difference in the network that the vehicles are operating on.

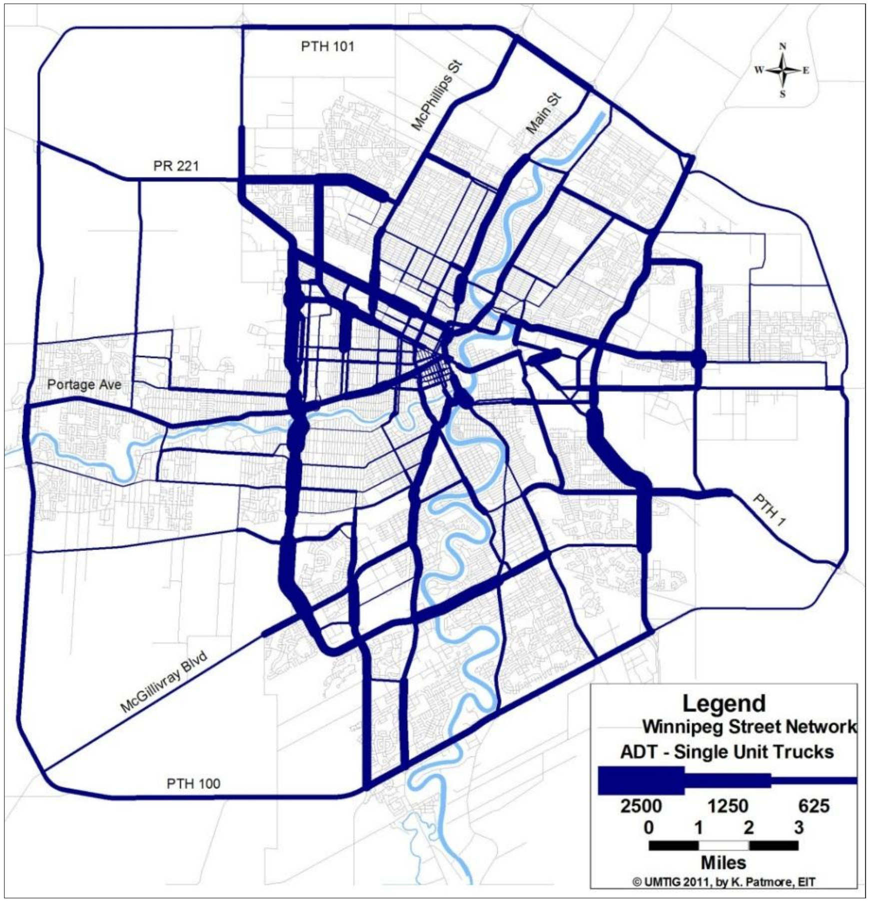


Figure 22: Single unit truck traffic flow map for Winnipeg.

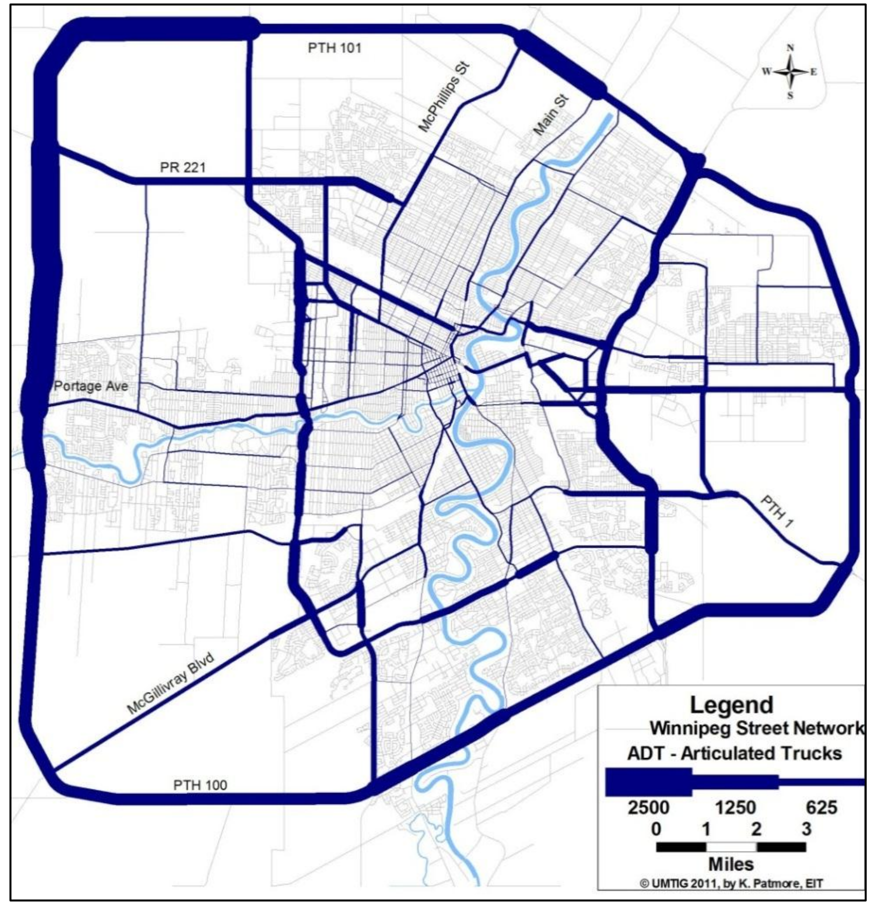


Figure 23: Articulated truck traffic flow map for Winnipeg.

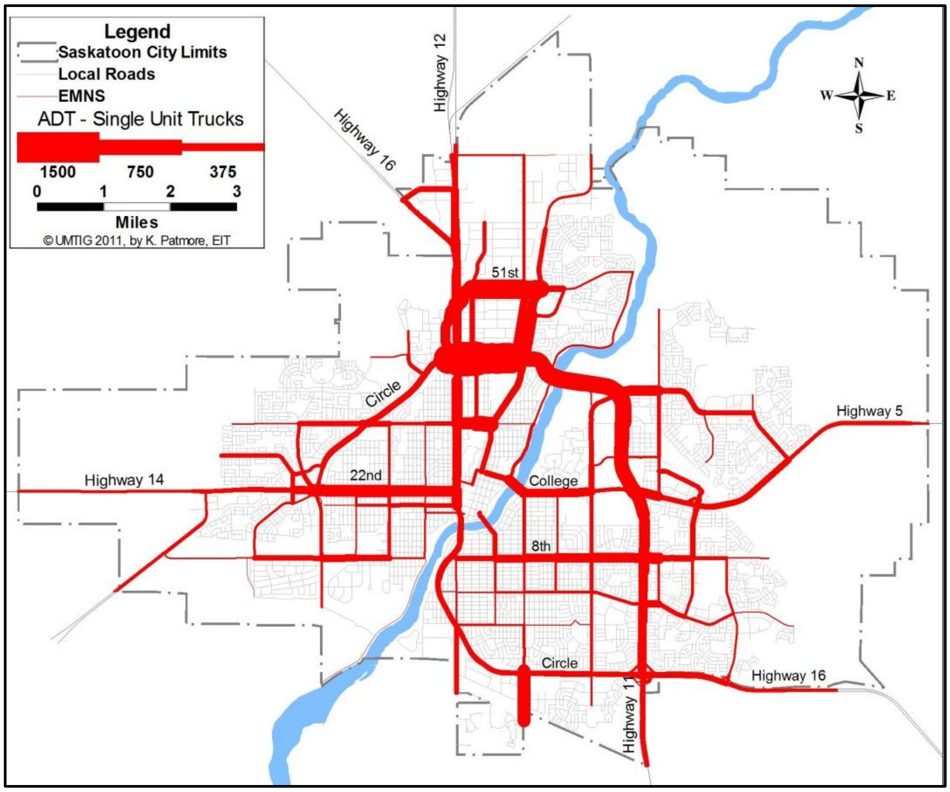


Figure 24: Single unit truck traffic flow map for Saskatoon.

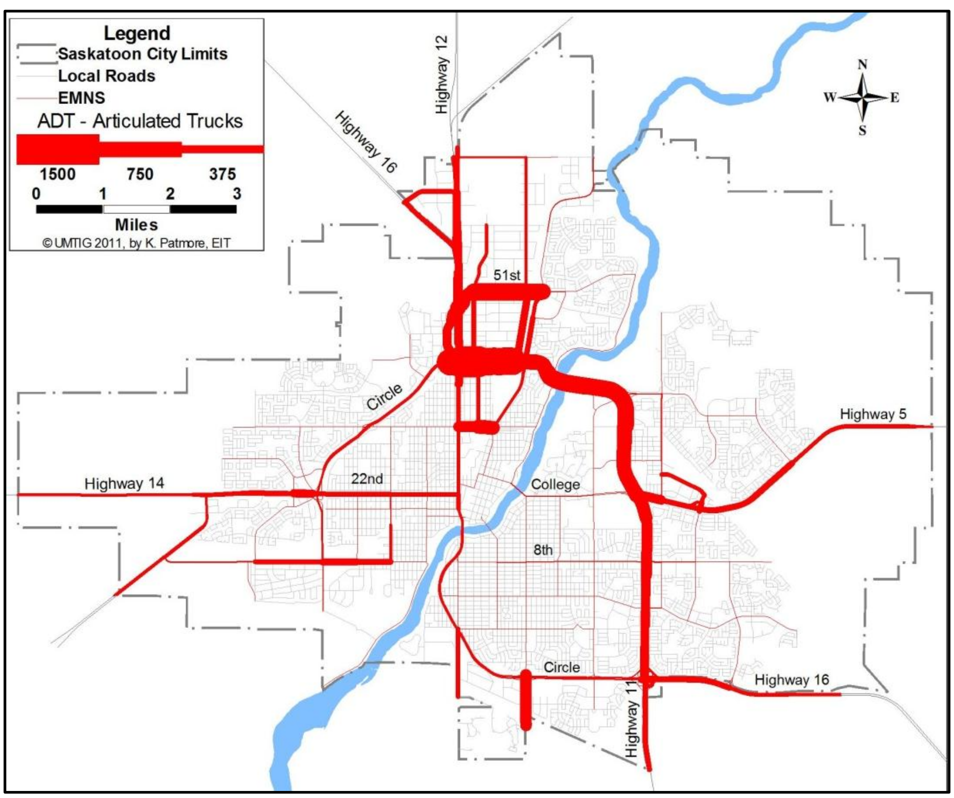


Figure 25: Articulated truck traffic flow map for Saskatoon.

The MOBILE6.2C input for this command is a 28 by 96 matrix. There are 28 columns representing the 28 vehicle classes and 96 rows representing an hourly VMT fraction for four road facility types (freeway, arterial/collector, local, freeway ramp). In this research local VMT and freeway ramp VMT is not estimated for Winnipeg, and the VMT for these facility types is zero. In this research local VMT is not estimated for Saskatoon, and the VMT for these facility types is zero. Figure 26 and Figure 27 illustrate the difference between VMT by hour produced by this research and MOBILE6.2C defaults for passenger cars on freeways and arterials, respectively. The figures show that, for passenger cars, Saskatoon VMT is similar to the default values, however Winnipeg VMT exhibits a higher proportion of arterial and lower proportion of freeway VMT. For each hour, the percent of VMT for each hour sums to 100 percent for each of the roadways. For example, in Winnipeg for the hour beginning at 00:00 approximately 16 percent of the passenger car hourly VMT occurs on freeways and 84 percent occurs on arterials.

This research collects roadway specific data for six vehicle classes (passenger cars, light duty trucks, single unit trucks, articulated trucks, buses, and motorcycles) and is therefore able to produce a unique percent of hourly VMT experienced on freeways for each of these classes. MOBILE6.2C default values use the same percent of hourly VMT experienced on freeways and arterials for all vehicle classes. For each vehicle class it is important to have an accurate percentage of VMT assigned to freeway and arterial roadways because the speeds that are assigned to each of these roadway types are different.

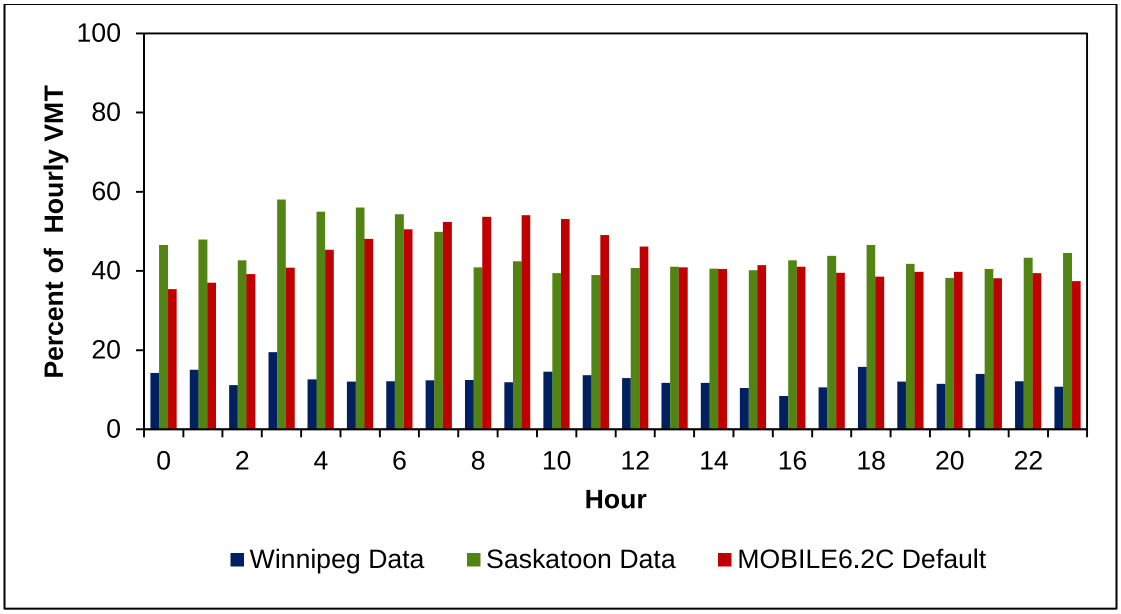


Figure 26: Passenger car percent of total hourly VMT on freeways.
Default values adapted from: U.S. Environmental protection Agency (2004)
Values are shown normalized to not include any local or freeway ramp VMT

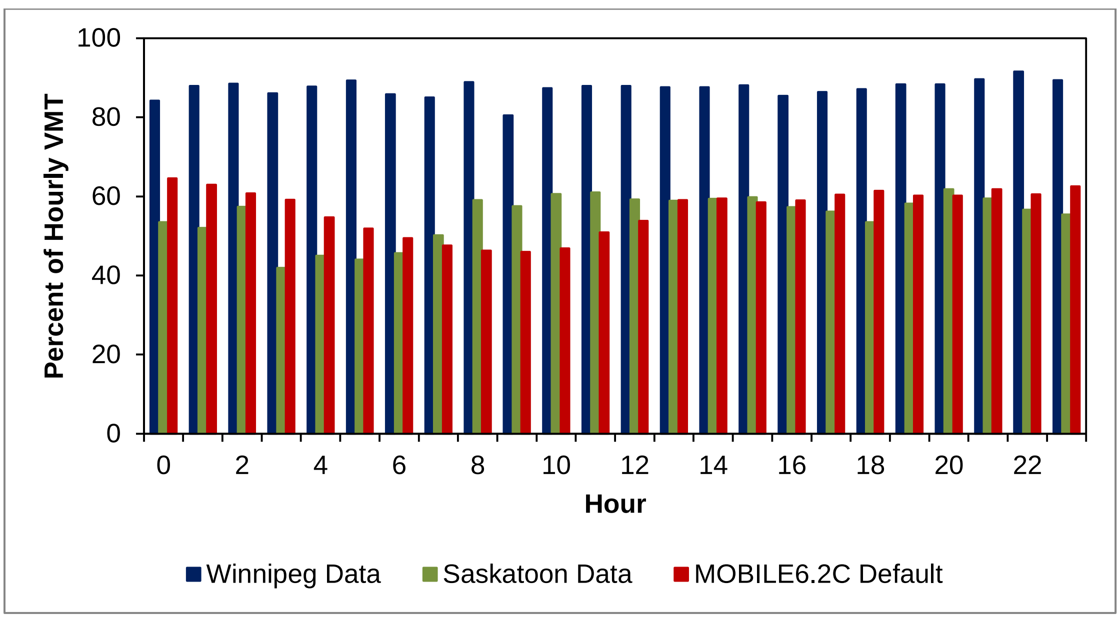


Figure 27: Passenger car percent of total hourly VMT on arterials.
Default values adapted from: U.S. Environmental protection Agency (2004)
Values are shown normalized to not include any local or freeway ramp VMT

Figure 28 illustrates the difference for four other classes (motorcycles are not shown because their VMT on the network is less than 0.03 percent of the total) for which this research develops a unique percent of hourly VMT by roadway. The figure shows that, for light duty trucks, Winnipeg VMT exhibits a higher proportion of arterial and lower proportion of freeway VMT. Saskatoon VMT is more similar to the default values, however similar to Winnipeg, there is less VMT on freeways and more on arterials compared to the default values. For single unit trucks Winnipeg VMT exhibits a higher proportion of arterial and lower proportion of freeway VMT, while the Saskatoon data is similar to the MOBILE6.2C default values. For articulated trucks Winnipeg and Saskatoon VMT estimates both show a greater percent of the hourly VMT occurring on freeways than the MOBILE6.2C default values and a lesser percent occurring on arterials. This is indicative of the different types of roadways that are planned and developed in different cities. Winnipeg does not have any freeways other than the Perimeter Highway, therefore assigning the MOBILE6.2C default distribution of approximately 40 percent of VMT occurring at each hour to the freeway road type is inaccurate.

4.1.3. VMT by Hour

VMT by hour requires the total VMT for each of the 24 hours of the day, independent of vehicle class, road facility type, and speed. This requires assigning total VMT on the network to each hour of the day. The input for this command is a 1 by 24 matrix with each row representing the VMT distribution by hour; the percent of VMT for the 24 hours sums to 100 percent. Figure 29 represents the temporal distribution of traffic for each hour of the day.

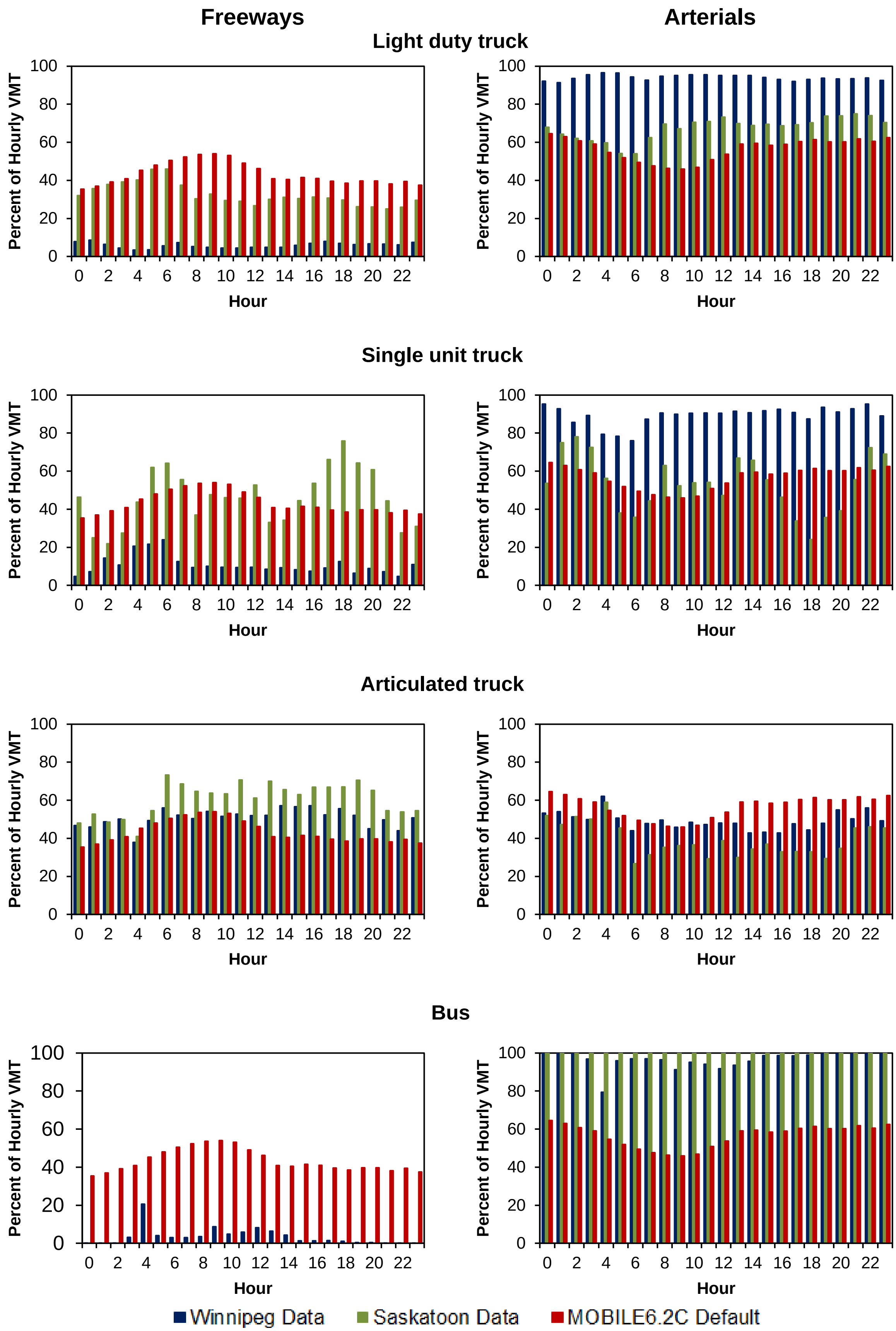


Figure 28: Percent of total hourly VMT by road type (Freeways on left; Arterials on right).

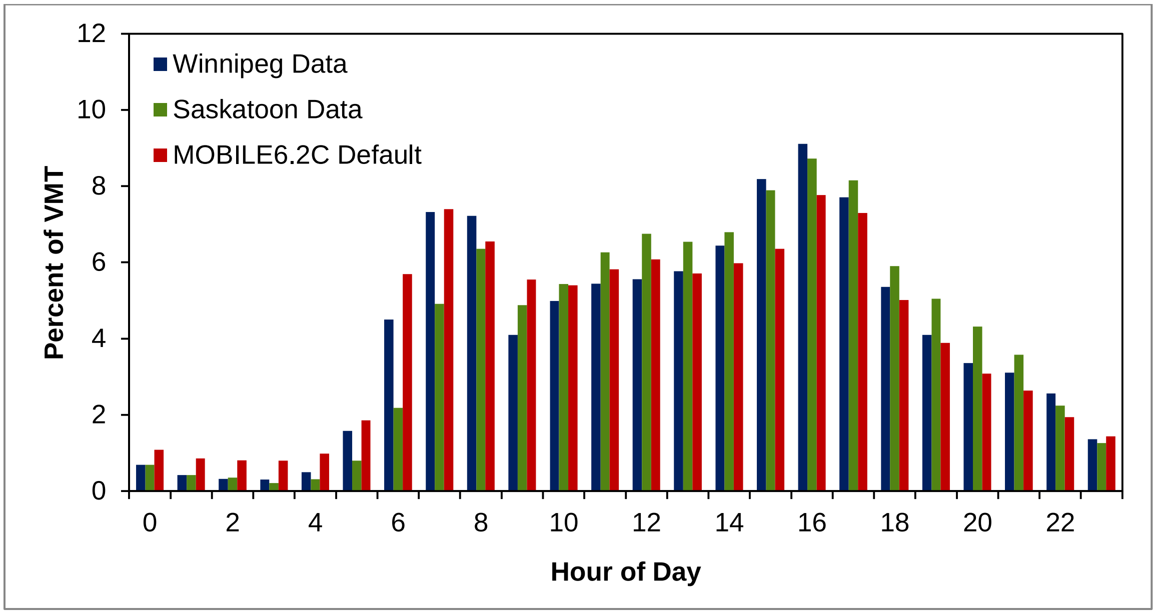


Figure 29: Percent of VMT by hour.

The figure shows that both Winnipeg and Saskatoon experience a higher percentage of total VMT during the PM peak period (15:00 to 18:00) compared to the MOBILE6.2C default percentages. The opposite occurs between 00:00 and 06:00 when Winnipeg and Saskatoon experience a lower fraction of total VMT compared to the default. This affects emissions estimates since environmental conditions (such as hourly temperature and relative humidity) are different during these hours and can influence vehicle emission impacts.

4.1.4. VMT by Speed

VMT by speed requires the average speed on freeways and arterial/collector roadways independent of vehicle class. The input for this command is a 48 by 14 matrix. The 48 columns represent each hour of the day for two road facility types (freeways and arterials/collectors) and the 14 rows represent each MOBILE6.2C speed bin. Figure 30 and Figure 31 show examples of the percentage of VMT by average speed for the hour starting at 08:00 for freeways and arterials, respectively. Appendix A shows similar distributions for other 23 hours of the day.

Figure 30 illustrates that freeway speeds are higher on the WEMN and the EMNS than those provided by the MOBILE6.2C freeway default values. On the WEMN and EMNS freeway, 80 percent of vehicles travel faster than 57.5 mph (compared to 45 percent as the default). This may be reflective of the different functions of these types of roadways in Canada and the U.S.

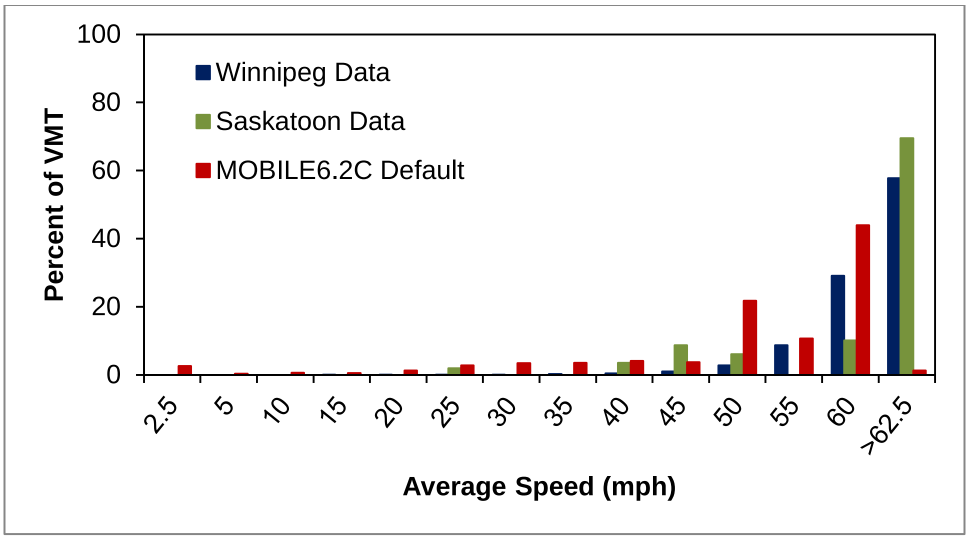


Figure 30: Freeway VMT percent by speed for 08:00.

Figure 31 illustrates that arterial speeds are lower on the WEMN and the EMNS than those provided by the MOBILE6.2C arterial default values. On WEMN and EMNS arterials/collectors approximately 75 percent of vehicles travel slower than 32.5 mph (compared to the default of 47 percent).

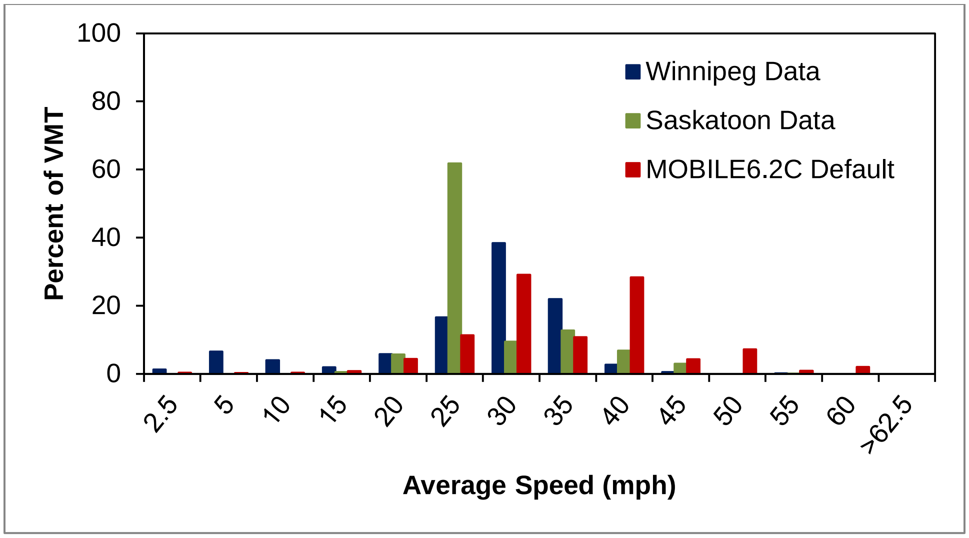


Figure 31: Arterial VMT percent by speed for 08:00.

4.2. EMISSIONS ESTIMATES

This section provides the results of the emissions estimate for Winnipeg and Saskatoon using the MOBILE6.2C model and provides a comparison to the estimate produced using default vehicle activity inputs. A summary of the emissions is discussed for volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2), and particulate matter ($PM_{2.5}$ and PM_{10}). MOBILE6.2C outputs a spreadsheet detailing the grams per mile (g/mi) emission rate for each pollutant produced for each of the vehicle types. The emission rates are multiplied by the VMT estimates produced by this research to generate total on-road emissions.

Appendix B includes a MOBILE6.2C input file and output file showing the results.

4.2.1. Winnipeg Emissions Estimates

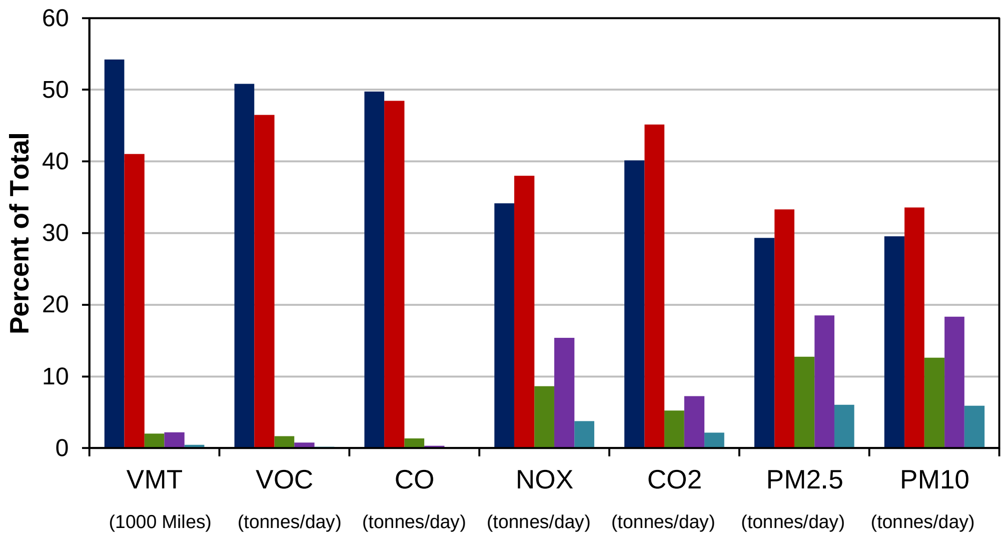
The daily VMT on the WEMN is 6,643,000, resulting in 2,425 million annual vehicle miles travelled (this is the daily VMT multiplied by 365). Table 41 shows the daily and annual emission estimates in tonnes.

Table 41: Summary of emission estimates for Winnipeg in 2006.

	VOC	CO	NO_x	CO_2	$PM_{2.5}$	PM_{10}
Daily tonnes	13.1	189.9	14.9	3310	1.44	1.60
Annual tonnes	4,774	69,297	5,434	1,208,022	526	582

These estimates are for freeways, and arterial/collectors on the Winnipeg Emissions Modelling Network produced using the MOBILE6.2C model (daily VMT 6.643 million).

Figure 32 shows the absolute emissions contribution from six aggregated vehicle types (Passenger car, light duty truck, single unit truck, articulated truck, bus, and motorcycle) and as a percentage of the total emission estimate.



	VMT (1000 Miles)	VOC (tonnes/day)	CO (tonnes/day)	NOX (tonnes/day)	CO2 (tonnes/day)	PM2.5 (tonnes/day)	PM10 (tonnes/day)
Passenger car	3601	6.65	94.43	5.08	1329	0.42	0.47
Light duty truck	2728	6.08	91.98	5.66	1494	0.48	0.54
Single unit truck	136	0.22	2.58	1.29	174	0.18	0.20
Articulated truck	146	0.10	0.64	2.29	240	0.27	0.29
Bus	31	0.03	0.21	0.56	72	0.09	0.09
Motorcycle*	1	<0.01	0.03	<0.01	<1	<0.01	<0.01
Total	**6643**	**13.08**	**189.87**	**14.89**	**3310**	**1.44**	**1.60**

Figure 32: Emission by vehicle type for Winnipeg in 2006 by percent of total vehicle emissions (top) and by absolute vehicle emissions (bottom).

* Motorcycle emissions are not shown in the percent of total graph because they make up less than 0.02 percent of all categories. These estimates are for freeways and arterial/collectors on the Winnipeg Emissions Modelling Network.

Figure 32 reveals the following:

- Passenger cars are the largest contributor to VMT (54 percent of total); however they only have the largest emission contribution to VOC and CO. They are most underrepresented in PM contribution (approximately 29 percent of total).
- Light duty trucks are the second largest contributor to VMT (41 percent of total), and are the largest contributor to NO_x, CO_2, PM emissions.
- Single unit trucks, articulated trucks, and buses contribute 2 percent, 2.2 percent, and 0.5 percent, respectively, to VMT. They are all overrepresented in their contribution to NO_x, CO_2, and PM emissions relative to their VMT. Articulated trucks exhibit the largest overrepresentation, although they only contribute 2.2 percent of the total VMT, they contribute approximately 15 percent of the total NO_x, 7 percent of the total CO_2, and 18 percent of the total PM.

4.2.2. Comparison of Emissions Estimates Using Winnipeg Data versus MOBILE6.2C Default Data

This section provides a comparison of the MOBILE6.2C emissions estimates produced using: (1) Winnipeg vehicle activity inputs produced by this research, and (2) MOBILE 6.2C default vehicle activity inputs. In both cases, ambient condition and vehicle fleet characteristic data provided by Environment Canada are used.

Table 42 provides a summary of the daily emission estimates on the WEMN from the vehicle activity inputs developed in this research and default inputs. The default inputs produce larger tonne per day emissions for all emissions except carbon monoxide (CO).

Table 42: Comparison of emission estimates for Winnipeg in 2006.

	VOC	CO	NO_X	CO_2	$PM_{2.5}$	PM_{10}
Winnipeg vehicle activity	13.1	189.9	14.9	3310	1.44	1.60
MOBILE default vehicle activity	12.3	177.5	17.3	3657	1.87	2.07
Percent difference	-7	-7	14	9	23	23

These estimates are for freeways, and arterial/collectors on the Winnipeg Emissions Modelling Network produced using the MOBILE6.2C model (daily VMT 6.643 million).

Figure 33 shows the difference in emissions estimates by using MOBILE6.2C default vehicle activity inputs versus the estimate using Winnipeg specific vehicle activity inputs produced by this research. A positive percent difference indicates that the respective vehicle type emission is greater using the MOBILE6.2C default input than the Winnipeg specific inputs. A negative percent difference indicates that the respective vehicle type emission is less using the MOBILE6.2C default input than the Winnipeg specific inputs. The percent change in motorcycle emissions is large (greater than 2,000 percent); however the absolute change is relatively small, (less than 0.02 percent of total emissions) therefore motorcycles are not shown in the percent change.

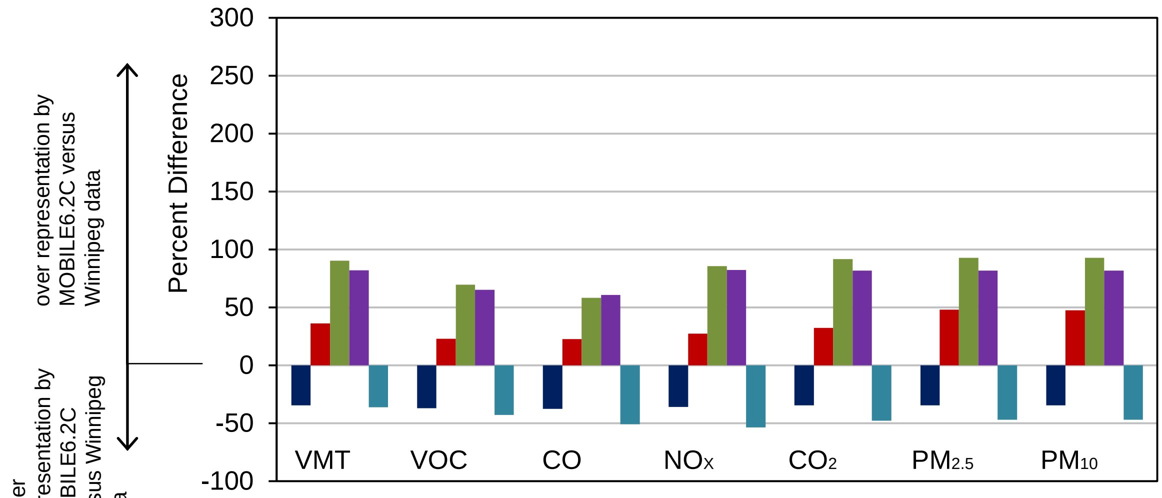
Figure 33 reveals the following:

- The absolute difference in total VMT is zero because there is no default value for it is applied to the gram per mile estimate produced by MOBILE6.2C. Therfore there is no difference in total VMT on the network between MOBILE6.2C default activity inputs and Winnipeg specific activity inputs, however there are differences in how this VMT is assigned.

- MOBILE6.2C underestimates passenger car VMT by 34 percent; this is reflected by an approximately 34 percent underestimation of all emissions types.

- Light duty truck VMT estimates are 36 percent higher using MOBILE6.2C defaults. However, because the defaults estimate a different proportion of the vehicles that comprise light duty trucks (MOBILE6.2C classes 2 through 6) the difference in emission estimate ranges from 22 to 48 percent difference.

- MOBILE6.2C overestimates single unit truck VMT by approximately 90 percent and articulated truck traffic by approximately 80 percent compared to the inputs developed by this research. Consequently, this also leads to overestimates of the emissions from these vehicle types.



	(1000 Miles)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)
Passenger car	-1248	-2.46	-35.49	-1.83	-460.76	-0.15	-0.16
Light duty truck	985	1.39	20.86	1.54	480.68	0.23	0.25
Single unit truck	123	0.15	1.50	1.10	158.98	0.17	0.19
Articulated truck	120	0.07	0.39	1.88	196.64	0.22	0.24
Bus	-11	-0.01	-0.11	-0.30	-34.31	-0.04	-0.04
Motorcycle*	32	0.08	0.53	0.05	5.66	0.00	0.00
Total	0	-0.80	-12.31	2.44	346.88	0.43	0.47

Figure 33: Default activity versus 2006 Winnipeg vehicle activity emissions by percent difference (top) and by absolute difference (bottom).

* Motorcycle percent change is not shown because the percent change is over 2000 for all emission types and skews the scale of the graph.

4.2.3. Saskatoon Emissions Estimates

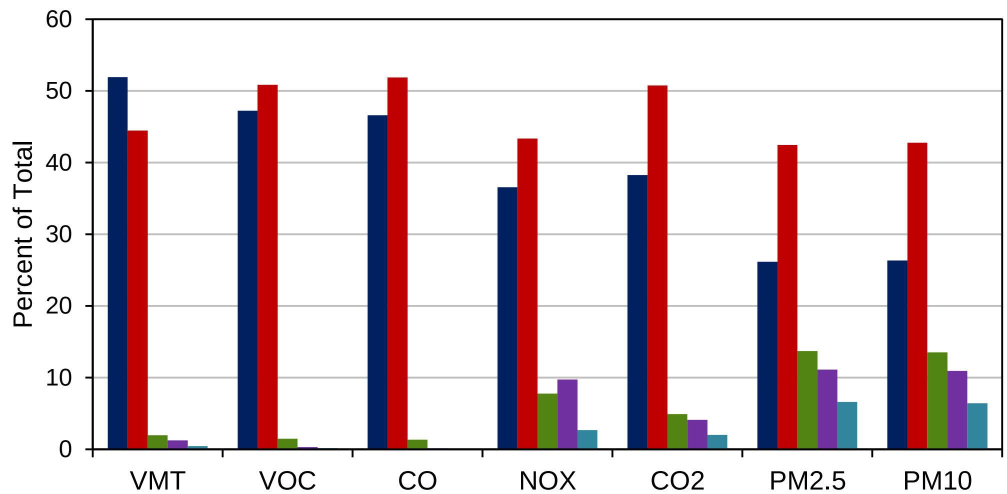
The daily VMT on the EMNS is 2,186,000, resulting in 798 million annual vehicle miles travelled (this is the daily VMT multiplied by 365). Table 43 shows the daily and annual emission estimates in tonnes.

Table 43: Summary of emission estimates for Saskatoon in 2006.

	VOC	CO	NO_x	CO_2	$PM_{2.5}$	PM_{10}
Daily tonnes	5.6	81.4	5.9	1098	0.5028	0.5586
Annual tonnes	2,044	29,711	2,153	400,770	183.5	203.9

These estimates are for freeways, arterial/collectors, and freeway ramps on the Emissions Modelling Network for Saskatoon (daily VMT equals 2.186 million) produced using the MOBILE6.2C model.

Figure 34 shows the absolute emissions contribution of six aggregate vehicle types (passenger car, light duty truck, single unit truck, articulated truck, bus, and motorcycle) and as a percentage of the total emission estimate.



	(1000 Miles)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)	(tonnes/day)
Passenger car	1134	2.64	37.91	2.13	420	0.13	0.15
Light duty truck	972	2.84	42.22	2.54	557	0.21	0.24
Single unit truck	43	0.08	1.12	0.48	54	0.07	0.08
Articulated truck	27	0.02	0.11	0.60	45	0.06	0.06
Bus	10	0.01	0.07	0.15	22	0.03	0.04
Motorcycle*	<1	<0.01	0.01	<0.01	<1	<0.01	<0.01
Total	**2186**	**5.59**	**81.44**	**5.89**	**1098**	**0.50**	**0.56**

Figure 34: Emission by vehicle type for Saskatoon in 2006 by percent of total vehicle emissions (top) and absolute vehicle emissions (bottom).

* Motorcycle emissions are not shown in the percent of total graph because they make up less than 0.02 percent of all categories. These estimates are for freeways, arterial/collectors, and freeway ramps on the Emissions Modelling Network for Saskatoon.

Figure 34 reveals the following:

- Passenger cars are the largest contributor to VMT (52 percent of total), however they are not the largest contributor to any emission types. They are most underrepresented in their contribution to PM (approximately 26 percent of total PM emissions).

- Light duty trucks are the second largest contributor to VMT (45 percent of total) and are the largest contributor to all criteria air contaminants. Their VOC, CO and CO2 emissions are overrepresented.

- Single unit trucks, articulated trucks, and buses contribute 2.0 percent, 1.2 percent, and 0.4 percent, respectively, to VMT. They are all overrepresented in their contribution to NOx, CO2, and PM emissions.

4.2.4. Comparison of Emissions Estimates Using Saskatoon Data versus MOBILE6.2C Default Data

This section provides a comparison of the MOBILE6.2C emissions estimates produced using (1) Saskatoon vehicle activity inputs produced by this research and (2) MOBILE 6.2C default vehicle activity inputs. In both cases, ambient condition and vehicle fleet characteristic data provided by Environment Canada are used. Vehicle activity attributes are an important source of uncertainty in emission inventory estimates and are often difficult to obtain. Although the default inputs are readily-available they are indifferent to jurisdiction-specific traffic characteristics.

Table 44 provides a summary of the daily emission estimates on the EMNS from the vehicle activity inputs developed in this research and default inputs. The default inputs produce larger tonne per day emissions for all emissions except carbon monoxide (CO).

Table 44: Comparison of emission estimates for Saskatoon in 2006.

	VOC	CO	NO_X	CO_2	$PM_{2.5}$	PM_{10}
Saskatoon vehicle activity	5.6	81.4	5.9	1098	0.50	0.56
MOBILE default vehicle activity	5.7	77.1	6.8	1186	0.66	0.73
Percent change	2	-5	17	8	33	32

Note: All values shown in tonnes per day. These estimates are for freeways, arterial/collectors, and freeway ramps on the Emissions Modelling Network for Saskatoon (daily VMT equals 2.186 million) produced using the MOBILE6.2C model.

Figure 35 shows the difference in emissions estimates by using MOBILE6.2C default vehicle activity inputs versus a benchmark estimate using Saskatoon specific vehicle activity inputs produced by this research. A positive percent change indicates that the respective vehicle type emission is greater using the MOBILE6.2C default input than the Saskatoon specific inputs. A negative percent change indicates that the respective vehicle type emission is less using the MOBILE6.2C default input than the Saskatoon specific inputs. The percent change in motorcycle emissions is large (greater than 2,000 percent); however the absolute change is relatively small, (less than 0.02 percent of total emissions) therefore motorcycles are not shown in the percent change.

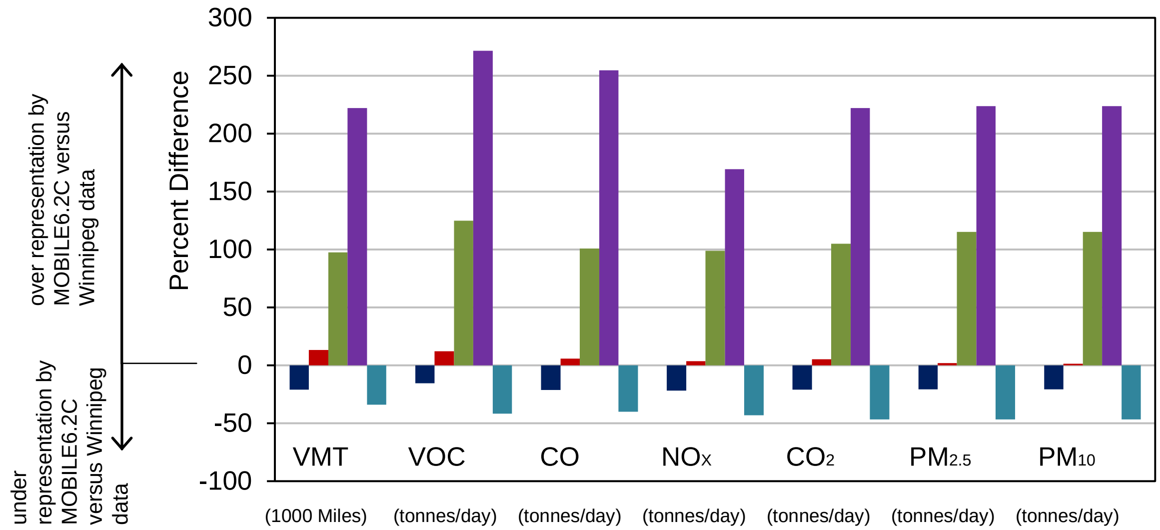
Figure 35 reveals the following:

- The absolute difference in total VMT is zero because there is no default value for it is applied to the gram per mile estimate produced by MOBILE6.2C. Therfore there is no difference in total VMT on the network between MOBILE6.2C default activity inputs and Saskatoon specific activity inputs, however there are differences in how this VMT is assigned.

- MOBILE6.2C underestimates passenger car VMT by 21 percent; this is reflected by an approximately 21 percent underestimation of all emissions types.

- Light duty truck VMT estimates are 13 percent higher using MOBILE6.2C defaults. However, because the defaults estimate a different proportion of the vehicles that comprise light duty trucks (MOBILE6.2C classes 2 through 6) the emission estimate is less than six percent greater.

- MOBILE6.2C overestimates single unit truck VMT by approximately 100 percent and articulated truck traffic by approximately 200 percent compared to the inputs developed by this research. Consequently, this also leads to large overestimates of the emissions from these vehicle types.



	VMT	VOC	CO	NOx	CO_2	$PM_{2.5}$	PM_{10}
Passenger car	-238.8	-0.41	-8.19	-0.47	-88.35	-0.03	-0.03
Light duty truck	128.4	0.33	2.30	0.07	29.34	<0.01	<0.01
Single unit truck	42.2	0.10	1.07	0.42	56.52	0.08	0.09
Articulated truck	59.7	0.05	0.28	0.92	99.10	0.12	0.14
Bus	-3.3	<-0.01	-0.03	-0.06	-10.42	-0.02	-0.02
Motorcycle*	11.8	0.03	0.20	0.02	2.09	<0.01	<0.01
Total	**0.0**	**0.10**	**-4.37**	**0.89**	**88.29**	**0.16**	**0.18**

Figure 35: Default activity versus 2006 Saskatoon vehicle activity emissions by percent difference (top) and absolute difference (bottom).

* Motorcycle percent change is not shown because the percent change is over 2000 for all emission types and skews the scale of the graph.

5. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes key findings of the research and discusses opportunities for future research.

5.1. CONCLUSIONS

This research develops and applies a methodology to calculate vehicle activity inputs for spatial and temporal modelling of emissions from on-road vehicles using traffic count data. It is critical to develop jurisdiction-specific vehicle activity input values to accurately reflect on-road vehicle emissions. The emission model results can be used as indicators to inform policy analysts, decision makers and the public for analysis ranging from estimating the national impacts of motor vehicle emissions control strategies to estimating human exposure to pollutants.

The research develops a six step methodology to calculate vehicle activity data.

- Step 1 defines the road network for which emissions are estimated. This network is a subset of the total urban road network.
- Step 2 obtains existing traffic data sources on the defined network, identifies data gaps, and develops a short-duration data collection program to acquire necessary vehicle activity data.
- Step 3 defines truck traffic pattern groups and assigns each segment on the network to these truck traffic pattern groups.
- Step 4 uses data from Step 2 and the truck traffic pattern groups defined in Step 3 to assign the VMT temporally for each segment on the network.

- Step 5 uses data from Step 2 to calculate VMT by MOBILE6.2C vehicle class.

- Step 6 estimates hourly vehicle speeds on each segment based on posted speed limit and hourly volumes.

Comparisons between developed inputs and MOBILE6.2C default inputs for VMT indicate differences in the hourly distribution of VMT for all vehicle types, the roadways the VMT is occurring on, and the distribution of vehicle speed for each hour of the day. This emphasizes the importance of obtaining jurisdiction-specific input values for emissions modeling.

By applying the methodology to Winnipeg and Saskatoon and comparing calculated vehicle activity inputs to default activity inputs the research found the following:

- Using the MOBILE6.2C model and the inputs developed by this research for Winnipeg the following daily emissions estimates are calculated (in tonnes per day): VOC - 13.1, CO - 189.9, NO_x -14.9, CO_2 - 3310, $PM_{2.5}$ - 1.44, and PM_{10} - 1.60.

- The emissions estimate for Winnipeg shows that passenger cars are the largest contributor to VMT (54 percent of total), however they are underrepresented in all emission types and are not the largest contributor to any type of emissions. Light duty trucks are the second largest contributor to VMT (41 percent) and are the largest contributor to NO_x, CO_2, and particulate matter. Single unit trucks and articulated trucks contribute 2.0 percent and 2.2 percent respectively to VMT. However, single unit trucks contribute to 8 percent of total NO_x, 5 percent of total CO_2, and 13 percent of total particulate matter. Articulated trucks contribute to 15 percent of total NO_x, 7 percent of total CO_2, and 18 percent of total particulate matter.

- A comparison between emissions estimates using Winnipeg specific vehicle activity inputs produced by this research versus MOBILE6.2C default vehicle activity inputs reveals advantages of using jurisdiction-specific traffic characteristics. Compared to the Winnipeg specific vehicle activity inputs produced by this research, MOBILE6.2C underestimates passenger car VMT by 34 percent, which is reflected by an approximately 34 percent underestimation of all emissions types from passenger cars. Light duty truck VMT estimates are 36 percent higher using MOBILE6.2C defaults. However, because the defaults estimate a different proportion of the vehicles that comprise light duty trucks (MOBILE6.2C classes 2 through 6) the emission estimate range from 22 to 48 percent greater. MOBILE6.2C overestimates single unit truck VMT by approximately 90 percent and articulated truck traffic by approximately 80 percent compared to the inputs developed by this research. Consequently, this also leads to parallel scaled overestimates of the emissions from these vehicle types.

- Using the MOBILE6.2C model and the inputs developed by this research for Saskatoon the following daily emissions estimates are calculated (in tonnes per day): VOC - 5.6, CO - 81.4, NO_x -5.9, CO_2 - 1098, $PM_{2.5}$ - 0.5, and PM_{10} - 0.56.

- The emissions estimate for Saskatoon shows that passenger cars are the largest contributor to VMT (52 percent of total); however, they are underrepresented in all emission types and are not the largest contributor to any type. Light duty trucks are the second largest contributor to VMT (45 percent) and are the largest contributor to all criteria air contaminants. Their VOC, CO and CO2 emissions are overrepresented. Single unit trucks and articulated trucks contribute 2.0 percent and 1.2 percent, respectively to VMT. However, single unit trucks contribute to 8 percent of total NO_x, 5 percent of total CO_2, and 14 percent of total particulate matter. Articulated trucks contribute to 10 percent of total NO_x, 4 percent of total CO_2, and 11 percent of total particulate matter.

- A comparison between emissions estimates using Saskatoon specific vehicle activity inputs produced by this research versus MOBILE6.2C default vehicle activity inputs reveals advantages of using jurisdiction-specific traffic characteristics. Compared to the Saskatoon specific vehicle activity inputs produced by this research, MOBILE6.2C underestimates passenger car VMT by 21 percent, which is reflected by an approximately 21 percent underestimation of all emissions types. Light duty truck VMT estimates are 13 percent higher using MOBILE6.2C defaults. However, because the defaults estimate a different proportion of the vehicles that comprise light duty trucks (MOBILE6.2C classes 2 through 6) the emission estimate is less than six percent greater. MOBILE6.2C overestimates single unit truck VMT by approximately 100 percent and articulated truck traffic by approximately 200 percent compared to the inputs developed by this research. Consequently, this also leads to parallel scaled overestimate of the emissions from these vehicle types.

5.2. RECOMMENDATIONS FOR FUTURE RESEARCH

This research has identified the following opportunities for research in the future:

- Due to data availability, VMT is calculated on the Winnipeg Emissions Modelling Network and the Emissions Modelling Network for Saskatoon. These networks exclude some roadways because of data availability (i.e., local roads and freeway ramps in Winnipeg and local roads in Saskatoon). Data for these road segments could be developed using a travel demand model for local roads or by conducting traffic counts at these locations (travel demand models are generally not strong at predicting truck movements but local roadways have small volumes of trucks). The effect of incorporating VMT from these facility types could be significant since they compose about 80 percent of total network centreline miles in each city. This does not necessarily indicate that these facility types compose 80 percent of the VMT; for instance MOBILE6.2C VMT default values indicate that the proportion of total VMT on local roads and freeway ramps are 13 and 3 percent, respectively. Data for Winnipeg and Saskatoon are currently unavailable to assess these default values. Therefore, further data collection on local roads or the development of a travel demand model could increase the existing scope of the emissions modelling network.

- This research develops vehicle activity data specific for Winnipeg and Saskatoon and demonstrates that this data can be different from default values derived from U.S. data. These differences are expected to occur in other Canadian jurisdictions; therefore further research is recommended to develop Canadian-based defaults by conducting similar research in other cities. Extending the research into other areas of Canada, such as British Columbia, Alberta, Ontario, Quebec, and the Maritimes, would facilitate improved emissions estimates for Canada.

- The U.S. Environmental Protection Agency has recently released the Motor Vehicle Emission Simulator (MOVES) as its approved motor vehicle emission model for on-road vehicles to replace MOBILE6.2. MOVES is to replace MOBILE6.2C as the model of choice for the estimation of emissions from on-road vehicles in Canada, and in the future will inform the relevant portions of Environment Canada's Air Pollutant Emissions Inventory, trends and forecasts. International customization of MOVES is possible. To adapt this model to Canadian conditions it is necessary to input custom vehicle fleet and activity data. New vehicle emission rates reflecting the emission standards applicable to Canada may be necessary. Additional, more fundamental changes to the model such as adding vehicle types, road types, or driving patterns may also produce more accurate estimates. For example, the vehicle activity inputs for MOVES (including vehicle type definitions) are more compatible with the standard data reporting requirements of the Highway Performance Monitoring System (HPMS) in the United States. Canadian jurisdictions are not subject to the requirements of the HPMS. These new vehicle types defined in MOVES may have limited benefit in Canada because there is a wider range of traffic data protocols in use across Canada. Therefore, there is a need to better understand the requirements of the MOVES inputs in the Canadian context.

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APPENDIX A:

COMPARISON OF VMT INPUTS

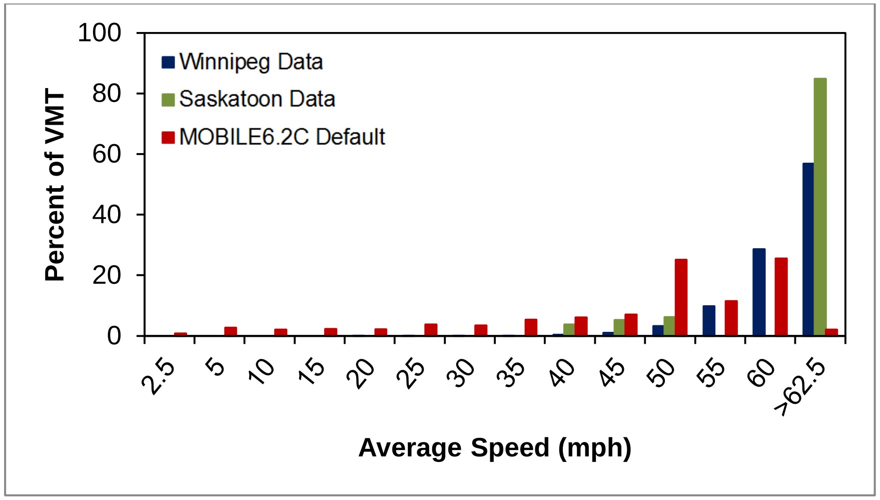

Figure A1: Freeway VMT percent by speed for 06:00

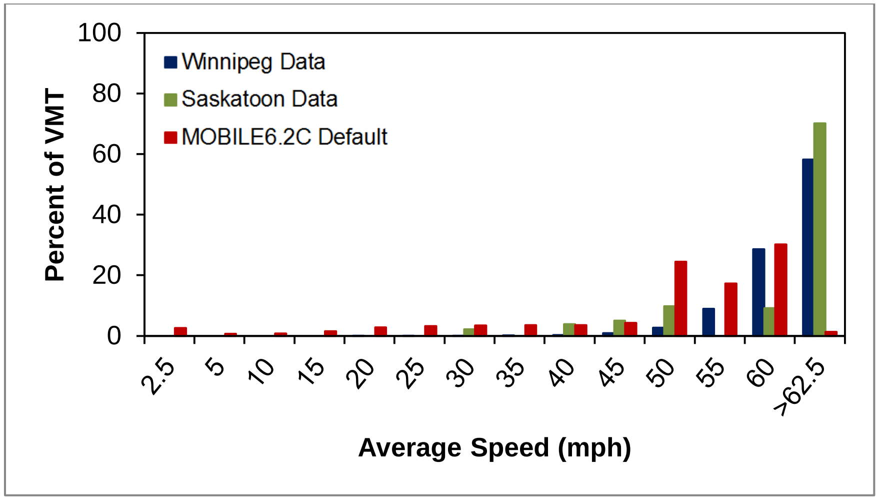

Figure A2: Freeway VMT percent by speed for 07:00

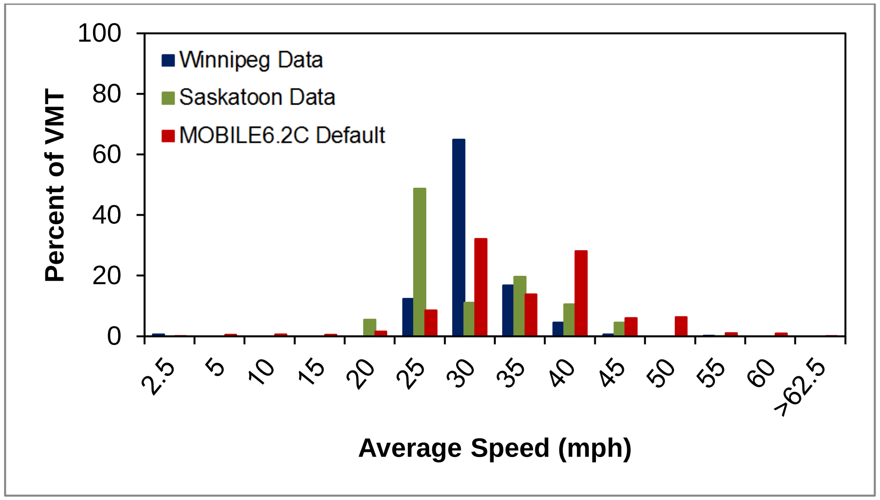

Figure A3: Arterial VMT percent by speed for 06:00

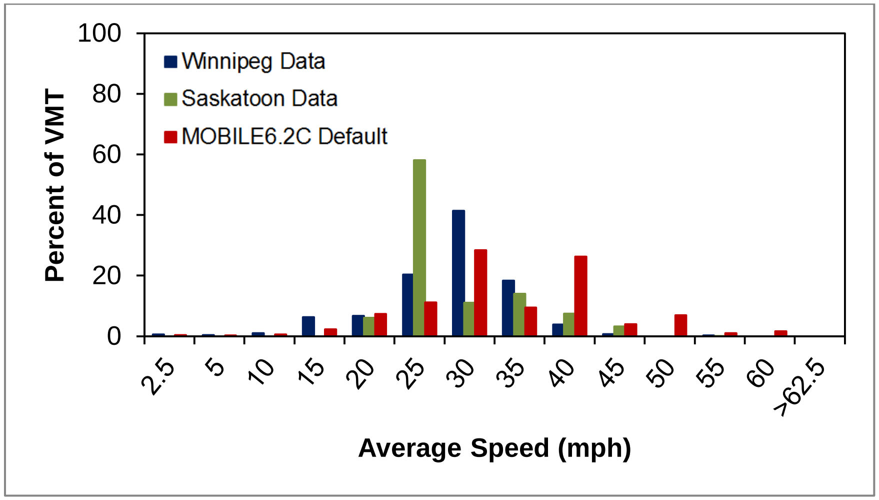

Figure A4: Arterial VMT percent by speed for 07:00

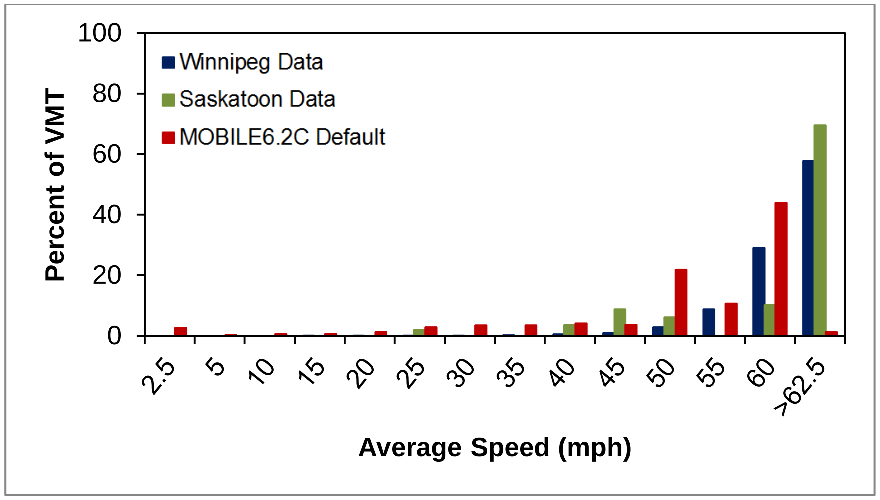

Figure A5: Freeway VMT percent by speed for 08:00

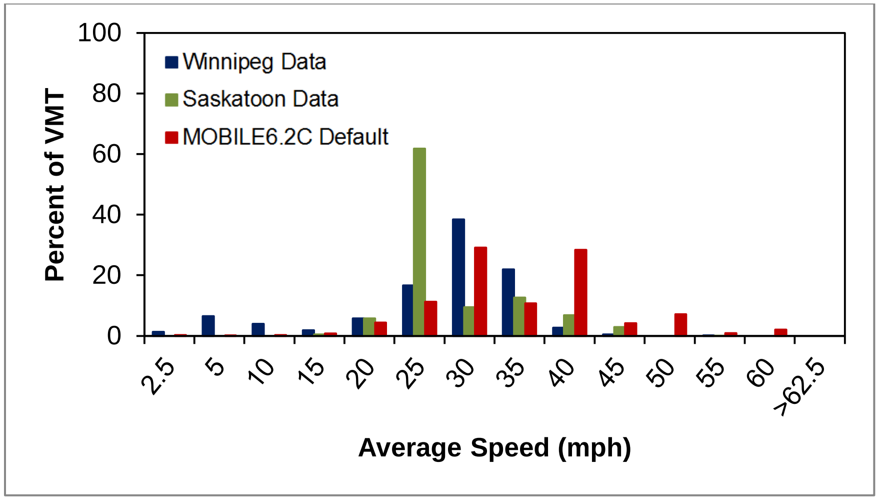

Figure A6: Freeway VMT percent by speed for 09:00

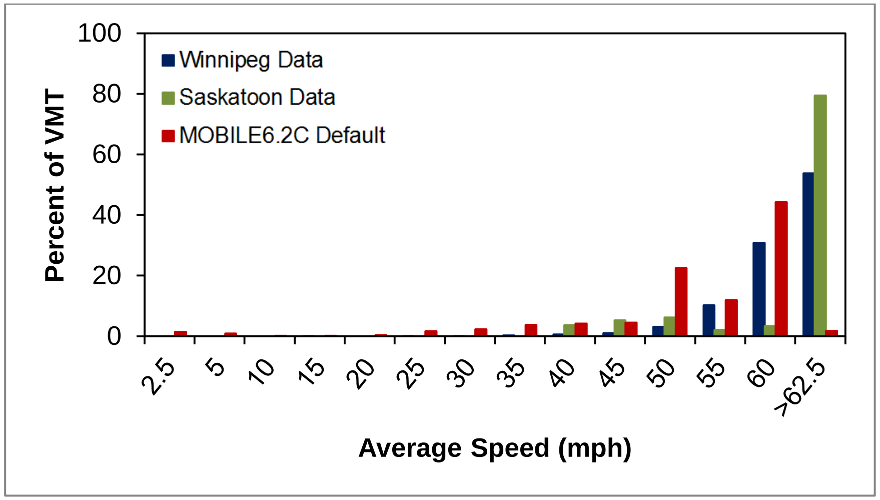

Figure A7: Arterial VMT percent by speed for 08:00

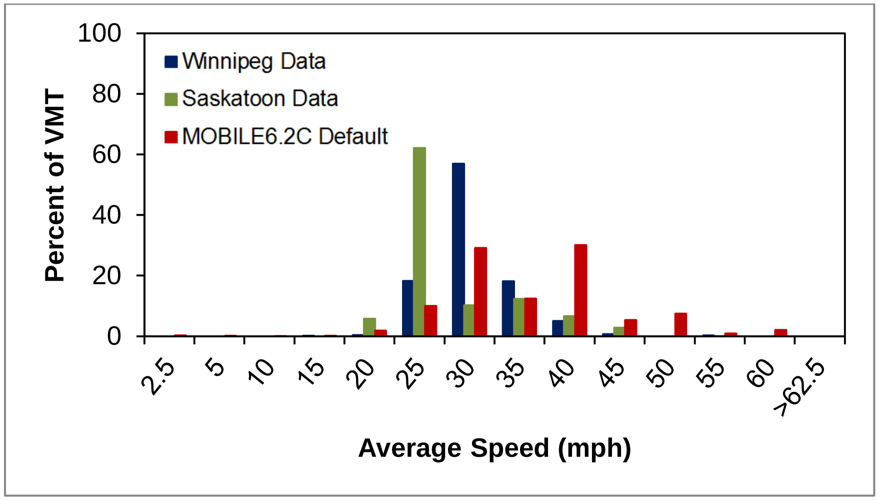

Figure A8: Arterial VMT percent by speed for 09:00

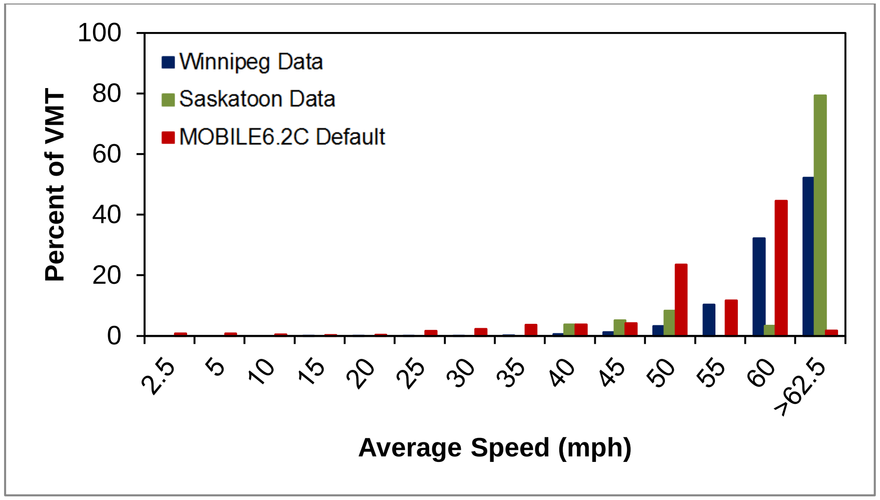

Figure A9: Freeway VMT percent by speed for 10:00

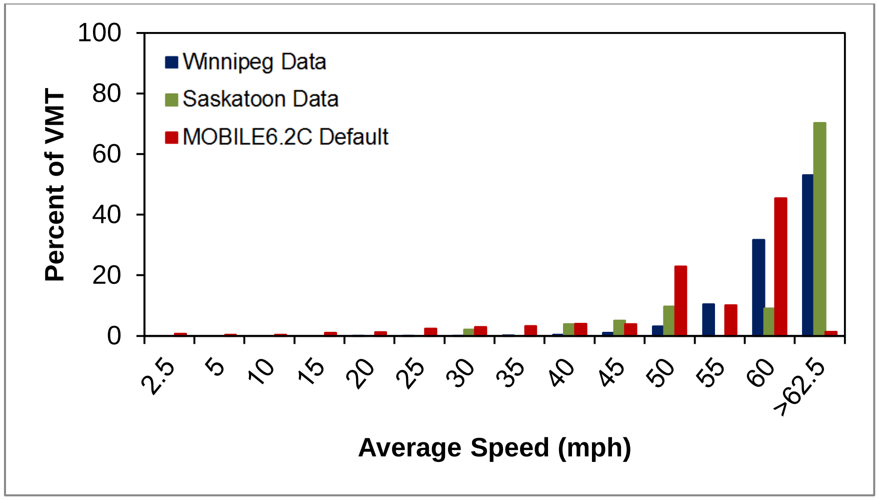

Figure A11: Freeway VMT percent by speed for 11:00

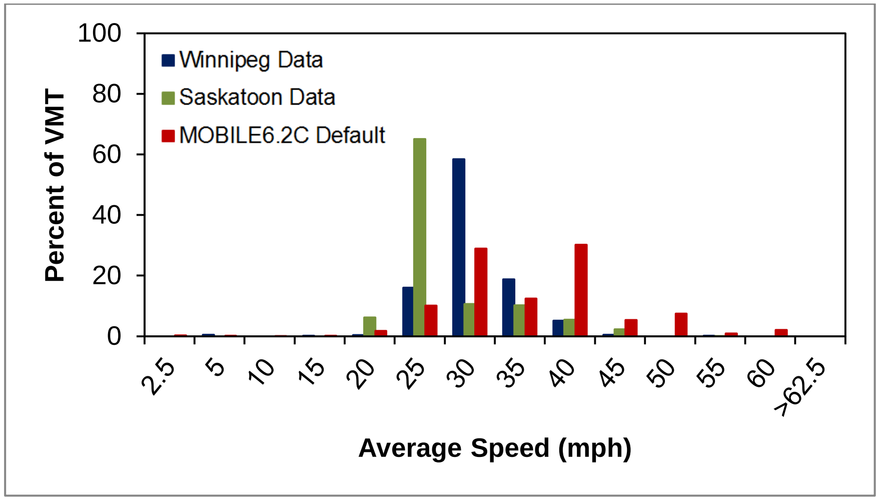

Figure A10: Arterial VMT percent by speed for 10:00

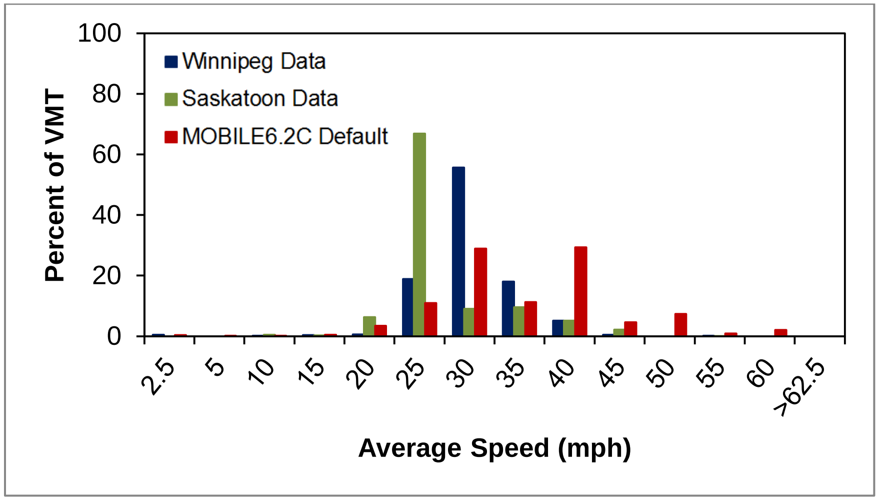

Figure A12: Arterial VMT percent by speed for 11:00

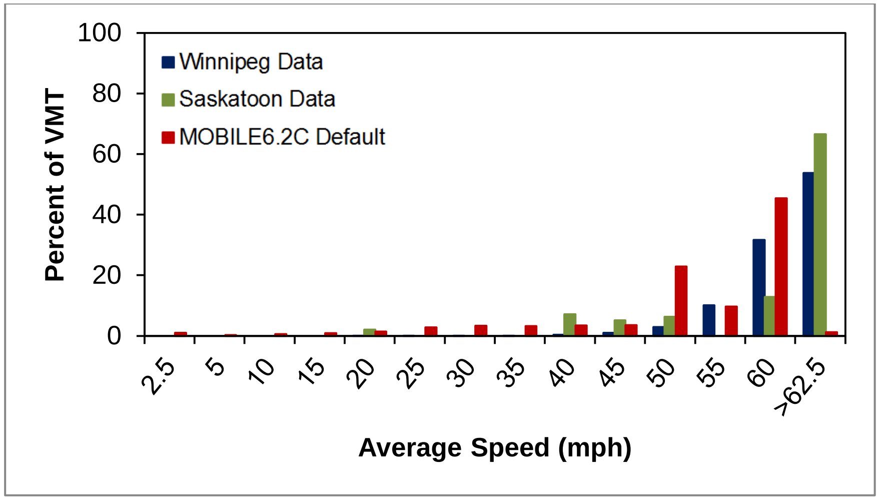

Figure A13: Freeway VMT percent by speed for 12:00

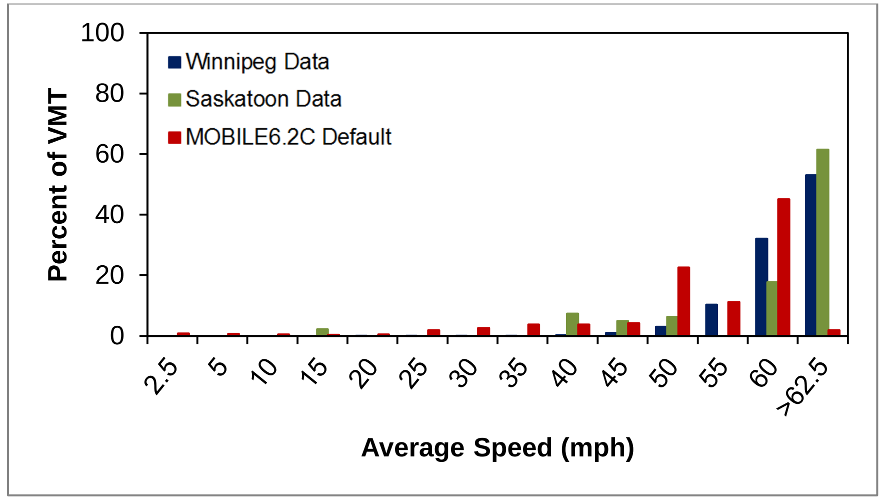

Figure A15: Freeway VMT percent by speed for 13:00

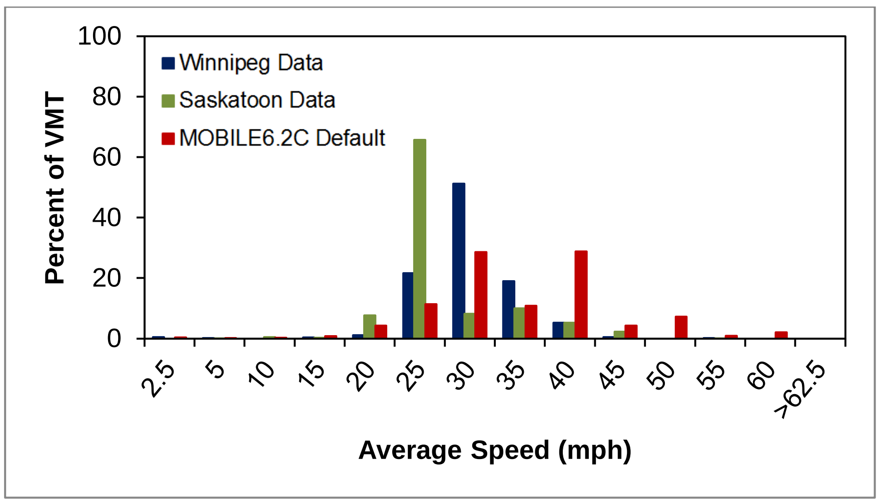

Figure A14: Arterial VMT percent by speed for 12:00

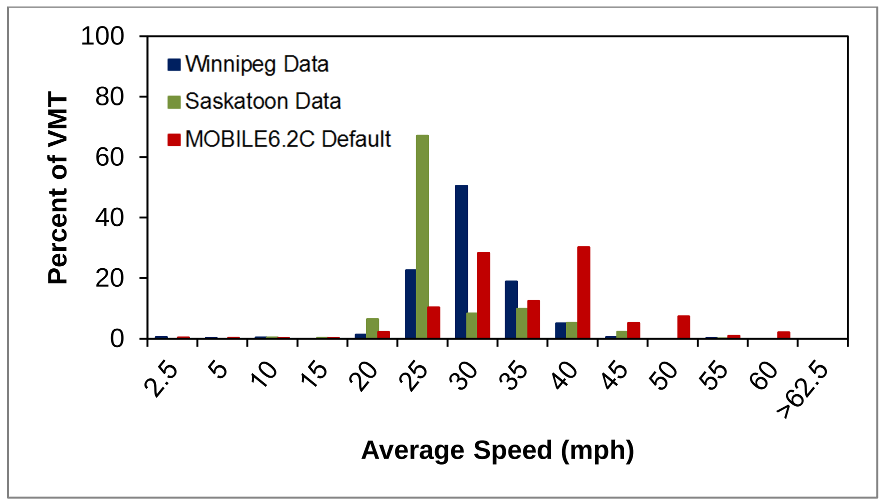

Figure A16: Arterial VMT percent by speed for 13:00

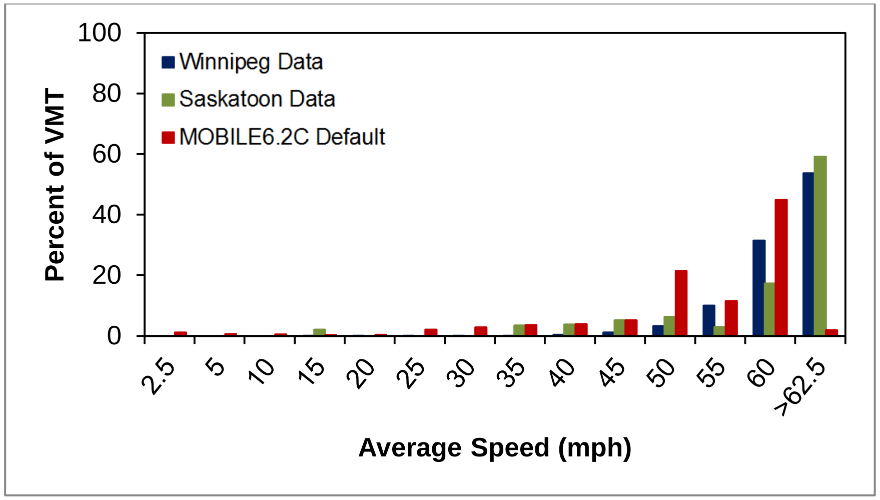

Figure A17: Freeway VMT percent by speed for 14:00

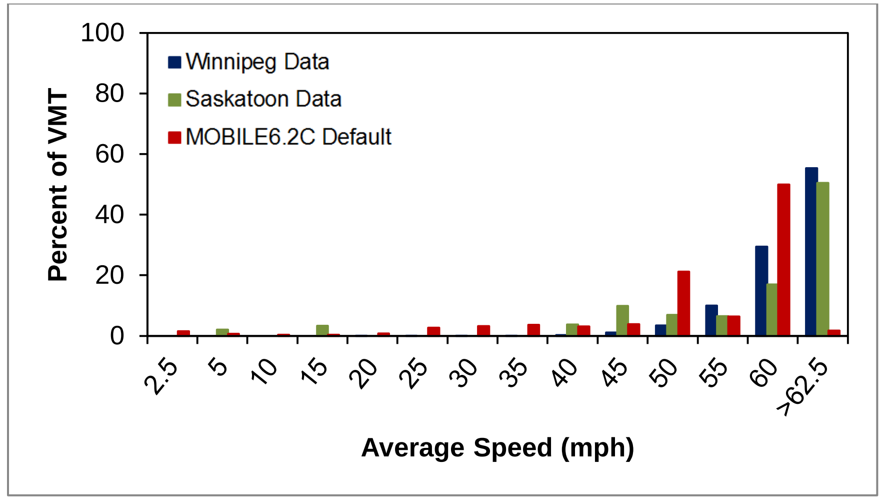

Figure A19: Freeway VMT percent by speed for 15:00

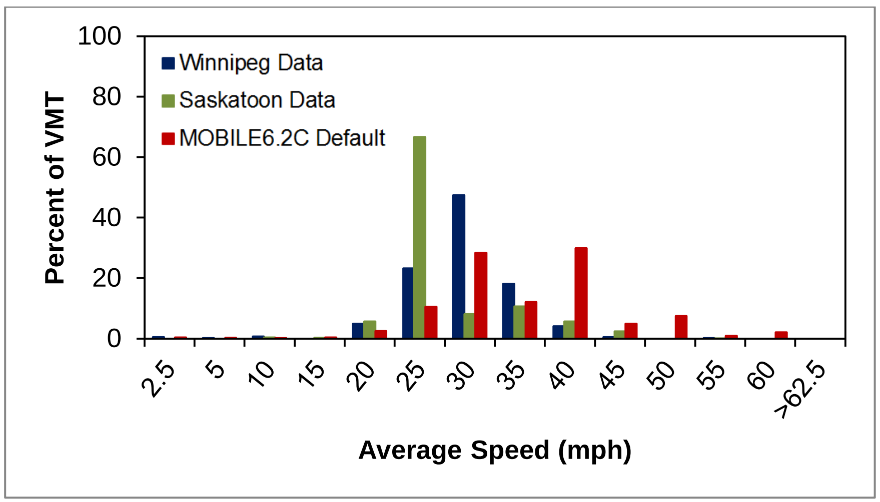

Figure A18: Arterial VMT percent by speed for 14:00

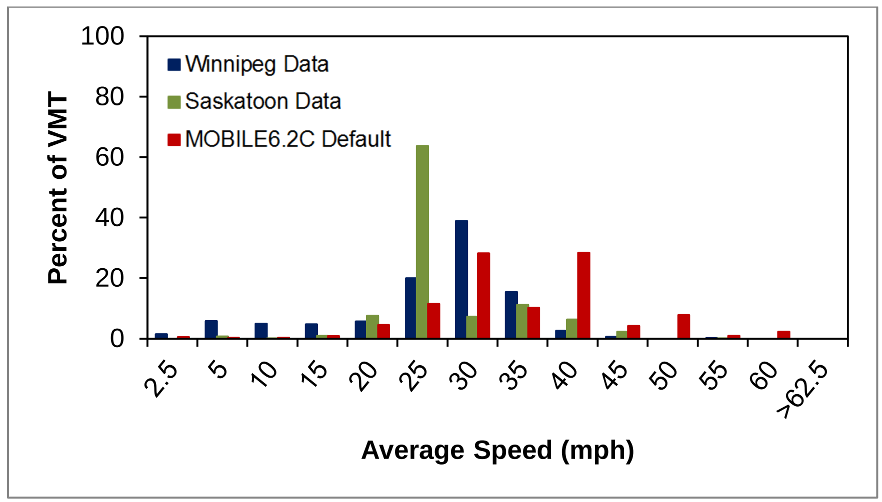

Figure A20: Arterial VMT percent by speed for 15:00

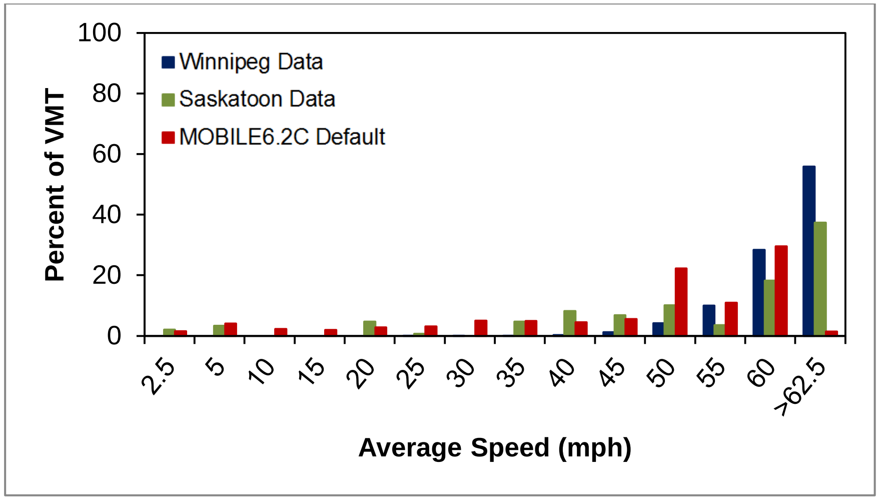

Figure A21: Freeway VMT percent by speed for 16:00

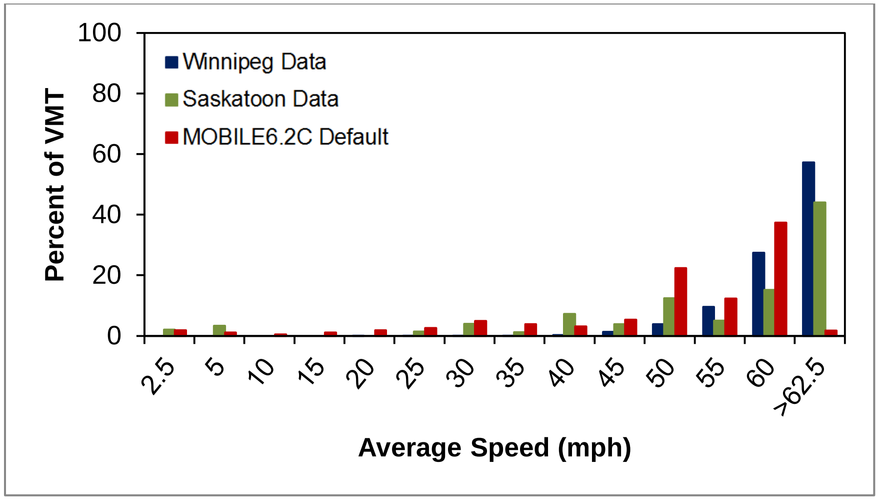

Figure A23: Freeway VMT percent by speed for 17:00

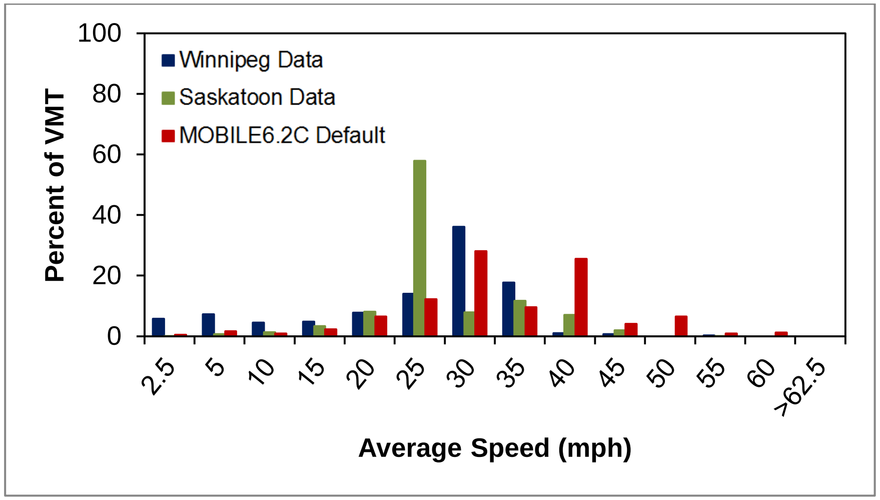

Figure A22: Arterial VMT percent by speed for 16:00

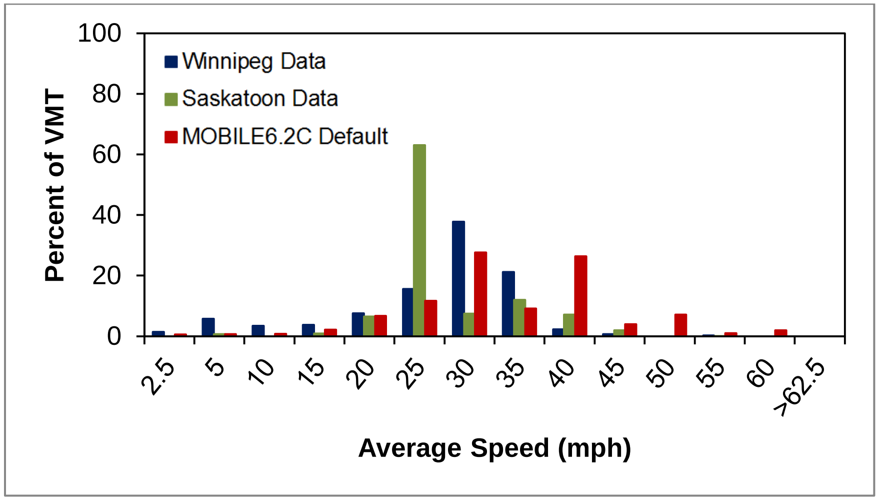

Figure A24: Arterial VMT percent by speed for 17:00

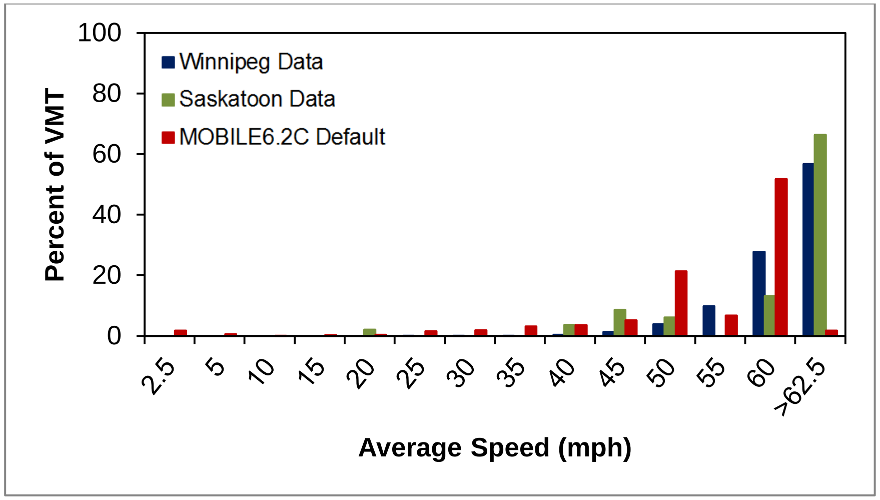

Figure A25: Freeway VMT percent by speed for 18:00

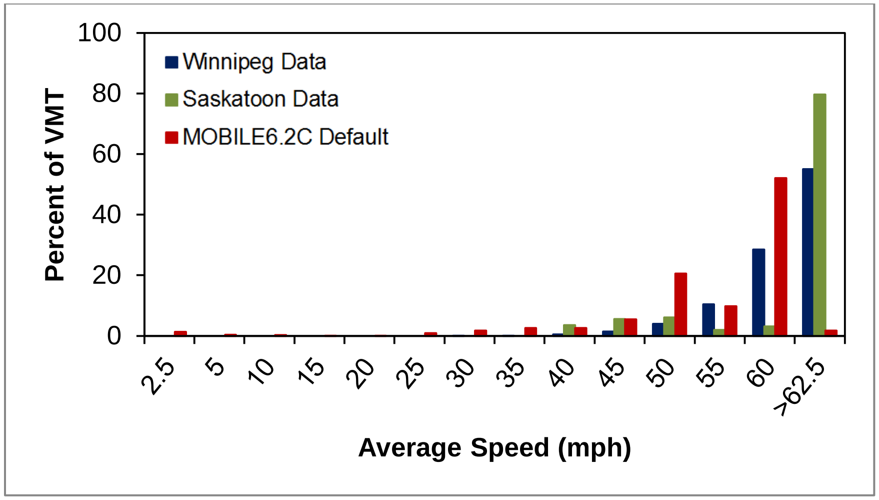

Figure A27: Freeway VMT percent by speed for 19:00

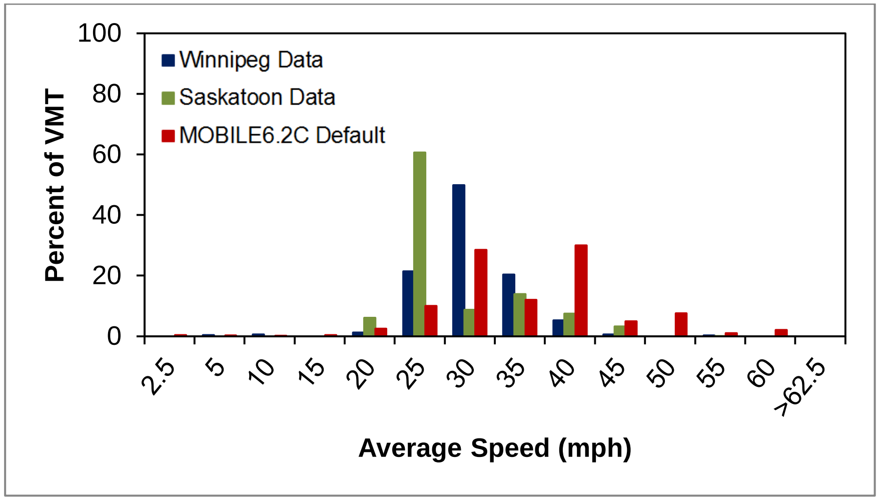

Figure A26: Arterial VMT percent by speed for 18:00

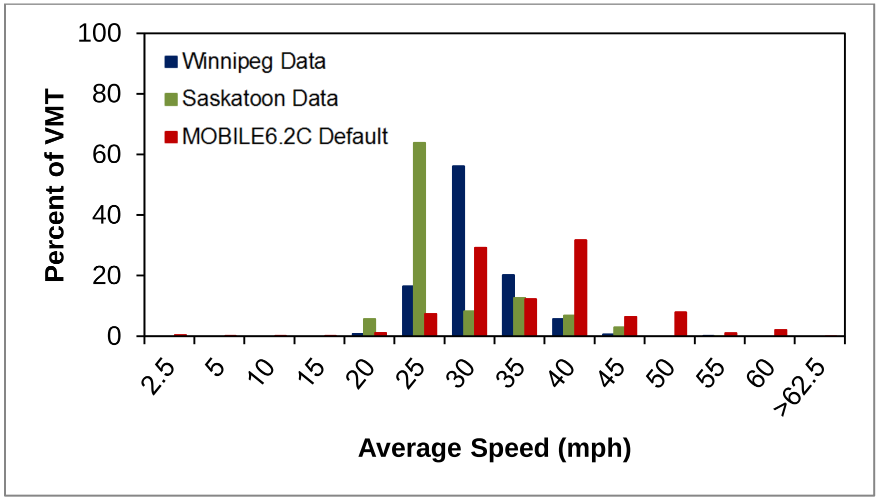

Figure A28: Arterial VMT percent by speed for 19:00

APPENDIX B:

SAMPLE MOBILE6.2C INPUT AND OUTPUT FILES

This sample input file shows the Header section, Run Section, and 1 Scenario Section (January) for Winnipeg.

```
********** Header section *****************************************************************
* DESCRIPTION: This file is designed for MOBILE6.2C and will provide output for the      *
* Winnipeg Emissions Modelling network. This file is Initialruna.in. Lower case 'a' in   *
* the file name indicates the file estimates PM10 and HC as VOC only. A lower case 'b'   *
* in the file in the file name indicates the file estimates PM2.5 and HC as THC only.    *
*                                                                                         *
* CREATED: The base file was created by Brett Taylor on May 21, 2009                      *
* MODIFIED: Keenan Patmore modified the file on January 10, 2011                          *
*                                                                                         *
* Sources to inputs are documented throughout.                                            *
* Each year will have twelve scenarios; one for each month.                               *
* Meteorological data from: Winnipeg's Richardson International Airport station.          *
*******************************************************************************************

MOBILE6 INPUT FILE
PARTICULATES        :
AIR TOXICS          :
POLLUTANTS          : HC CO NOX CO2
SPREADSHEET         :
DATABASE OUTPUT     :
WITH FIELDNAMES     :
DAILY OUTPUT        :

RUN DATA


********** Run  Section 1 Winnipeg 2006 **********
> Winnipeg 2006  - All MOBILE6.2C pollutants
EXPRESS HC AS VOC   :
NO REFUELING        :

VMT FRACTIONS       :
0.5421 0.0213 0.2029 0.0863 0.0787 0.0213 0.0036 0.0009
0.0005 0.0046 0.0041 0.0068 0.0220 0.0006 0.0041 0.0002

* Specify  mileage accumulation rates
MILE ACCUM RATE     : MARDATA.in

* Specify  age distribution
* Source: M6C-10-E.doc
REG DIST            : REGDATA.in

* Expand vehicle class descriptive output
EXPAND BUS EFS      :
EXPAND HDDV EFS     :
EXPAND HDGV EFS     :
EXPAND LDT EFS      :

IDLE PM EMISSIONS   :


* Expand exhaust emissions descriptive output
EXPAND EXHAUST      :

* Expand evaporative emissions descriptive output
EXPAND EVAPORATIVE :

* Specify the fraction of total VMT that occurs at each hour of the day
VMT BY HOUR         : HVMT.in

* Specify the fraction of total VMT that occurs at each hour of the day on each facility
VMT BY FACILITY     : FVMT.in

* Specify  vehicle miles traveled (VMT) by average speed on freeways and arterial roads
SPEED VMT           : SVMT.in

* Because it is now post-1999 calendar year  sulphur levels in gasoline must be specified
* using the FUEL PROGRAM command (see Advanced Training Guide manual  Day 1  page 46)
* Sulphur source: Environment Canada's Sulphur in Liquid Fuels annual report
* Max Sulphur content from CEPA Sulphur in Gasoline Regulation Registration June 4  1999
* The regulation implies the use of 25ppm for years after 2004.
* The 4 rows and 8 columns below represent;
* row 1 - average sulphur levels (ppm) from 2000 to 2007
* row 2 - average sulphur levels (ppm) from 2008 to 2015
* row 3 - maximum sulphur levels (ppm) from 2000 to 2007
* row 4 - maximum sulphur levels (ppm) from 2008 to 2015
FUEL PROGRAM        : 4
220.0 220.0 200.0 157.0 61.0 25.0 25.0 25.0
25.0 25.0 25.0 25.0 25.0 25.0 25.0 25.0
500.0 500.0 500.0 500.0 500.0 25.0 25.0 25.0
25.0 25.0 25.0 25.0 25.0 25.0 25.0 25.0
```

```
* Specify  diesel fractions
* Source: M6C-10-E.doc
* If actual data is not available for this year  use most recent available year. Data used in this case was
*| estimated for calendar year:    2006
DIESEL FRACTIONS    :
0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096
0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0097 0.0096
0.0095 0.0097 0.0095 0.0095 0.0096
0.0394 0.0391 0.0393 0.0389 0.0389 0.0393 0.0395 0.0394 0.0390 0.0394
0.0390 0.0392 0.0388 0.0390 0.0392 0.0390 0.0395 0.0391 0.0382 0.0407
0.0380 0.0398 0.0000 0.0000 0.0388
0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008
0.0008 0.0008 0.0008 0.0008 0.0008 0.0009 0.0008 0.0008 0.0008 0.0009
0.0011 0.0010 0.0000 0.0000 0.0009
0.0159 0.0158 0.0160 0.0159 0.0159 0.0159 0.0158 0.0161 0.0160 0.0159
0.0158 0.0161 0.0161 0.0160 0.0161 0.0161 0.0158 0.0160 0.0161 0.0163
0.0155 0.0158 0.0161 0.0161 0.0159
0.2206 0.2205 0.2205 0.2206 0.2206 0.2205 0.2205 0.2206 0.2205 0.2205
0.2205 0.2206 0.2205 0.2205 0.2205 0.2204 0.2206 0.2207 0.2206 0.2203
0.2208 0.2205 0.2208 0.2202 0.2205
0.6708 0.6709 0.6711 0.6702 0.6709 0.6706 0.6703 0.6707 0.6708 0.6710
0.6705 0.6706 0.6708 0.6704 0.6710 0.6701 0.6713 0.6701 0.6715 0.6711
0.6716 0.6709 0.6000 0.0000 0.6667
0.3971 0.3970 0.3988 0.3983 0.3962 0.3982 0.3955 0.3986 0.3974 0.3980
0.3971 0.3970 0.3972 0.3970 0.3986 0.3980 0.3966 0.3980 0.3989 0.4000
0.4000 0.3984 0.3889 0.3902 0.3978
0.3915 0.3947 0.3889 0.3889 0.3902 0.3926 0.3939 0.3929 0.3913 0.3951
0.3962 0.3966 0.3902 0.3932 0.3913 0.4063 0.4000 0.4000 0.3929 0.4000
0.4000 0.4167 0.0000 0.0000 0.3929
0.3167 0.3208 0.3214 0.3158 0.3182 0.3235 0.3000 0.3226 0.3077 0.3000
0.3077 0.3000 0.3000 0.3182 0.3182 0.3750 0.2857 0.3333 0.3077 0.3333
0.3333 0.3243 0.3333 0.3077 0.3177
0.2533 0.2535 0.2530 0.2538 0.2537 0.2518 0.2516 0.2561 0.2539 0.2530
0.2560 0.2551 0.2530 0.2560 0.2535 0.2549 0.2537 0.2554 0.2526 0.2537
0.2542 0.2539 0.2532 0.2539 0.2541
0.7313 0.7288 0.7313 0.7312 0.7302 0.7301 0.7325 0.7320 0.7301 0.7292
0.7296 0.7292 0.7310 0.7330 0.7304 0.7312 0.7317 0.7321 0.7328 0.7288
0.7281 0.7313 0.7319 0.7333 0.7303
0.7871 0.7861 0.7870 0.7887 0.7862 0.7889 0.7857 0.7890 0.7887 0.7891
0.7857 0.7857 0.7895 0.7875 0.7892 0.7879 0.7895 0.7895 0.7905 0.7931
0.7895 0.7857 0.7882 0.7849 0.7874
0.9552 0.9551 0.9555 0.9551 0.9553 0.9554 0.9560 0.9555 0.9559 0.9549
0.9547 0.9567 0.9563 0.9549 0.9552 0.9563 0.9548 0.9562 0.9553 0.9524
0.9559 0.9567 0.9544 0.9554 0.9552
0.8902 0.8917 0.8878 0.8876 0.8881 0.8896 0.8876 0.8889 0.8872 0.8881
0.8876 0.8947 0.8926 0.8897 0.8869 0.8874 0.8903 0.8913 0.8854 0.8846
0.8846 0.8947 0.8846 0.8929 0.8874

********** Scenario Section 1 Run  1 Winnipeg 2006 January
SCENARIO RECORD     :  Winnipeg 2006 January
CALENDAR YEAR       :  2006

* Evaluation month is set to 7 for 'summer'; 1 for 'winter'. October 1 through April 31 get 'winter' fuel properties; Ma
EVALUATION MONTH    :  1

* Specify PM10 size
PARTICLE SIZE       : 10.0
PARTICULATE EF      : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV

* On-road diesel sulphur content  in parts per million (ppm)  from Sulphur in Liquid Fuels reports (OGEB)
DIESEL SULFUR       :  167.0

* The SULFUR CONTENT command  below  becomes irrelevant for years after 1999
* the FUEL COMMAND in the RUN section above is used to specify sulphur levels
* SULFUR CONTENT      :  25.0

HOURLY TEMPERATURES: 18.2 18.1 18.1 18.2 18.9 19.9 20.4 21.4 22.1 22.1 22.0 21.6
20.6 20.5 20.3 20.5 20.5 20.2 19.9 19.3 18.9 18.7 18.7 18.7

* Relative humidity by percent
RELATIVE HUMIDITY   : 86. 86. 86. 85. 85. 84. 84. 83. 82. 82. 82. 82.
83. 84. 84. 84. 85. 85. 84. 85. 86. 85. 86. 86.

* Barometric pressure measure in inches of mercury
BAROMETRIC PRES     : 29.0

* All the fuel parameters below come from Appendix B of the report <Emissions of Air Toxics from on-Highway sources in C
* Volume percent is needed (not %wt). ETOH conversion factor in MOBILE6 users' manual should be 0.3488.

FUEL RVP            :  14.4
GAS AROMATIC%       :  23.6
GAS OLEFIN%         :  10.1
GAS BENZENE%        :  0.7
E200                :  55.6
E300                : 86.6
OXYGENATE           :  MTBE 0.0 0.00
                    :  ETOH 0.0 0.00 1 1 NA NA
                    :  ETBE 0.0 0.00
                    :  TAME 0.0 0.00
ADDITIONAL HAPS     :  HAP_BASE.CSV
```

This sample output file shows output for the month of January in Winnipeg.

```
*****************************************************************************
* MOBILE6C 6.2ETOH (27-May-2005)                                            *
* Input file: REVISEDB.IN (file 1, run 1).                                  *
*****************************************************************************
* Winnipeg 2006  - All MOBILE6.2C pollutants
  M603 Comment:
             User has disabled the calculation of REFUELING emissions.

  M615 Comment:
             User supplied VMT mix.

* Reading non-default MILEAGE ACCUMULATION RATES from the following external
* data file: MARDATA.IN

* Reading Registration Distributions from the following external
* data file: REGDATA.IN

* Reading Hourly VMT distribution from the following external
* data file: HVMT.IN

* Reading Hourly Roadway VMT distribution from the following external
* data file: FVMT.IN

  Reading User Supplied ROADWAY VMT Factors

* Reading Hourly, Roadway, and Speed VMT dist. from the following external
* data file: SVMT.IN
  M616 Comment:
             User has supplied post-1999 sulfur levels.
  M614 Comment:
             User supplied diesel sale fractions.

* # # # # # # # # # # # # # # # # # # # # # # # # #
*  Winnipeg 2006 January
* File 1, Run 1, Scenario 1.
* # # # # # # # # # # # # # # # # # # # # # # # # #

* Reading PM Gas Carbon ZML Levels
* from the external data file PMGZML.CSV

* Reading PM Gas Carbon DR1 Levels
* from the external data file PMGDR1.CSV

* Reading PM Gas Carbon DR2 Levels
* from the external data file PMGDR2.CSV

* Reading PM Diesel Zero Mile Levels
* from the external data file PMDZML.CSV

* Reading the First PM Deterioration Rates
* from the external data file PMDDR1.CSV

* Reading the Second PM Deterioration Rates
* from the external data file PMDDR2.CSV

* Reading the Additional HAPS Rates
* from the external data file HAP_BASE.CSV

* Successfully read in  917 Additional HAPS lines
* from the external data file HAP_BASE.CSV

* Reading Ammonia (NH3) Basic Emissiion Rates
* from the external data file PMNH3BER.D

* Reading Ammonia (NH3) Sulfur Deterioration Rates
* from the external data file PMNH3SDR.D

                    Calendar Year:  2006
                            Month:  Jan.
                         Altitude:  Low
              Minimum Temperature:  18.1 (F)
              Maximum Temperature:  22.1 (F)
                Minimum Rel. Hum.:  82.0 (%)
                Maximum Rel. Hum.:  86.0 (%)
              Barometric Pressure: 29.00 (inches Hg)
                 Nominal Fuel RVP:  14.4 psi
                    Weathered RVP:  14.4 psi
              Fuel Sulfur Content:   25. ppm

              Exhaust I/M Program:  No
                 Evap I/M Program:  No
                      ATP Program:  No
                 Reformulated Gas:  NA (See Air Toxics Output)

              User supplied hourly temperatures.

   Ether Blend Market Share: 0.000       Alcohol Blend Market Share: 0.000
   Ether Blend Oxygen Content: 0.000     Alcohol Blend Oxygen Content: 0.000
                                          Alcohol Blend RVP Waiver: No
                                   Ethanol Evap Permeation Effects: No
                                               Ethanol NOx Effects: No
```

Vehicle Type:	LDGV	LDGT12	LDGT34	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
GVWR:		<6000	>6000	(All)						
VMT Distribution:	0.5369	0.2231	0.1444		0.0139	0.0052	0.0217	0.0546	0.0002	1.0000
Fuel Economy (mpg):	24.0	18.7	14.4	16.8	8.8	32.3	17.3	7.2	50.0	18.2
Composite Emission Factors (g/mi):										
Composite THC :	1.851	2.184	3.323	2.632	2.292	0.373	0.642	0.595	2.49	2.042
Composite CO :	34.33	39.25	59.85	47.34	35.33	1.304	1.168	3.392	21.54	36.544
Composite NOX :	1.692	2.056	2.891	2.384	5.503	1.023	1.408	12.195	1.92	2.564
Composite CO2 :	369.7	473.4	615.9	529.4	1004.7	315.0	589.0	1407.6	177.4	498.34
Exhaust emissions (g/mi):										
THC Start:	0.823	1.065	1.737	1.329		0.116	0.188		0.862	
THC Running:	0.615	0.771	1.189	0.935		0.257	0.454		1.575	
THC Total Exhaust:	1.438	1.836	2.925	2.264	1.757	0.373	0.642	0.595	2.44	1.677
CO Start:	16.60	20.23	37.60	27.06		0.483	0.416		6.941	
CO Running:	17.72	19.01	22.26	20.29		0.822	0.751		14.596	
CO Total Exhaust:	34.33	39.25	59.85	47.34	35.33	1.304	1.168	3.392	21.54	36.544
NOx Start:	0.320	0.413	0.626	0.496		0.035	0.040		0.699	
NOx Running:	1.372	1.643	2.265	1.888		0.988	1.367		1.222	
NOx Total Exhaust:	1.692	2.056	2.891	2.384	5.503	1.023	1.408	12.195	1.92	2.564
Non-Exhaust Emissions (g/mi):										
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.139	0.114	0.145	0.126	0.263	0.000	0.000	0.000	0.053	0.125
Running Loss:	0.264	0.223	0.237	0.228	0.260	0.000	0.000	0.000	0.000	0.229
Crankcase Loss:	0.010	0.012	0.016	0.013	0.012	0.000	0.000	0.000	0.000	0.010
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.413	0.348	0.398	0.361	0.535	0.000	0.000	0.000	0.053	0.364

Veh. Type:	LDGT1	LDGT2	LDGT3	LDGT4	LDDT12	LDDT34
VMT Mix:	0.0204	0.2027	0.0848	0.0597	0.0011	0.0206
Fuel Economy (mpg):	18.7	18.7	14.4	14.4	22.1	17.1
Composite Emission Factors (g/mi):						
Composite THC :	2.106	2.192	3.283	3.379	0.457	0.652
Composite CO :	38.19	39.35	59.73	60.03	0.991	1.177
Composite NOX :	1.698	2.092	2.689	3.178	0.898	1.434
Composite CO2 :	473.4	473.4	615.9	615.9	460.2	595.8
Exhaust emissions (g/mi):						
THC Start:	1.018	1.070	1.713	1.770	0.141	0.190
THC Running:	0.739	0.774	1.173	1.211	0.316	0.462
THC Total Exhaust:	1.757	1.844	2.885	2.982	0.457	0.652
CO Start:	19.44	20.31	37.51	37.73	0.365	0.419
CO Running:	18.75	19.04	22.23	22.30	0.626	0.758
CO Total Exhaust:	38.19	39.35	59.73	60.03	0.991	1.177
NOx Start:	0.354	0.419	0.595	0.670	0.030	0.041
NOx Running:	1.344	1.673	2.095	2.508	0.868	1.394
NOx Total Exhaust:	1.698	2.092	2.689	3.178	0.898	1.434
Non-Exhaust Emissions (g/mi):						
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.114	0.114	0.145	0.145	0.000	0.000
Running Loss:	0.223	0.223	0.237	0.237	0.000	0.000
Crankcase Loss:	0.012	0.012	0.016	0.016	0.000	0.000
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.348	0.348	0.398	0.398	0.000	0.000

Veh. Type:	HDGV2B	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	HDGV8B
VMT Mix:	0.0066	0.0021	0.0004	0.0003	0.0029	0.0007	0.0005	0.0002
Fuel Economy (mpg):	10.0	9.2	9.1	7.9	7.6	7.3	7.0	6.6
Composite Emission Factors (g/mi):								
Composite THC :	1.244	2.046	1.709	2.453	5.021	2.519	1.610	2.118
Composite CO :	15.62	31.14	25.59	31.86	86.26	40.29	24.24	32.77
Composite NOX :	4.443	5.288	4.654	5.251	7.654	6.708	5.824	8.294
Composite CO2 :	887.9	968.4	972.6	1121.1	1161.3	1214.7	1271.0	1341.5
Exhaust emissions (g/mi):								
THC Total Exhaust:	0.925	1.630	1.257	1.536	3.878	2.034	1.240	1.671
CO Total Exhaust:	15.62	31.14	25.59	31.86	86.26	40.29	24.24	32.77
NOx Total Exhaust:	4.443	5.288	4.654	5.251	7.654	6.708	5.824	8.294
Non-Exhaust Emissions (g/mi):								
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.095	0.124	0.221	0.719	0.735	0.225	0.205	0.246
Running Loss:	0.211	0.280	0.222	0.188	0.396	0.248	0.157	0.193
Crankcase Loss:	0.012	0.012	0.008	0.009	0.012	0.013	0.009	0.008
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.319	0.416	0.452	0.917	1.143	0.486	0.371	0.447

Veh. Type:	HDDV2B	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	HDDV8B
VMT Mix:	0.0147	0.0015	0.0005	0.0002	0.0017	0.0034	0.0063	0.0218
Fuel Economy (mpg):	12.8	11.3	10.1	9.7	8.4	7.5	6.5	6.2
Composite Emission Factors (g/mi):								
Composite THC :	0.278	0.427	0.441	0.469	0.898	0.748	0.615	0.704
Composite CO :	1.215	1.980	2.039	2.353	4.740	3.206	3.570	4.268
Composite NOX :	4.462	6.024	6.555	6.743	11.576	11.541	13.703	16.321
Composite CO2 :	797.4	896.9	1011.4	1046.7	1206.5	1355.8	1563.6	1650.4
Exhaust emissions (g/mi):								
THC Total Exhaust:	0.278	0.427	0.441	0.469	0.898	0.748	0.615	0.704
CO Total Exhaust:	1.215	1.980	2.039	2.353	4.740	3.206	3.570	4.268
NOx Total Exhaust:	4.462	6.024	6.555	6.743	11.576	11.541	13.703	16.321
Non-Exhaust Emissions (g/mi):								
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Running Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crankcase Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Veh. Type:	GasBUS	URBAN	SCHOOL
VMT Mix:	0.0001	0.0041	0.0005
Fuel Economy (mpg):	6.4	4.2	6.2
Composite Emission Factors (g/mi):			
Composite THC :	2.074	0.919	0.778
Composite CO :	31.91	6.626	2.859
Composite NOX :	7.083	19.472	12.594
Composite CO2 :	1385.8	2401.8	1641.4
Exhaust emissions (g/mi):			
THC Total Exhaust:	1.677	0.919	0.778
CO Total Exhaust:	31.91	6.626	2.859
NOx Total Exhaust:	7.083	19.472	12.594
Non-Exhaust Emissions (g/mi):			
Hot Soak Loss:	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000
Resting Loss:	0.150	0.000	0.000
Running Loss:	0.236	0.000	0.000
Crankcase Loss:	0.011	0.000	0.000
Refueling Loss:	0.000	0.000	0.000
Total Non-Exhaust:	0.398	0.000	0.000

This sample input file shows the Header section, Run Section, and 1 Scenario Section (January) for Saskatoon.

```
********** Header section ****************************************************************
* DESCRIPTION: This file is designed for MOBILE6.2C and will provide output for the     *
* Emissions Modelling Network for Saskatoon.                                             *
*                                                                                        *
* This file is Saskatoona.in.  Lower case 'a' in the file name indicates the file       *
* estimatesPM10 and HC as VOC only. A lower case 'b' in the file in the file name       *
* indicates the file estimates PM2.5 and HC as THC only.                                 *
*                                                                                        *
* CREATED: The base file was created by Brett Taylor on May 21, 2009                    *
* MODIFIED: Keenan Patmore modified the file on February 7, 2011                        *
*                                                                                        *
* Sources to inputs are documented throughout. Vehicle activity data in this model is   *
* developed in the project "Development of Inputs for Modelling Vehicle Emissions:      *
* Spatial, Temporal, and Vehicle Specific Factors for Saskatoon" (Patmore et al., (2011)*
* Meteorological data from: Winnipeg's Richardson International Airport station.        *
*                                                                                        *
* Each year will have twelve scenarios; one for each month.                              *
******************************************************************************************

MOBILE6 INPUT FILE
PARTICULATES       :
AIR TOXICS         :
POLLUTANTS         : HC CO NOX CO2
SPREADSHEET        :
DATABASE OUTPUT    :
WITH FIELDNAMES    :
DAILY OUTPUT       :

RUN DATA


********** Run  Section 1 Saskatoon 2006 **********
> Manitoba 2006  - All MOBILE6.2C pollutants
EXPRESS HC AS VOC  :
NO REFUELING       :

VMT FRACTIONS      :
0.5188 0.0185 0.1688 0.1050 0.1107 0.0415 0.0049 0.0010
0.0003 0.0048 0.0035 0.0053 0.0123 0.0006 0.0038 0.0002


* Specify  mileage accumulation rates
MILE ACCUM RATE    : MARDATA.in

* Specify  age distribution
* Source: M6C-10-E.doc
REG DIST           : REGDATA.in

* Expand vehicle class descriptive output
EXPAND BUS EFS     :
EXPAND HDDV EFS    :
EXPAND HDGV EFS    :
EXPAND LDT EFS     :

IDLE PM EMISSIONS  :

* Expand exhaust emissions descriptive output
EXPAND EXHAUST     :

* Expand evaporative emissions descriptive output
EXPAND EVAPORATIVE :

* Specify the fraction of total VMT that occurs at each hour of the day
VMT BY HOUR        : HVMT.in

* Specify the fraction of total VMT that occurs at each hour of the day on each facility
VMT BY FACILITY    : FVMT.in

* Specify  vehicle miles traveled (VMT) by average speed on freeways and arterial roads
SPEED VMT          : SVMT.in

* Because it is now post-1999 calendar year  sulphur levels in gasoline must be specified
* using the FUEL PROGRAM command (see Advanced Training Guide manual  Day 1  page 46)
* Sulphur source: Environment Canada's Sulphur in Liquid Fuels annual report
* Max Sulphur content from CEPA Sulphur in Gasoline Regulation Registration June 4  1999
* The regulation implies the use of 25ppm for years after 2004.
* The 4 rows and 8 columns below represent;
* row 1 - average sulphur levels (ppm) from 2000 to 2007
* row 2 - average sulphur levels (ppm) from 2008 to 2015
* row 3 - maximum sulphur levels (ppm) from 2000 to 2007
* row 4 - maximum sulphur levels (ppm) from 2008 to 2015
FUEL PROGRAM       : 4
220.0 220.0 200.0 157.0 61.0 25.0 25.0 25.0
25.0 25.0 25.0 25.0 25.0 25.0 25.0 25.0
500.0 500.0 500.0 500.0 500.0 25.0 25.0 25.0
25.0 25.0 25.0 25.0 25.0 25.0 25.0 25.0
```

```
* Specify  diesel fractions
* Source: M6C-10-E.doc
* If actual data is not available for this year  use most recent available year. Data used in
* this case was estimated for calendar year:    2006

DIESEL FRACTIONS   :
0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096
0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0096 0.0097 0.0096
0.0095 0.0097 0.0095 0.0095 0.0096
0.0394 0.0391 0.0393 0.0389 0.0389 0.0393 0.0395 0.0394 0.0390 0.0394
0.0390 0.0392 0.0388 0.0390 0.0392 0.0390 0.0395 0.0391 0.0382 0.0407
0.0380 0.0398 0.0000 0.0000 0.0388
0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008 0.0008
0.0008 0.0008 0.0008 0.0008 0.0008 0.0009 0.0008 0.0008 0.0008 0.0009
0.0011 0.0010 0.0000 0.0000 0.0009
0.0159 0.0158 0.0160 0.0159 0.0159 0.0159 0.0158 0.0161 0.0160 0.0159
0.0158 0.0161 0.0161 0.0160 0.0161 0.0161 0.0158 0.0160 0.0161 0.0163
0.0155 0.0158 0.0161 0.0161 0.0159
0.2206 0.2205 0.2205 0.2206 0.2206 0.2205 0.2205 0.2206 0.2205 0.2205
0.2205 0.2206 0.2205 0.2205 0.2205 0.2204 0.2206 0.2207 0.2206 0.2203
0.2208 0.2205 0.2208 0.2202 0.2205
0.6708 0.6709 0.6711 0.6702 0.6709 0.6706 0.6703 0.6707 0.6708 0.6710
0.6705 0.6706 0.6708 0.6704 0.6710 0.6701 0.6713 0.6701 0.6715 0.6711
0.6716 0.6709 0.6000 0.0000 0.6667
0.3971 0.3970 0.3988 0.3983 0.3962 0.3982 0.3955 0.3986 0.3974 0.3980
0.3971 0.3970 0.3972 0.3970 0.3986 0.3980 0.3966 0.3980 0.3989 0.4000
0.4000 0.3984 0.3889 0.3902 0.3978
0.3915 0.3947 0.3889 0.3889 0.3902 0.3926 0.3939 0.3929 0.3913 0.3951
0.3962 0.3966 0.3902 0.3932 0.3913 0.4063 0.4000 0.4000 0.3929 0.4000
0.4000 0.4167 0.0000 0.0000 0.3929
0.3167 0.3208 0.3214 0.3158 0.3182 0.3235 0.3000 0.3226 0.3077 0.3000
0.3077 0.3000 0.3000 0.3182 0.3182 0.3750 0.2857 0.3333 0.3077 0.3333
0.3333 0.3243 0.3333 0.3077 0.3177
0.2533 0.2535 0.2530 0.2538 0.2537 0.2518 0.2516 0.2561 0.2539 0.2530
0.2560 0.2551 0.2530 0.2560 0.2535 0.2549 0.2537 0.2554 0.2526 0.2537
0.2542 0.2539 0.2532 0.2539 0.2541
0.7313 0.7288 0.7313 0.7312 0.7302 0.7301 0.7325 0.7320 0.7301 0.7292
0.7296 0.7292 0.7310 0.7330 0.7304 0.7312 0.7317 0.7321 0.7328 0.7288
0.7281 0.7313 0.7319 0.7333 0.7303
0.7871 0.7861 0.7870 0.7887 0.7862 0.7889 0.7857 0.7890 0.7887 0.7891
0.7857 0.7857 0.7895 0.7875 0.7892 0.7879 0.7895 0.7895 0.7905 0.7931
0.7895 0.7857 0.7882 0.7849 0.7874
0.9552 0.9551 0.9555 0.9551 0.9553 0.9554 0.9560 0.9555 0.9559 0.9549
0.9547 0.9567 0.9563 0.9549 0.9552 0.9563 0.9548 0.9562 0.9553 0.9524
0.9559 0.9567 0.9544 0.9554 0.9552
0.8902 0.8917 0.8878 0.8876 0.8881 0.8896 0.8876 0.8889 0.8872 0.8881
0.8876 0.8947 0.8926 0.8897 0.8869 0.8874 0.8903 0.8913 0.8854 0.8846
0.8846 0.8947 0.8846 0.8929 0.8874

********** Scenario Section 1 Run  1 Saskatoon 2006 January
SCENARIO RECORD    :  Saskatoon 2006 January
CALENDAR YEAR      :  2006

* Evaluation month is set to 7 for 'summer'; 1 for 'winter'. October 1 through April 31
* get 'winter' fuel properties; May 1 through September 31 get 'summer' fuel properties
* (or special RVPs where applicable).

EVALUATION MONTH   :  1

* Specify PM10 size
PARTICLE SIZE      : 10.0
PARTICULATE EF     : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV

* On-road diesel sulphur content  in parts per million (ppm)  from Sulphur in Liquid Fuels
* reports (OGEB)
DIESEL SULFUR      :  167.0

* The SULFUR CONTENT command  below  becomes irrelevant for years after 1999
* the FUEL COMMAND in the RUN section above is used to specify sulphur levels
* SULFUR CONTENT     :  25.0

HOURLY TEMPERATURES: 16.5 16.3 16.3 16.3 16.7 17.6 19.1 20.0 21.0 21.8 21.8 20.9
19.4 18.8 18.3 17.8 17.3 16.8 17.2 16.9 16.8 16.8 16.3 16.2

* Relative humidity by percent
RELATIVE HUMIDITY  : 84.6 84.8 84.5 84.0 83.8 83.7 83.7 82.9 82.4 81.6 81.5 81.8
82.7 83.6 83.9 83.8 83.9 84.6 85.0 85.0 85.0 85.0 84.9 84.7

* Barometric pressure measure in inches of mercury
BAROMETRIC PRES    : 28.0

* All the fuel parameters below come from Appendix B of the report <Emissions of Air Toxics
* from on-Highway sources in Canada>  March 2002
* Volume percent is needed (not %wt). ETOH conversion factor in MOBILE6 users' manual should
* be 0.3488.

FUEL RVP           :  14.4
GAS AROMATIC%      :  23.6
GAS OLEFIN%        :  10.1
GAS BENZENE%       :  0.7
E200               :  55.6
E300               : 86.6
OXYGENATE          :  MTBE 0.0 0.00
                   :  ETOH 0.0 0.00 1 1 NA NA
                   :  ETBE 0.0 0.00
                   :  TAME 0.0 0.00
ADDITIONAL HAPS    :  HAP_BASE.CSV
```

This sample output file shows output for the month of January in Saskatoon.

```
******************************************************************************
* MOBILE6C 6.2ETOH (27-May-2005)                                             *
* Input file: SASKATOONA.IN (file 1, run 1).                                 *
******************************************************************************
* Manitoba 2006  - All MOBILE6.2C pollutants
  M603 Comment:
             User has disabled the calculation of REFUELING emissions.

  M615 Comment:
             User supplied VMT mix.

* Reading non-default MILEAGE ACCUMULATION RATES from the following external
* data file: MARDATA.IN

* Reading Hourly VMT distribution from the following external
* data file: HVMT.IN

* Reading Hourly Roadway VMT distribution from the following external
* data file: FVMT.IN

  Reading User Supplied ROADWAY VMT Factors

* Reading Hourly, Roadway, and Speed VMT dist. from the following external
* data file: SVMT.IN
  M616 Comment:
             User has supplied post-1999 sulfur levels.
  M614 Comment:
             User supplied diesel sale fractions.

* # # # # # # # # # # # # # # # # # # # # # # # # #
*  Saskatoon 2006 January
* File 1, Run 1, Scenario 1.
* # # # # # # # # # # # # # # # # # # # # # # # # #

* Reading PM Gas Carbon ZML Levels
* from the external data file PMGZML.CSV

* Reading PM Gas Carbon DR1 Levels
* from the external data file PMGDR1.CSV

* Reading PM Gas Carbon DR2 Levels
* from the external data file PMGDR2.CSV

* Reading PM Diesel Zero Mile Levels
* from the external data file PMDZML.CSV

* Reading the First PM Deterioration Rates
* from the external data file PMDDR1.CSV

* Reading the Second PM Deterioration Rates
* from the external data file PMDDR2.CSV

* Reading the Additional HAPS Rates
* from the external data file HAP_BASE.CSV

* Successfully read in  917 Additional HAPS lines
* from the external data file HAP_BASE.CSV

* Reading Ammonia (NH3) Basic Emissiion Rates
* from the external data file PMNH3BER.D

* Reading Ammonia (NH3) Sulfur Deterioration Rates
* from the external data file PMNH3SDR.D

                    Calendar Year:  2006
                            Month:  Jan.
                         Altitude:  Low
              Minimum Temperature:  16.2 (F)
              Maximum Temperature:  21.8 (F)
                Minimum Rel. Hum.:  81.5 (%)
                Maximum Rel. Hum.:  85.0 (%)
              Barometric Pressure: 28.00 (inches Hg)
                 Nominal Fuel RVP:  14.4 psi
                    Weathered RVP:  14.4 psi
              Fuel Sulfur Content:   25. ppm

              Exhaust I/M Program:  No
                 Evap I/M Program:  No
                      ATP Program:  No
                 Reformulated Gas:  NA (See Air Toxics Output)

              User supplied hourly temperatures.

   Ether Blend Market Share: 0.000        Alcohol Blend Market Share: 0.000
   Ether Blend Oxygen Content: 0.000      Alcohol Blend Oxygen Content: 0.000
                                           Alcohol Blend RVP Waiver: No
                                    Ethanol Evap Permeation Effects: No
                                                Ethanol NOx Effects: No
```

Vehicle Type: GVWR:	LDGV	LDGT12 <6000	LDGT34 >6000	LDGT (All)	HDGV	LDDV	LDDT	HDDV	MC	All Veh
VMT Distribution:	0.5138	0.1864	0.1870		0.0207	0.0050	0.0296	0.0573	0.0002	1.0000
Fuel Economy (mpg):	23.9	18.8	14.4	16.3	9.1	32.2	17.3	8.4	50.0	18.1
Composite Emission Factors (g/mi):										
Composite VOC :	2.313	2.997	4.127	3.563	1.781	0.411	0.710	0.469	2.34	2.606
Composite CO :	43.68	49.31	77.93	63.65	33.29	1.254	1.197	2.588	24.02	47.093
Composite NOX :	2.263	2.595	3.452	3.024	5.550	1.172	1.441	11.162	2.46	3.096
Composite CO2 :	370.8	472.6	615.0	543.9	971.7	316.3	589.3	1211.7	177.4	502.24
Exhaust emissions (g/mi):										
VOC Start:	1.178	1.669	2.369	2.019		0.152	0.230		0.902	
VOC Running:	0.648	0.899	1.301	1.100		0.259	0.480		1.380	
VOC Total Exhaust:	1.825	2.568	3.669	3.120	1.268	0.411	0.710	0.469	2.28	2.179
CO Start:	21.56	25.20	52.71	38.98		0.547	0.483		7.113	
CO Running:	22.12	24.11	25.23	24.67		0.707	0.714		16.911	
CO Total Exhaust:	43.68	49.31	77.93	63.65	33.29	1.254	1.197	2.588	24.02	47.093
NOx Start:	0.442	0.503	0.802	0.653		0.042	0.047		0.705	
NOx Running:	1.821	2.091	2.650	2.371		1.129	1.394		1.757	
NOx Total Exhaust:	2.263	2.595	3.452	3.024	5.550	1.172	1.441	11.162	2.46	3.096
Non-Exhaust Emissions (g/mi):										
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.224	0.188	0.209	0.198	0.303	0.000	0.000	0.000	0.053	0.196
Running Loss:	0.251	0.224	0.229	0.226	0.199	0.000	0.000	0.000	0.000	0.218
Crankcase Loss:	0.012	0.017	0.020	0.018	0.011	0.000	0.000	0.000	0.000	0.013
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.488	0.428	0.458	0.436	0.514	0.000	0.000	0.000	0.053	0.427

Veh. Type:	LDGT1	LDGT2	LDGT3	LDGT4	LDDT12	LDDT34
VMT Mix:	0.0177	0.1687	0.1031	0.0839	0.0009	0.0287
Fuel Economy (mpg):	18.8	18.8	14.4	14.4	22.2	17.1
Composite Emission Factors (g/mi):						
Composite VOC :	2.949	3.002	4.091	4.170	0.507	0.717
Composite CO :	48.42	49.40	77.80	78.10	0.999	1.203
Composite NOX :	2.272	2.629	3.247	3.705	0.981	1.456
Composite CO2 :	472.6	472.6	615.0	615.0	459.3	593.5
Exhaust emissions (g/mi):						
VOC Start:	1.637	1.672	2.345	2.398	0.177	0.231
VOC Running:	0.883	0.901	1.289	1.315	0.330	0.485
VOC Total Exhaust:	2.519	2.573	3.634	3.713	0.507	0.717
CO Start:	24.51	25.27	52.61	52.83	0.424	0.485
CO Running:	23.91	24.13	25.19	25.27	0.575	0.718
CO Total Exhaust:	48.42	49.40	77.80	78.10	0.999	1.203
NOx Start:	0.450	0.509	0.770	0.841	0.036	0.048
NOx Running:	1.822	2.120	2.477	2.864	0.944	1.408
NOx Total Exhaust:	2.272	2.629	3.247	3.705	0.981	1.456
Non-Exhaust Emissions (g/mi):						
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.188	0.187	0.209	0.209	0.000	0.000
Running Loss:	0.224	0.224	0.229	0.229	0.000	0.000
Crankcase Loss:	0.017	0.017	0.020	0.020	0.000	0.000
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.430	0.428	0.457	0.458	0.000	0.000

Veh. Type:	HDGV2B	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	HDGV8B
VMT Mix:	0.0129	0.0029	0.0005	0.0002	0.0030	0.0006	0.0004	0.0001
Fuel Economy (mpg):	10.0	9.1	8.8	7.8	7.4	7.2	6.9	6.5
Composite Emission Factors (g/mi):								
Composite VOC :	0.869	1.516	2.417	3.817	5.500	3.007	1.491	1.748
Composite CO :	13.30	30.17	44.63	49.20	114.17	61.12	26.20	34.52
Composite NOX :	4.327	5.739	6.217	6.584	9.444	8.773	6.626	9.734
Composite CO2 :	887.2	971.1	1002.8	1134.1	1201.7	1237.2	1279.3	1354.0
Exhaust emissions (g/mi):								
VOC Total Exhaust:	0.616	1.166	1.640	1.753	3.889	2.261	1.012	1.206
CO Total Exhaust:	13.30	30.17	44.63	49.20	114.17	61.12	26.20	34.52
NOx Total Exhaust:	4.327	5.739	6.217	6.584	9.444	8.773	6.626	9.734
Non-Exhaust Emissions (g/mi):								
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.093	0.135	0.513	1.864	1.210	0.451	0.318	0.372
Running Loss:	0.148	0.203	0.257	0.191	0.392	0.281	0.151	0.160
Crankcase Loss:	0.012	0.012	0.007	0.008	0.010	0.014	0.010	0.009
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.253	0.350	0.777	2.064	1.611	0.746	0.479	0.542

Veh. Type:	HDDV2B	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	HDDV8B
VMT Mix:	0.0286	0.0020	0.0005	0.0001	0.0018	0.0029	0.0049	0.0122
Fuel Economy (mpg):	12.8	11.3	9.9	9.6	8.3	7.5	6.5	6.1
Composite Emission Factors (g/mi):								
Composite VOC :	0.238	0.377	0.539	0.515	0.933	0.781	0.578	0.603
Composite CO :	1.058	1.836	2.619	2.780	5.455	3.741	3.387	3.900
Composite NOX :	4.198	6.666	8.886	8.554	14.121	14.215	17.510	22.954
Composite CO2 :	796.7	899.6	1028.2	1062.4	1227.8	1359.5	1572.8	1664.8
Exhaust emissions (g/mi):								
VOC Total Exhaust:	0.238	0.377	0.539	0.515	0.933	0.781	0.578	0.603
CO Total Exhaust:	1.058	1.836	2.619	2.780	5.455	3.741	3.387	3.900
NOx Total Exhaust:	4.198	6.666	8.886	8.554	14.121	14.215	17.510	22.954
Non-Exhaust Emissions (g/mi):								
Hot Soak Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Resting Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Running Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crankcase Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Refueling Loss:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Non-Exhaust:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Veh. Type:	GasBUS	URBAN	SCHOOL
VMT Mix:	0.0001	0.0038	0.0005
Fuel Economy (mpg):	6.4	4.2	6.2
Composite Emission Factors (g/mi):			
Composite VOC :	2.149	1.162	0.837
Composite CO :	32.52	6.982	2.852
Composite NOX :	7.051	16.658	10.473
Composite CO2 :	1389.6	2427.9	1639.4
Exhaust emissions (g/mi):			
VOC Total Exhaust:	1.647	1.162	0.837
CO Total Exhaust:	32.52	6.982	2.852
NOx Total Exhaust:	7.051	16.658	10.473
Non-Exhaust Emissions (g/mi):			
Hot Soak Loss:	0.000	0.000	0.000
Diurnal Loss:	0.000	0.000	0.000
Resting Loss:	0.219	0.000	0.000
Running Loss:	0.271	0.000	0.000
Crankcase Loss:	0.012	0.000	0.000
Refueling Loss:	0.000	0.000	0.000
Total Non-Exhaust:	0.502	0.000	0.000