MODELING VEHICLE FUEL CONSUMPTION AND EMISSIONS AT SIGNALIZED INTERSECTION APPROACHES: INTEGRATING FIELD-COLLECTED DATA INTO MICROSCOPIC SIMULATION

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16. Abstract

Microscopic models produce emissions and fuel consumption estimates with higher temporal resolution than other scales of models. Most emissions and fuel consumption models were developed with data from dynamometer testing which are sufficiently accurate for macroscopic level emissions inventories. The primary goal of this project is to improve the microscopic modeling of emission and fuel consumption by integrating detailed vehicle data into the simulation. The proposed approach combines a microscopic traffic simulation model (VISSIM) with detailed emissions and fuel consumption data that is either collected in the field or obtained from an existing emission inventory dataset. The project also examines the possibility of using the vehicle's on-board diagnostic board (OBD) to record real-time engine and emissions data at a high temporal resolution. The outcome of this project provides transportation operators with a model that is capable of reliably estimating the environmental impact of various traffic management policies at the microscopic modeling and would fill a gap that currently exists in traffic modeling capabilities.

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EXECUTIVE SUMMARY

Microscopic models produce emissions and fuel consumption estimates with higher temporal resolution than other scales of models. Most emissions and fuel consumption models were developed with data from dynamometer testing which are sufficiently accurate for macroscopic level emissions inventories. The primary goal of this project is to improve the microscopic modeling of emission and fuel consumption by integrating detailed vehicle data into the simulation. The proposed approach combines a microscopic traffic simulation model with detailed emissions and fuel consumption data that are either collected in the field or obtained from an existing emission inventory dataset.

There are two basic approaches that may be taken to combine the Environmental Protection Agency (EPA) detailed emissions and fuel consumption data, used in the Motor Vehicle Emission Simulator (MOVES) model, with microscopic simulation tools, such as VISSIM. One alternative is to use the microscopic simulation model vehicle specific power trajectory data as source activity input for a MOVES emissions model. This approach has the potential to improve the quality of source activity input to MOVES project scale analysis, as well as make the process of generating activity input simpler for the user. The second alternative is to use the emissions and vehicle data contained in the MOVES default database to improve the input to the microscopic simulation emissions module to assist users in developing custom emissions profiles in the emission module in order to more accurately represent the vehicle fleet operating in the United States. Full descriptions of the two alternatives as well as a case study to illustrate how EPA MOVES' data can be integrated into microscopic simulation are provided in this report.

Most microscopic simulation tools model vehicle operations only from the kinematic point of view with little or no consideration to kinetic components of the motion (drag force, wind resistance, slope resistance, momentums, etc.). The microscopic vehicle trajectories produced by these models show speed and acceleration values that are erratic leading to higher vehicle specific power (VSP) than observed in the real world. The vehicle speed data generated by the microscopic simulation models should be validated to ensure that the VSP estimated using these trajectories are consistent with field operations.

Using vehicle on-board diagnostics (OBD), it is possible to record a large number of vehicle operating parameters. A discussion of the validity of using vehicle on-board diagnostics and portable emissions analyzers to collect real-time emissions and fuel consumption data from vehicles operating in the field is also presented in this report. Specifically it will review the temporal resolution of the data that can be gathered from each device.

The outcome of this project provides transportation operators with a model that is capable of reliably estimating the environmental impact of various traffic management policies at the microscopic modeling and would fill a gap that currently exists in traffic modeling capabilities. The project also examines the possibility of using the vehicle’s OBD to record real-time engine and emissions data at a high temporal resolution.

DESCRIPTION OF PROBLEM

1.1 Overview

The transportation sector in the United States requires the use of 27% of our energy nationally, and is a major contributor to air pollution. Mobile sources (i.e., highway and non-road vehicles) are responsible for emitting a variety of pollutants and air toxics. Unburned hydrocarbons (UHCs) and other volatile organic compounds (VOCs), carbon monoxide (CO), and particulate matter (PM) are produced by incomplete combustion of fuel. Nitrogen oxides (NO_x) are a result of fuel combustion at high temperature and pressure. Carbon dioxide (CO_2) is produced by complete combustion of fuel molecules, but has been implicated in climate change. Sulfur dioxide (SO_2) is a product from mostly the combustion of diesel fuel. There are two major components of motor vehicle emissions: exhaust emissions and evaporative emissions. Exhaust emissions are comprised of start-up emissions and running emissions. Start-up emissions are caused when a catalytic converter is not hot enough to be fully effective, and the air/fuel mixture is often fuel-rich to ensure the engine will start. Running emissions are primarily a result of incomplete combustion of fuel, although oxides of nitrogen are primarily caused by fuel-lean mixtures, and the resulting high in-cylinder temperatures. There are four ways in which evaporative emissions occur:

1. Diurnal evaporation is caused by an increase in ambient air temperature which vaporizes fuel inside of vehicle tanks, regardless of whether they are running or not.
2. Running losses are the result of the heat of in-use vehicle engines vaporizing fuel.
3. Engines retain heat for some time after being shut off, so vaporization will continue to occur. This process is known as hot soak emissions.
4. The act of refueling expels fuel vapors from fuel tanks.

1.2 Variables Affecting Emissions and Fuel Consumption

The National Research Council (NRC 1995) defined four categories of variables related to mobile source emissions and fuel consumption: driver behavior, travel-related factors, highway network characteristics, and vehicle characteristics. In addition, meteorological conditions will also affect both fuel consumption and emission levels. Vehicle operating modes (i.e., acceleration, deceleration, cruise, and idle) greatly effect emissions and fuel consumption. Smooth, cruise-type steady-state driving results in better fuel economy and lower emissions than stop-and-go and aggressive driving. Vehicle start-up conditions have a significant impact on emissions and fuel consumption. Start-ups may be cold or hot, depending on whether the catalytic converter is sufficiently hot to be immediately effective. Cold start-ups result in much higher emissions and lower fuel efficiency than hot start-ups. Speed and acceleration are the most significant variables of fuel consumption. Heavy acceleration increases emissions and fuel consumption rates. Fuel efficiency is generally lower at low speeds because of the effects of engine friction and rolling resistance, and in congested conditions, because of frequent decelerations and accelerations.

At higher speeds, fuel efficiency decreases due to drag. Highway networks may also have features that increase emission and fuel consumption rates, such as grades, signalized intersections, driveways, and rough pavement. Emissions are also impacted by vehicle age and condition. In general, older vehicles and vehicles with more accumulated mileage have higher emission rates and lower fuel efficiencies, due to degradation of emission controls and less stringent emission standards at the time of manufacture. Vehicles that have been poorly maintained or have faulty devices are responsible for emission rates that are about one order of magnitude higher than other vehicles, and thus are referred to as high emitters or super-emitters. Poor vehicle maintenance can reduce fuel efficiency as well, such as having underinflated tires, or poorly tuned or maintained engines.

The type and amount of pollutants emitted is affected by vehicle type. Light duty vehicles (LDVs) in the U.S., including passenger cars and light duty trucks (LDTs), are normally fueled with gasoline or a gasoline/ethanol blend, are smaller, and have less weight than heavy duty trucks (HDTs), which typically use diesel fuel. Lighter vehicles tend to have better fuel economy; although diesel-fueled HDTs have better fuel efficiency by weight than gasoline-fueled LDVs. Larger vehicles also have greater drag, which lessens fuel efficiency. Different pollutant mixes are associated with different fuel types. The emissions of gasoline-fueled vehicles are mostly CO, with lower amounts of VOCs and NO_x, while diesel-fueled vehicles emit mostly NO_x, with lower amounts of CO, PM, SO_2, and VOCs.

1.3 Modeling Vehicle Emissions: Analysis Scales

There are three general scales at which emissions and fuel consumption may be modeled: macroscopic (e.g., regional level), mesoscopic (e.g., corridor level), and microscopic (e.g., individual vehicle level). Typically, the inputs to macroscopic models are variables that have been aggregated temporally and spatially, such as average speed and vehicle miles traveled (VMT). A common application of macroscopic models is calculating regional emission inventories. Microscopic models produce emissions and fuel consumption estimates with higher temporal resolution. Modeling variables other than time and space may be aggregated as well, for example vehicle characteristics such as type, age, and condition. Regardless of analysis scale, models may be considered comprehensive if their input parameters can reflect a relatively high degree of variability.

1.4 Field Measurements of Emissions and Fuel Consumption

Most emissions and fuel consumption models were developed with data from dynamometer tests using selected vehicle types over different drive cycles. The laboratory setting does not accurately reflect the temporal and spatial variability of the factors affecting emissions and fuel consumption. Models based on dynamometer testing may be sufficiently accurate for macroscopic level emissions inventories. Dynamometer testing is often done under steady-state conditions, and so cannot reflect the variability of real-world driving. They also cannot be used for analysis in macroscopic level projects, such as signal timing improvements. Recent research has noted the importance of incorporating real-world data into emissions and fuel consumption models in order to improve the accuracy of model predictions. In recent years, on-board measurement technology has become common and less expensive, and is therefore a feasible means of collecting emissions and fuel consumption data. Some type of on-board diagnostic port is available in most modern passenger cars and other vehicles, primarily to assist repair technicians with engine troubleshooting.

Emissions may also be measured in the field with a portable gas analyzer. A standard five-gas analyzer measures five components of vehicle exhaust, namely, UHC, CO, CO_2, NO_x, and O_2. Engine operational variables may be accessed with a computer via a vehicle's OBD port. The actual variables that are available depend on the specific vehicle but typically include variables such as vehicle speed, engine speed, and intake air flow rate. Measurement of fuel consumption may be performed with a fuel flow meter, which connects to the fuel supply pipe and reports instantaneous fuel consumption. Alternatively, fuel consumption may be calculated from CO_2 emissions because of the high correlation between the two variables.

1.5 Vehicle Emission Models

Vehicle emissions models are necessary for quantifying the impact of traffic flows on air quality. It has been widely recognized that models based on the average speed from fixed driving cycles, such as the U.S. EPA MOVES, do not adequately capture the effects of driving and vehicle dynamics on emissions. Therefore, applicability is limited to estimate and forecast large-scale emissions inventories. In order to predict traffic emissions more accurately and with a higher spatial and temporal detail, microscopic emissions models are necessary. They are based on instantaneous vehicle kinematics, such as speed and acceleration, or on more aggregated modal variables, such as time spent in acceleration mode and time spent in cruise mode. These models can be classified into regression-based models, load-based models, and emissions map models. Regression-based models typically employ functions of instantaneous vehicle speed and acceleration as independent variables. These models overcome some limitations of the emission maps, such as sparseness and non-flexibility, but can lack a physical interpretation and can also overfit the calibration data as they typically use a large number of variables. Through a series of modules, load-based models are used to simulate the physical phenomena that generate emissions. The primary variable of these models is the fuel consumption rate, which is a surrogate for engine power demand (or engine load). They have a detailed and flexible physical basis, which defines the variables and parameters that should be included when modeling emissions. On the other hand, these models are quite complex, and the computational effort can be high when applied to the entire flow of vehicles in a network over a period of time. Ultimately, they are sensitive to calibration data, though they are more robust as a result of their physical basis. Emissions maps are typically matrices that contain the average emission rates for every combination of speed and acceleration in the driving cycle used. Emission maps are often based on steady-state data. They can also be highly sensitive to the driving cycle and may not be flexible enough to account for such factors as road grade, driver characteristics, or the interaction between the driver and different roadway elements. Microscopic traffic simulation modeling provides an accurate and reliable representation of vehicular operations in roadway networks. These models, when integrated with a detailed microscopic emission and fuel consumption use data, can provide a microscopic emission modeling tool suitable for project-level environmental modeling analysis. Some of the major findings of a previous project that documented the state-of-the-practice in the area of fuel consumption and emission modeling include:

1. Most of the vehicle emissions data used in emission and fuel consumption modeling are collected in a controlled laboratory environment. With the rapid technological changes to vehicle designs that lead to reduction in vehicle emissions and fuel use, it is necessary to develop cost-effective real-time emission and fuel consumption data collection methods for use in the field to support microscopic traffic modeling applications.
2. Engine and vehicle performance data available through the OBD port in vehicles may provide information on real-time field emissions and fuel consumption. Research efforts are needed to develop and verify models that use engine and vehicle performance data available via this port to estimate emissions and fuel consumption levels.
3. The VISSIM simulation model has an environmental modeling package EnViver, (Environmental Vissim-Versit+ simulations). EnViver incorporates the Dutch national research institution’s (TNO’s) microscopic exhaust gas emission model into VISSIM microscopic simulation. The TNO data include emissions from around 2,800 cars measured in various conditions. Such European emissions values are not appropriate for U.S. emissions modeling. There is a need for the integration of updated U.S.-based microscopic emissions and fuel consumption data into the VISSIM microscopic simulation model to develop a microscopic environmental modeling tool suitable for U.S. applications. However, this approach may present some challenges in air quality modeling due to differences in U.S. fuels, meteorology data, and air conditioning use.

1.6 Project Scope, Objectives, and Tasks

This project represents the second phase of an exploratory research effort that focuses on understanding and quantifying the relationship between vehicle fuel use and emissions and its trajectory throughout signalized intersection approaches. The aim of this phase of the project is to develop a microscopic emission and fuel consumption model that can describe various traffic conditions based on the detailed simulation of vehicle activity on a traffic network. Specifically, the proposed work seeks to address a number of shortcomings associated with the use of existing macroscopic emission and fuel consumption models, especially the traffic operations at urban corridors. The proposed model combines a microscopic traffic simulation model (VISSIM), microscopic vehicle emissions, and fuel consumption inventory. It is expected that this project would provide transportation operators with a model that is capable of reliably estimating the environmental impact of various traffic management policies and would fill a gap that currently exists in traffic modeling capabilities.

The objectives of this research project are:

1. Develop a microscopic emissions and fuel consumption model by integrating currently available U.S. data into the VISSIM microscopic simulation model,
2. Test and validate the developed model, and
3. Examine the validity of using vehicle on-board diagnostics to collect real-time emissions and fuel consumption data from vehicles operating in the field.

1.7 Report Organization

This report is organized in four chapters. The current Chapter 1 includes a description of the problem. Chapter 2 provides details on the procedures used to integrate emission and fuel consumption data into the VISSIM microscopic simulation model as well as the results of the model validation tests. Chapter 3 includes a discussion of the validity of using vehicle on-board diagnostics and portable emissions analyzers to collect real-time emissions and fuel consumption data from vehicles operating in the field. The last chapter documents the study conclusions and recommendations.

INTEGRATING EMISSIONS AND FUEL CONSUMPTION DATA INTO MICROSCOPIC SIMULATION

2.1. Overview

There are two basic approaches that may be taken to combine the emissions and vehicle data in MOVES with the microscopic modeling capabilities of VISSIM. One alternative is to use VISSIM vehicle specific power trajectory data as source activity input for a MOVES emissions model. This approach has the potential to improve the quality of source activity input to MOVES project scale analysis, as well to make the process of generating activity input simpler for the user. The second alternative is to use the emissions and vehicle data contained in the MOVES default database to improve the input to the VISSIM emissions module to assist VISSIM users in developing custom emissions profiles in the emission module in order to more accurately represent the vehicle fleet operating in the U.S.

2.2. Alternative 1: Using VISSIM Vehicle Data to Generate MOVES Activity Input

In order to create an accurate MOVES project scale emissions model, the user must provide detailed vehicle operation information in the form of drive schedules or an operating mode distribution table. Representing microscopic vehicle operation and interaction can be the most difficult and time consuming part of constructing a MOVES project-scale model, and can also be a major source of inaccuracy in the model. In response to this, the idea put forward here is to use microscopic traffic simulation software (VISSIM) to generate second-by-second vehicle drive schedules, which can then be used to create MOVES user input database tables.

In MOVES, vehicle activity and operating mode assignment are calculated in two different steps. One, the project Total Activity Generator (TAG) calculates the sum total of source (vehicle) hours for each of the three vehicle activity categories: operating, extended idle, and non-operating, as well as the total number of starts[1]. The project TAG also allocates activity to source types, links, and road types. The allocation of vehicle activity to operating modes takes place in the second calculation step, and is controlled by a core model input table containing the "Operating Mode Distribution" (OMD). The OMD table is the basis for assigning emission rates to hours of source activity, and so is a critical input for nearly all exhaust emission calculations[1]. Therefore, realistically representing vehicle operation in the OMD table is essential to creating an accurate MOVES model and is the purpose of using VISSIM vehicle specific power for MOVES input.

There is more than one approach that may be taken to represent source activity in the OMD table. The allocation of activity to operating modes can be performed by the MOVES Operating Mode Distribution Generator (OMDG), which computes the contents of the OMD table from roadway geometry and user defined or default vehicle drive schedules. This step is automatically initiated if an OMD table is not present in the user input database[2]. If this method is used, individual vehicle speed profiles would likely need to be aggregated into a single profile for each link, with links defined physically according to VISSIM VSP and vehicle trajectory data speed profile. This method could get prohibitively complex as the size of the simulation area grows, because the number of potential vehicle trajectories increase multiplicatively. In such case, and to maintain statistically significant level, a number of vehicle trajectories in the VISSIM output files can be sampled. It would, however, be fairly simple computationally, and would require no MOVES default or other additional data.

Alternatively, VSP can be calculated for each second for each vehicle, and this information can be used to generate an operating mode distribution table directly outside of the MOVES computational structure. Computing VSP and assigning operating modes would involve several MOVES default tables, but would make it possible to preserve much of the detail from the micro simulation activity data. It should be noted here that MOVES default tables are not adjusted for local conditions such as temperature, humidity, sulfur contents, fuels used, etc. Either of these approaches can be used effectively, although there are benefits and drawbacks associated with each.

2.3 Alternative 2: Generating VISSIM Vehicle Emission and Fuel Consumption Characteristics from MOVES Default Data

The MOVES default database contains a massive quantity of vehicle population, emissions, and fuel data derived from research on American vehicles. The default vehicle and emissions data contained in the VISSIM emissions module, on the other hand, is derived from a comparatively small number of European vehicles. The idea proposed here is to use MOVES data to create vehicle types in the VISSIM emissions model that accurately represent both the operational and emission characteristics of typical American vehicles. The main technical challenge is to assemble and reformat MOVES data from a number of separate default tables to fill the required fields in the VISSIM emission module. One possible alternative is to adjust the MOVES project level model for local conditions using the EPA's JAVA source code. MOVES project level analysis could then be run to generate emission rates table that contains data sets adjusted by local conditions.

The VISSIM emissions module requires an "emissions layer file" containing a detailed list of characteristics for each vehicle type that is included in emissions calculations. There are three key components to this file: physical vehicle attributes, dynamic adjustment factors, and "engine map files" which are essentially emission rate tables[3]. Much of the information required by the layer file is not defined for MOVES source use types, and so would come from VISSIM default or external data. Many of the layer-file fields that can be filled from MOVES default data would require significant changes to fit the VISSIM formatting.

There are a number of limitations to how MOVES data can be used in VISSIM. For example, many emissions rates in MOVES are linked to other calculated emission quantities, which means that the rates are in terms of mass-per-unit-mass instead of mass-per-activity[1]. This effectively makes the rates unusable for VISSIM input unless a method can be devised to recalculate rates in terms of mass per unit activity. In addition, accessory adjustments are calculated differently in the two programs, which makes the MOVES adjustment factors difficult to apply or even unusable. One possible solution to this problem would be to use a software application to pre-process the MOVES emission rates by applying all adjustment factors, thereby avoiding the complexities of transferring problematic or unsupported data types. In any case, the biggest obstacle to undertaking this alternative is in the lack of information that is published about the VISSIM emission module. Nowhere in published literature is a thorough description of the calculations for vehicle power, emission quantities, or model calibration, which severely hampers any efforts to improve the model.

2.4 MOVES Project-Scale Emissions Modeling

MOVES can model vehicle emissions at three scales: national, county, and project. Of these, project scale is the highest resolution and so requires the greatest detail in user input information[1]. For example at the national scale, the vehicle operating mode distribution is calculated largely from default drive schedules that are specific to very general roadway parameters and do not differentiate between geographic locations, road length, or most other link-specific roadway characteristics. At the project scale, operating mode information must be provided by the user in the form of link-specific speed profiles, operating mode distributions, or link average speed. The additional information required for project scale modeling must be provided in the form of a special "user Input database", which is entered under the geographic bounds tab of the MOVES Runspec[2]. When MOVES is executed, the user input database is combined with default and Runspec information to create the execution database, which is where all information is read and written in subsequent calculation steps.

2.4.1 Core Model Input Generators[1]

Before emission calculations begin, a series of generators convert user and default data into Core Model Input Tables (CMITs), which describe all vehicle activity and environmental conditions in the correct format for emissions calculations. The CMIT generators used in a typical project-level MOVES run are listed below.

- Operating Mode Distribution Generator (OMDG)
    - Generates the OpModeDistribution table
    - Allocates total activity to operating modes with distinct emissions profiles
- Total Activity Generator (TAG)
    - Generates the SourceHours, Starts, ExtendedIdleHours, and SHO tables
    - Calculates total hours for each activity category in each link, road type, and source type
- Source Bin Distribution Generator (SBDG)
    - Generates the SourceBin and SourceBinDistribution tables
    - Creates detailed source type population distribution for each source use type
    - Maps "source use types" used in TAG and OMDG to "source bins" used by the emissions calculators
- Meteorology
    - Generates two fields in the ZoneMonthHour table

- Calculates heat index and specific humidity from user defined temperature and relative humidity

In addition to those listed above, several generators related to evaporative emissions are run at larger model scales. However, MOVES does not currently model evaporative emissions at the project level. In addition, the start OMDG is not used at the project level, because a start operating mode distribution requires user input if an off-network link (e.g. parking lot) is specified.

At the project scale, nearly all of the information used to populate the CMITs is contained in the user input database. The SBDG is an exception to this rule, as it is essentially a mechanism for mapping user defined vehicle types and model years to the source types that are used in emissions calculations. For example, the source use type “light commercial truck” of a certain model year is mapped to a population distribution that contains multiple distinct emission rates, and is calculated from default tables.

The tables produced by the TAG and OMDG provide all vehicle activity information for energy and emission calculations in MOVES. These tables are key to understanding how emissions are calculated in MOVES, and are further explained in the following two subsections.

2.4.2 The Total Activity Generator (TAG)[1]

The project TAG computes and allocates source activity based on user supplied information in the Runspec and the user input database. All data used in the project TAG is supplied by the user. The inputs to the project TAG are the user defined Links, OffNetworkLink, SourceTypeDistribution, and AgeDistribution tables. Source activity is calculated separately for each link and source type, and is allocated to activity categories as follows:

Source Hours Operating (SHO)

SHO is calculated by multiplying the hourly volume of each source type in a link by the average time spent in the link. All operating activity takes place within the link network.

Source Hours Parked (SHP)

SHP is calculated by multiplying the vehicle population in the off-network link by the fraction of vehicles that are parked. It is calculated separately for each vehicle age. All parked vehicle activity takes place in the off network link.

Starts

The number of starts is calculated by multiplying the vehicle population in the off-network link by the hourly fraction of vehicle starts. It is calculated separately for each vehicle age. All starts take place in the off network link.

Extended Idle (ExtIdle)

Extended idle is calculated as the product of the vehicle population and the extended idle fraction. It is calculated separately for each vehicle age. All extended idle activity takes place in the off network link.

Source Hours (SH)

This is calculated in the same way as SHO for roadway links and the same as SHP for off-network links. It is used for evaporative emission processes, and so is not currently used in project-level analysis.

2.4.3 The Operating Mode Distribution[1]

The Operating Mode Distribution (OMD) table contains a fractional distribution of operating modes for each link and source type. Operating mode bins are differentiated by a number of operational parameters, most notably vehicle specific power (VSP). The information contained in this table is used to allocate the total vehicle activity calculated by the TAG to operating modes for emissions calculations.

One option in a MOVES project-scale model is for the user to enter an OMD directly in the user input database. If this is done, the user supplied table is used as-is by the emissions generators and the OMDG is unnecessary. Alternatively, the user may enter a vehicle drive schedule speed profile for every link, and this is used with default vehicle parameters in the OMDG to create an OMD table. A third option, a simple average speed may be entered for each link. In this case, default drive schedules are used in the place of user supplied drive schedules to compute the OMD.

In the OMDG, link drive schedules are used to calculate VSP, which is a key distinguishing point for operating mode bins. VSP is calculated with an algorithm based on vehicle dynamics, and is a function of acceleration, speed, grade, and vehicle characteristics. The inputs for this calculation are as follows:

- Speed and acceleration from second-to-second vehicle drive schedule
- Link grade from user input link table
- Vehicle mass, rolling term, drag term, and rotating term from default SourceUseType table

VSP is calculated for every second of vehicle activity in the drive schedule, which allows travel time to be divided into VSP-specific operating mode bins. Based on this, a fraction of the total operating hours is then assigned to each operating mode bin to create the OMD table. It should be noted that some operating mode bins are not differentiated by specific power, including starts, braking, and idling.

2.4.4 Emission Calculations[1]

MOVES models a wide range of running and start emissions, some of which require several computation steps. An overview of some of the key elements is given here. From the following discussion, it is apparent that MOVES emission calculations can be rather complex. Unlike in the VISSIM emission module, MOVES emission rates vary in the method of application, units, and interconnection with other calculated emission quantities.

Emission Rate Tables

All default data including emission rate tables can be found in the MOVES default database. Rates for age dependent and non-age dependent emissions are contained in the EmissionRateByAge and EmissionRate tables respectively. There are two major types of emissions, mass and energy. Mass emissions are those that are typically measured in mass terms, including N_2O, CH4, and other air pollutants. Energy emissions are used to calculate the quantities of different sources of energy, including total, petroleum, and fossil fuel. Many emission types have two separate sets of rates, one for base emissions and one that reflects the ideal impact of a reference inspection/maintenance program.

Chained Emissions

A number of emission types are "chained" to other emission quantities in MOVES. This means that the associated emission rates are simply multiplicative factors that relate the quantity of one emission to another. For example, atmospheric CO_2 and CO_2 equivalent are functions of the total energy consumed.

Criteria Pollutants

Criteria pollutants are those that are affected by the presence of an inspection and maintenance (I/M) program. There are multiple I/M program types supported in MOVES, as well as additional adjustments that can be made to better represent the effectiveness of any given program. The user-defined I/M program information determines which pollutants and vehicles are affected as well as to what extent emissions are reduced by the program. The calculation process for criteria pollutant emissions has an additional step in which the effects of the inspection/maintenance program are calculated. In this step, an intermediate table of emission rates is created that weights I/M and non-I/M emission rates according to the coverage and effectiveness of the I/M program.

Air Toxics

There is no direct relationship between air toxics and vehicle activity in MOVES, as all toxics are chained to other emission quantities. This class of emissions are related to either volatile organic compounds or PM 10 emissions. This illustrates the complexity of tracing default emission rates to final computed quantities, because PM 10 emissions are themselves chained to PM 2.5, some of which are in turn chained to total energy consumed. Toxics include Benzene, Ethanol, MTBE, Naphthalene, 1,3-Butadiene, Formaldehyde, Acetaldehyde, and Acrolein, with some additional air toxics added to the MOVES 2010b release. The rates for these emission types are stored separately from the general emission rates, in a series of default tables with prefix ATRatio.

A/C Adjustment Factors

There are several emission types in MOVES that are affected by air conditioner (A/C) use, either directly or by way of being chained to emissions that are directly affected. This process involves the calculation and application of A/C adjustment factors, and is the same for all relevant emission types. First, MOVES calculates how much time a vehicle's A/C compressor is engaged based on scenario date and time information, in addition to a heat index calculated from user-defined local meteorological information. Next, the overall fraction of A/C compressors in use is calculated based on default data. This step accounts for several A/C-related variables, including the population fraction of inoperable systems. A/C adjustment factors are then calculated from default A/C factors and the previously computed A/C activity fraction. Emission rates are adjusted by multiplying the default rates by the calculated A/C adjustment factors.

Other Adjustment Factors

- Fuel adjustment factors: Listed in some emission calculation steps, but no default values are contained in the default database. It is likely that this field is a place holder for future improvements, or possibly a user input calibration point.
- Temperature adjustment: Calculated from user defined current temperature and default factors in the TemperatureAdjustment table.
- Humidity adjustment: NO_x emissions are adjusted for humidity affects.

2.5 VISSIM Emissions/Fuel Module

The VISSIM emissions module uses the vehicle operation information produced by the traffic flow model to compute exhaust emissions, evaporative emissions, and fuel consumption. Twelve emission types are supported by the VISSIM module: Benzene, CO, CO_2, HC, Fuel, NMOG, NMHC, NO_x, Particulate, Soot, SO_2, and Evaporation. Emissions are not dependent on or "chained to" each other, so any combination of pollutants may be modeled in a simulation. However, an "engine map" or emission rate table must be defined for each combination of vehicle and emission type that is to be modeled. Fuel consumption is modeled as an emission, and so for each vehicle type the inputs are the same as other pollutant categories[3].

2.5.1 Note on VISSIM Information

This subsection explains the calculation methods used in the VISSIM emissions module in limited depth, as detailed documentation of the calculation algorithms has not been made public. This means that some calculation steps are glossed over or not mentioned at all. Available information is limited to underlying technical documents and user manuals made available by PTV America, the developer of VISSIM[3,4,5].

2.5.2 Engine Map Files[3]

Before a VISSIM simulation model with emissions calculations can be run, an emissions layer file (*.sch) should be defined and selected in the emissions dialog box. This file contains the vehicle information needed to calculate emissions, including file names for the "engine maps" that relate specific vehicle operation parameters to emissions rates. Each vehicle type must have an engine map for each emission type to be modeled6.

There are three different engine map formats for warm running emissions, one each for passenger car, heavy commercial vehicle (HCV), and motorcycle. Warm running emissions are modeled differently for each of these three vehicle categories, as described in 2.5.5. A single engine map format is defined for cold emissions processes, in which emissions rates are a function of operating temperature and normalized required power6. The format of the engine map file for each vehicle emissions category is described below:

Passenger cars

- Function of velocity and the product of velocity and acceleration
- Matrix format
- Emission rates in units of mg/s

Heavy commercial vehicles

- Function of engine power and normalized rotational speed
- Matrix format
- Emission rates in units of g/hr/kW

Motorcycles

- Function of velocity only
- Two column table format

- Emission rates in units of g/km

Sub-operating temperature

- Function of operating temperature and normalized required power
- Matrix format
- Emissions rates in units of g/hr/kW

2.5.3 Physical Vehicle Characteristics[3,6]

In addition to engine maps, a number of attributes must be defined for each vehicle type in order for emissions to be calculated. Physical vehicle characteristics are needed to compute engine speed and instantaneous power requirements, and one or both of these quantities are required for multiple emissions calculations. Many attributes are self-explanatory and readily available for any common vehicle make and model. Others, like the two frontal area coefficients, are not as straight forward in derivation or application. For many typical scenarios, default vehicle types will be used or customized somewhat to better represent actual conditions. Otherwise, input from the developer may be needed to generate some of the less transparent parameters for custom vehicle types. A full list of the vehicle description fields in VISSIM layer file is given in subsection 2.8.1.

2.5.4 Dynamic Correction Factors

Dynamic correction factors are entered as a file name in the layer file. Supporting documentation describes the dynamic adjustment factors as being based on kinematic variables such as the number of changes from positive to negative acceleration, idling portions, and mean acceleration values[4,5]. Little information is provided on the derivation or application of these adjustment factors. It seems that factors were developed independently for several vehicle types, each with a unique set of input variables. Next, they were averaged over multiple vehicle types with input based on the most significance for the greatest number of vehicles[4,5]. This indicates that vehicle-specific adjustment factors may not be necessary, and that default factors may be used effectively. However, the document that describes this process dates from 1999, and changes may have been implemented in the more recent releases of VISSIM[7]. Also, HCV dynamic adjustment factors are specific to individual engine concepts (suction engine, exhaust gas turbocharger, and exhaust gas turbocharger with charging air cooling)[4,5].

2.5.5 Calculation Steps for Warm Running Emissions

Passenger Cars

The calculation process for passenger car emissions differs significantly from the process used for HCVs. Passenger car emissions are calculated for each second of operation by looking up the emissions rates in the engine map for each pollutant, and summing for all seconds of operation. VISSIM calculates speed and acceleration values at high temporal resolution for every vehicle in the simulation, so identifying the correct emission rate is a simple matter of looking up speed and speed*acceleration on the engine map for each pollutant. Warm running passenger car emission rates are in units of mg/s, so emission quantities for each second are read directly from the engine maps. An averaged dynamic correction factor is applied to the calculated emission quantities to account for the difference between experimental and calculated results[4,5].

Heavy Commercial Vehicles

The calculation process for HCVs includes intermediate steps to calculate vehicle power and normalized engine speed. Engine power for each second in the analysis is calculated from the vehicle speed profile produced by the VISSIM traffic flow model and the vehicle characteristics contained in the layer file. From the original document describing the calculation process, it seems that grade is not considered in power calculations[4]. More recent documents suggest that grade sensitivity has been added in newer versions of the software, but provide no indication of whether this has been incorporated into instantaneous power calculations[7]. Engine rotational speed is calculated using the vehicle speed profile and the gear ratio information contained in the layer file. Engine speed is normalized by dividing current engine rotational speed by the maximum rotational speed for the vehicle type listed in the layer file. With the second-to-second power and normalized speed calculated, emissions rates can be found in the engine map files. It should be noted that the warm running emissions rates for HCVs are in units of g/hr/kW, which means that the rates must be multiplied by instantaneous engine power to get mass/time. Similar to passenger cars, a dynamic correction factor is applied to HCV emissions to account for the differences between experimental and calculated values[4,5].

Motorcycles

The calculation process for motorcycle emissions is not described in any readily available supporting documents. It is clear that emission rates for each pollutant are found by looking up the vehicle speed for each second of operation in the engine maps. It is not clear, however, whether any type of correction factor is applied.

2.5.6 Calculation Steps for Sub-Operating Temperature Emissions[3,5]

The VISSIM emissions module includes a separate component to account for the additional emissions produced by vehicles operating at warm-up temperatures. This is calculated as an additional emission quantity produced in the time between a vehicle start and when normal operating temperature is reached, during which the engine consumes more fuel and the catalytic converter does not perform to its full potential. This calculation requires a separate engine map for each pollutant and vehicle type, as well as an engine temperature distribution.

As mentioned previously, sub-operating temperature engine maps are in the same format for all vehicle emissions categories. The independent variables needed to look up emission rates are instantaneous vehicle power and engine or catalytic converter temperature. Instantaneous power must be computed for each vehicle using the vehicle characteristics contained in the layer file and the speed profile produced by the VISSIM traffic flow model. Emission rate lookup values for power must be normalized to reach a maximum of 1. Engine coolant and catalytic converter temperature are readily available from the VISSIM vehicle traffic flow simulation. These temperatures are defined or edited by the user as a distribution in the VISSIM user interface, and can be accessed under Base Data>Distributions>Temperature[6]. Because sub-operating temperature emission rates are in units of g/hr/kW, each must be multiplied by instantaneous vehicle power to get g/hr.

There is no location for sub-operating temperature dynamic adjustment factors in the layer file, and this subject is not discussed in any available supporting documentation. It is possible that no adjustment or calibration factors are used in this calculation, but further research should be conducted on this topic.

2.6 Integrating VISSIM Vehicle Operation Information into MOVES

The following sections describe two different ways in which VISSIM microscopic traffic simulation software may be used to generate vehicle operation information for MOVES input. They represent the most intuitive interface points for the two programs, and both rely on existing user data input points in the MOVES project level Runspec. The average speed method is not discussed here, but most certainly would be the simplest and least detailed way to translate VISSIM output into MOVES input. There are several technical challenges associated with each method of using VISSIM output to generate MOVES project-level input. In addition, there are some issues that will be faced regardless of the method used, including:

- Mapping vehicle types in VISSIM to source use types in MOVES
- Insuring continuity between MOVES RunSpec and VISSIM input

2.6.1 Using VISSIM Data to Create a DriveSheduleSecondLink Table

One of the ways in which vehicle activity is entered in a MOVES project-level model is by creating a second-to-second vehicle speed profile for each link[1]. MOVES uses this speed profile to calculate vehicle specific power (VSP) and generate an Operating Mode Distribution (OMD) for emissions calculations. In a MOVES project-scale Runspec, the speed profile can be entered as a spreadsheet table in the user input database. It would seem intuitive, then, to create a table of speed profiles from VISSIM model output and use it as input for a project-scale MOVES user input database. The problem with this is that VISSIM provides a speed schedule for each vehicle, and MOVES only allows a single drive schedule for each link. This would require either that each vehicle path be defined as a link (resulting in an unfeasibly large number of links), or that individual vehicle paths are grouped and averaged into a more realistic number of aggregate links.

The desired format for MOVES input is a spreadsheet table with a single, 1-second resolution vehicle speed and grade profile for each link in the analysis. In this case, links will be partially defined by speed profiles produced in the VISSIM simulation, which will require that the physical location of the link correspond to VISSIM vehicle trajectories. This also implies that links should not be defined in the MOVES Runspec until VISSIM output is processed.

VISSIM output should be in the form of 1-second or higher resolution velocity and grade profiles for each vehicle in the analysis. Because MOVES requires 1-second resolution, higher resolution output will have to be sampled at 1-second intervals. The speed profiles must be processed to identify and average similar profile shapes. This step may prove challenging because each speed profile will cover a slightly different time span for the same distance traveled, making a point-by-point averaging of similar profiles impossible. Speed profiles must also be associated with a physical roadway section, so that the correct road geometry and vehicle population are assigned. It should be noted that no acceleration information is required, because the MOVES OMDG uses the discrete changes in velocity to calculate acceleration and the resulting change in VSP.

This technique would require a reliable method for identifying and combining statistically similar velocity profiles. There are likely a number of ways to simplify this process, such as:

- Because each link has a single length value, and because a single grade may be assigned to each entry in a drive schedule, velocity profiles for more than one link can be grouped if the road sections are geometrically similar. For example, west bound left turn and east bound left turn traffic can be combined if the intersection is flat and the source type distribution is the same.
- A single road section may be split into multiple links if different vehicle performance characteristics result in significantly dissimilar speed profiles. For example, a steep road grade may have separate speed profiles for passenger cars and heavy trucks. This would require special care to insure that the correct vehicle type distribution is assigned to each link.
- Because of the large number of speed profiles that are output by VISSIM, a software application may be developed to combine and average similar speed profiles.

However, this may prove challenging due to the inherent subjectivity in identifying "similar" profiles.

2.6.2 Using VISSIM Data to Create an OpModeDistribution Table.

Vehicle operation information can be input to a MOVES project-scale user input database in the form of a distribution of vehicle operating modes for each link and source type. Note that, in any case, total vehicle activity or operating time is calculated in the MOVES total activity generator, so the OMD table is simply a way of allocating total activity to vehicle operating modes. Nearly all operating mode bins are distinguished by VSP and/or vehicle speed.

Each operating mode bin has a number of pollutant processes associated with it, and is characterized by the operating parameters related to those pollutant processes. For example, most exhaust emissions depend largely on VSP, and the associated cruise/acceleration bins are differentiated by speed and VSP. Non-running evaporative emissions are dependent strictly on soak time, as are the non-running operating mode bins. In addition, several operating mode bins are simply "catch-all" categories for pollutant processes that do not depend on the operating parameters listed above. These categories include starts, extended idle, and braking.

Because the OMD table is a core model input, it represents the highest level of detail for vehicle operation information that is supported by MOVES[1]. If VISSIM output could be used to generate this table directly instead of going through the MOVES OMD generator, a higher level of detail could be preserved thereby taking maximum advantage of the microscale simulation. A software application would likely be required as an interface between the two programs, otherwise each MOVES run would require a great deal of spreadsheet calculations and manual data processing.

The format of the MOVES OMD input table is a list of all possible combinations of link, source type, pollutant process, and operating mode. Each entry in the list is associated with a fraction of the total activity for that combination of source type, link, and operating mode. That is, each combination of source type and link, an operating mode will have a given quantity of running activity calculated by the total activity generator, and the sum of operating modes fractions for each combination of link and source type is 1.

The algorithm used to calculate the OMD can be loosely based on the MOVES project-level OMD generator, but must be executed for each vehicle trajectory. Computationally, this would be similar to executing the MOVES OMD generator with each vehicle path defined as a link. The difference is that the many individual vehicle paths are then pre-aggregated into a realistic number of links to simplify subsequent MOVES calculations. Essentially, the calculation for each vehicle would consist of a) calculating VSP (if applicable) and b) assigning the operating mode for each second to a MOVES operating mode bin. After this is complete for all vehicles, the second-to-second, individual vehicle data can be converted into a fractional distribution.

The biggest challenge of using VISSIM output to generate an OMD table would be in making sure that enough information is available for each step in the calculation process. For example, each VSP calculation requires several pieces of information including time variables (speed, etc.) link geometry, and default vehicle parameters. This would require that several MOVES default tables be available to lookup vehicle parameters and operating mode ID numbers. However, once the OpModeDistribution table is generated and input to the project-level user input database, MOVES would be executed in the typical fashion.

2.7 Case Study 1: Generating MOVES Activity Tables from VISSIM Vehicle Data

This subsection describes a case study in which VISSIM vehicle profile information is used to create an operating mode distribution for MOVES input. A hypothetical stop sign controlled intersection with approach road sections is used in the example, although along with all scenarios and vehicle operation parameters, the intersection geometry is essentially arbitrary. A 1-hour time span is modeled with results output in 1-second resolution. Because vehicle activity is calculated from the VISSIM data, and because all directional traffic is given the same vehicle type distribution, the intersection is modeled as a single link. The data could be easily disaggregated to allow road sections or lanes to be modeled separately, which would require that link identification be included in the VISSIM output file.

2.7.1 Scenario Description

Vehicle Types and Population

Three default vehicle types with associated operational parameters were used for this example, Passenger car, HCV, and Bus. The only relevant difference between vehicle types is in performance characteristics, as the resistance terms and emission characteristics are sourced from the MOVES default database. In many cases, custom vehicle types correlating to MOVES source types will need to be created in VISSIM. This step is avoided in this case study because only source types that correlate with VISSIM default vehicle types are included in the MOVES model. Detailed vehicle performance data is not defined for MOVES source types, so VISSIM default data is used as an alternative to seeking out and formatting vehicle manufacturer's data. The population fraction for each vehicle type is shown below. Note that the population fractions need not sum to 1, as VISSIM recalculates each one as a fraction of the sum.

0.85 Passenger cars (default parameters)
0.10 HCV (default parameters)
0.10 Busses (default parameters)

Vehicle populations for each direction of travel are given below. The vehicle type distribution given above is assigned to all directions of travel.

North bound: 200 vph
South bound: 200 vph
East bound: 300 vph
West bound: 400 vph

Vehicle Behavior

Vehicle routing is highly simplified for this example. The Wiedemann 74 car following model was used to describe vehicle interaction. A summary of vehicle behavior and route choice is given below.

- Four-way stop

- All vehicle types in the simulation are assigned to a desired speed of 50 km/hr, with a maximum and minimum of 58 and 48 km/hr respectively
- All north and south bound traffic turns right
- All east and west bound traffic goes straight
- All links are described as “urban motorized”

Roadway Geometry

The intersection used in this example is approximately 62 meters is each direction, with a single lane for each direction of travel. A 1% grade slopes in the south direction, so that the north and south bound lanes have a -1% and 1% grade respectively.

2.7.2 Generating the OMD Table

VISSIM can produce a report of vehicle operation information as part of the simulation run, and this report is used to generate the OpModeDistribution and SHO tables describing all running vehicle activity. To generate vehicle profile data in a VISSIM simulation model, select the vehicle profile box under Evaluation>Files, then choose configure>select parameters. In this menu box, a number of vehicle operation data points can be selected for inclusion in the output. Select and add the following:

Simulation time
Vehicle type
Gradient
Speed (m/s)
Vehicle number
Acceleration

A screenshot of the output data headings and data is given below in Figure 1. The file is exported from VISSIM rows with fields delimited by semicolons, and can be opened and converted to the spreadsheet format by selecting the “text to columns” option in the data menu.

	A	B	C	D	E	F
1	Vehicle Record					
2						
3	File: C:\Users\henr2237\Desktop\Kris_VISSIM.inp					
4	Comment:					
5	Date: Monday, June 04, 2012 1:09:58 PM					
6	VISSIM: 5.30-08 [29295]					
7						
8	t : Simulation Time [s]					
9	Type : Number of the Vehicle Type					
10	Grad : Gradient [%] of the current link					
11	vMS : Speed [m/s] at the end of the simulation step					
12	VehNr : Number of the Vehicle					
13	a : Acceleration [m/s²] during the simulation step					
14						
15	Simulation time	Vehicle type	Grade	Velocity (m/s)	Vehicle number	Acceleration
16	12	100	0	14.84	1	0.29
17	13	100	0	7.56	1	-7.28
18	13	100	0	15.02	2	0.26
19	14	100	0	10.53	1	2.97

Figure 1: VISSIM vehicle data.

The desired OMD table consists of six data columns, four of which are created in the following steps. The remaining two columns are hourDayID and LinkID, and are generated as follows: HourDayID must be selected by the user, and only a single hour/day combination is allowed in MOVES at the project level. Because the intersection in this study is modeled as a single link, the linkID is also selected by the user and is the same for all rows.

Step 1: Calculate VSP for Each Second in the Vehicle Data Output

In this case study, all data processing and calculations are completed using a Microsoft Excel spreadsheet and a number of VBA macros that were coded for this purpose. This could also be accomplished with MySQL, which would save the time required to import/export files into the database software. This would, however, require more advanced programming knowledge.

There is a number of operating mode ID numbers that a vehicle may fall under at a given time, and each one is specific to a particular pollutant or group of pollutants. For example, consider a vehicle driving at 50 miles per hour up a hill, for which exhaust emissions are largely a function of how much work the engine is doing to overcome the drag, rolling resistance, and vehicle weight on the grade. This vehicle will have a certain operating mode classification ID for the purpose of exhaust emissions that is based on VSP, and another ID for the purpose of brake wear emissions that depends only on speed.

In this case study, only the braking, idling, and VSP-based operating mode classifications are used because only a limited number of exhaust emissions are being modeled. The first step to generating an operating mode distribution from VISSIM output is to calculate VSP for every second in the data. To do this, the SourceUseType table was imported to the spreadsheet from the MOVES default database. A VBA function was designed to lookup vehicle characteristics in the SourceUseTable and combine them with grade, speed, and acceleration values to compute VSP as shown (Equation 1):

Equation 1: Vehicle Specific Power Calculation[1]

$$VSP = [(speed \times 0.44704) \times ((rollingTermA) + (RollingTermB) + (DragTermC))] \,/\, (SourceMass\ ) + (speed * 0.44704) \times ((a\_Speed - b\_speed\ ) \times 0.44704 + (9.81 \times \sin(\mathrm{atan}(grade/100)\ ))$$

Step 2: Assign an Operating Mode ID Number to Each Second in the Vehicle Data Output

To accomplish this step, the OperatingMode table was imported to the spreadsheet from the MOVES default database. A simple VBA subroutine was designed to lookup instantaneous speed, VSP, and, in the case of braking, acceleration in the OperatingMode table to find an operating mode ID number. For this study, braking was defined as acceleration < -1 m/s^2.

Step 3: Count Occurrences of all Vehicle Type/Operating Mode ID Combinations.

Even though the VISSIM output is for one hour at 1-second resolution, there are nearly 15,000 data points in the output. This is because there is a point for every vehicle in every second, and a number of vehicles may be in the intersection at a given time. For the purpose of calculating the time each vehicle type spends in each operating mode, the occurrence of a given vehicle type/operating mode combination in the data file is equivalent to a second of time for that vehicle type in that operating mode. A simple VBA subroutine was devised to lookup the occurrence of every possible vehicle type/operating mode combination and list the results under the following three column headings: OpModeID, SourceTypeID, and count. This is shown in the spreadsheet screen shot in Figure 2.

SourceTypeID	OpModeID	Count
100	0	2237
100	1	1731
100	11	805
100	11	805
100	13	520

Figure 2: Results of Step 3.

Step 4: Calculate Operating Mode Fraction from Count Data

The operating mode fraction is calculated by dividing the count for each operating mode/source type combination (previous step) by the total count for that source type. If more than one link were present, this would be done separately for each link.

Step 5: Assign Pollutant Process IDs to Each Operating Mode ID

To accomplish this step, the OpModePolProcAssoc table was imported to the spreadsheet from the MOVES default database. This table contains a list of all pollutant process ID numbers that are associated with each operating mode ID. The calculation process is simply to lookup all pollutant process ID numbers that are associated with each operating mode, and write a new series of data columns containing SourceTypeID, PolProcessID, OpModeID, and OpModeFraction. In this study, this was accomplished with a VBA subroutine. The results of Step 5 are shown below in Figure 3. Note that HourID and LinkID will be inserted between the SourceTypeID and PolProcessID columns.

SourceTypeID	PolProcessID	OpModeID	OpModeFraction
100	-1	0	0.185
100	101	0	0.185
100	201	0	0.185
100	301	0	0.185
100	3001	0	0.185
100	9101	0	0.185

Figure 3: Results of Step 5.

2.7.3 Generate Source Hours Operating Table

MOVES calculates the source hours operating (SHO) in the project TAG from link average speed and length. This is only possible if the links are defined as physical, homogenous road sections, which is not the case in this study. This step can be skipped altogether if the links are to be defined as physical road sections in MOVES. Fortunately, the SHO table can be easily generated from the VISSIM output data. The total SHO is the total number of vehicle operating hours in the model, which is calculated as the number of data points in the VISSIM output divided by 3600. The total SHO must be allocated to source type and age, and at the project level this must be based on user input data. The source type allocation is done according to the vehicle type distribution used in the VISSIM simulation as follows:

0.85/1.05 Passenger cars
0.10/1.05 Busses
0.10/1.05 HCV

The age distribution for each source type is required user input data at the project level. The calculation for each source type is performed by multiplying the SHO fraction that source type by each age fraction in the SourceTypeAgeDistribution table. The results are then written to AgeID, SourceTypeID, and SHO columns in the SHO table. The remaining yearID, monthID, and hourID columns in the SHO table are user defined and are unchanged for all rows at the project level. A VBA subroutine was used in this example to populate the SHO table.

2.7.4 Create MOVES Project-Level Model

The final step in this case study is to create a project-level model in MOVES and input the tables generated from VISSIM data. The OpModeDistribution table is input through the required user input database, in the form of a CSV file. Note that if the SHO and OpModeDistribution tables are input directly, the link average speed information is not used. An off-network link was not included in this model, but this would be required if start and extended idle processes were to be computed. At the project level, a separate OpModeDistribution table must be entered for the off-network link containing all idle and start activity. VISSIM could be used to generate this table as well, but would require a separate (but similar to the one used in this case study) process to convert VISSIM output to MOVES input.

The SHO table is not input through the user input database, instead it must be entered in the "Manage input data sets" tab in MOVES. To do this, a blank database is created and named in the Selections box under the Manage input data sets tab. Next, the SHO table must be added to this blank database. If the SHO table is created in a spreadsheet program, it must be imported as a database table in MySQL. For this study, HeidiSQL browser software was used to import the spreadsheet file to MySQL. Note that the table must be named SHO so that MOVES identifies and uses the contents instead of running the TAG. In addition, all unused tables in the blank database should be removed to insure that MOVES does not import blank or incorrect tables. Other than the two tables described in this study, the MOVES run is set up and executed as normal. Some care may be required to insure that the date/time and scenario information entered in the Runspec is consistent with the user input tables.

2.7.5 Summary of Case Study

This case study described a method that may be used to calculate and input MOVES vehicle activity information from VISSIM output data. The basic steps are given below:

Outline of steps

1) Set up VISSIM simulation of case scenario, specify desired vehicle profile data
2) Create or select vehicle types corresponding to desired MOVES source use types

3) Execute VISSIM traffic simulation
4) Calculate VSP for every entry in the output file
5) Create operating mode distribution table
6) Calculate SHO table from data output file and user defined age distribution
7) Input SHO and OpModeDistribution tables to MOVES
8) Run MOVES as normal, taking special care to insure continuity between VISSIM and MOVES input

2.8 Using MOVES Default Vehicle and Fuel Parameters in VISSIM

This section describes how MOVES default vehicle and fuel data may be used to improve input to the VISSIM emissions module. As described previously, all of the vehicle information needed to calculate emissions from VISSIM traffic flow model output is contained in an “emission layer file” (*.sch), which must be populated and selected before the simulation model is run. In theory, MOVES default data may be used to assist in developing layer files for custom vehicle types in VISSIM, in order to better represent the emissions characteristics of typical American vehicles. There are three major challenges that must be overcome in order for this to be made possible: One, rates and characteristics that can be used in the VISSIM format must be identified and preprocessed as needed, in part to insure that emission rates are in terms of mass per activity. Two, applicable MOVES emission rates must be mapped to appropriate vehicle types in VISSIM, either by using vehicle type definitions that correspond to MOVES source bins or by using vehicle types that correspond to MOVES source use types, in which case source bins and their associated emission rates must be aggregated to cover all possible vehicles that fall under each source type definition. Three, rates and characteristics must be recalculated to fit VISSIM units and formatting. These challenges are addressed in the following subsections, first by describing the differences between the data requirements of the two software applications, followed by some guidelines for transferring MOVES data to VISSIM.

2.8.1 Vehicle Operation and Performance Characteristics

This subsection discusses the differences in how performance and operation data is used in MOVES and VISSIM, as well as the extent to which MOVES default data may assist in developing vehicle types in VISSIM. While the emission rates for MOVES source types are unique for a wide range of model years, ages, and pollutant processes, physical vehicle characteristics are only unique to a small number of source use types. In addition, relatively few characteristics are defined for each source use type compared to the number of parameters required for a VISSIM layer file.

The vehicle characteristics contained in the VISSIM layer file are used only to assign emission rates, as the modeling of vehicle operation (speed, acceleration, etc.) takes place in the VISSIM traffic flow model[6]. VISSIM models the operation of every vehicle individually according to the characteristics and limitations placed by the vehicle type description, and so detailed performance data is required to accurately capture the quantities that emission calculations are based on. However, because so much detail and specificity is required for each vehicle type, and because vehicle types must be defined and described individually in terms of performance and emissions profiles, capturing the diversity of an actual vehicle fleet may be a very tedious process. MOVES, on the other hand, approaches vehicle performance in a different way, by allowing the speed profile to be predefined for all vehicle types under the assumption that every vehicle is capable of operating as the drive schedule dictates. VSP is then calculated based on a short list of vehicle parameters (drag, mass, etc.) that are defined for a relatively small number of source use types. The approach taken in MOVES requires much less detail in the vehicle description, and as a result the physical vehicle characteristics contained in the MOVES default database may only be of limited use in creating VISSIM layer files.

It is possible that the nationwide statistics for vehicle attributes such as fuel type regulatory class contained in the MOVES default database may be used to aid in developing VISSIM vehicle types. More likely, however, local data with higher resolution and accuracy will be available. In fact, the basis for the user input data requirements in MOVES project level analysis is that much of the default nationwide statistical data is not considered accurate enough for link-level analysis.

An additional challenge that will be faced in creating VISSIM layer files (regardless of the source of the information that is used) is in the definition and use of VISSIM numerical factors, including rolling resistance and frontal area coefficients. The algorithms used to calculate vehicle power are not published for VISSIM, and it is unlikely that the analogous terms in MOVES will transfer directly. It is also unlikely that these terms can be calculated directly for any vehicle types without a clear understanding of the terms themselves. This and similar definitional questions/clarifications can probably be resolved by communicating directly with PTV, as the software is intended to permit user-created layer files.

Table 2 shows the VISSIM requirements for emissions calculations, along with the analogous MOVES default table. It is clear from this comparison that VISSIM requires a great deal of information that is not defined in MOVES.

Table 1: Required Vehicle Characteristics Comparison: VISSIM and MOVES Error! Reference source not found.**,1**

Attribute	**Description**	**Corresponding MOVES Table**
Category	Emission category (KR, KKR, PKW, LNF or SNF)	NA
Name	Vehicle layer name	NA
Concept	Engine description	NA
Displ-Kl.	Engine displacement	Engine size (Not used)[1]
Strokes	Propelling description: # of engine strokes	NA
Energy	Energy type: Fuel type	FuelSupply, FuelFormulation
Comment	Emission comment	NA
Gearbox{0,1}	Gearbox type (1 = manual, 2 = automatic)	NA
Displ.[ccm]	Average engine displacement [ccm]	EngineSize (Not used)
Power[kW]	Average nominal power [kW].	NA
Length[mm]	Average length [cm]	
Net Weight[kg]	Average net weight [kg]	RegulatoryClass and SourceUseType
V-Max[km/h]	Average maximum velocity [km/h]	NA
Mileage[km/a]	Average annual mileage [km/a]	
Cw*A[-]	Air drag coefficient [m2]	SourceUseType
Front1[-]	Frontal area coefficient 1 [-]	
Front2[-]	Frontal area coefficient 2 [-]	
Coeff_gw[-]	SNF category only: Gross weight coefficient [-]	
1.Gear[-]	Gear ratio [-]	NA
2.Gear[-]	Gear ratio [-]	
20.Gear[-]	Gear ratio [-]	
Axle[-]	Axle ratio [-]	
Revs.[u/min]	Average engine speed [U/min]	
Nom.Revs.[u/min]	Average nominal engine speed [U/min]	
Torque[N.m]	Average torque [N · m]	
Power Train[-]	Average powertrain efficiency [-]	

[1] The source bin ID code includes placeholders for engine size and weight, but these discriminators are not used in the current version of MOVES[1].

Rim[in]	Average rim size [in]	
Tire[mm]	Average tire size [mm]	
Wheel[m]	Average wheel ratio [m]	
Roll0[-]	Rolling resistance coefficient 1 [-]	SourceUseType
Roll1[-]	Rolling resistance coefficient 2 [-]	
inertia[kg*m^2]	Moment of inertia [kg*m^2]	
Comf.-Power[kW]	Power consumption per accessories [kW]	ACAdjustmentFactors
Lower heating val.[kJ/kg]	No description given	NA
Dyn.Correction	Filename for the dynamic correction	

2.8.2 *Chained Emission Rates*[1]

Of the 12 emission types that are supported in the VISSIM emission module, only three have direct activity-to-mass relationships in MOVES[2]. These three (listed under "Direct rates" in Table 2) are the most easily transferable, and would require the fewest calculation steps to make them useable in VISSIM engine map files. The three emission types listed under "2 or more chains" are chained to emission quantities that are themselves chained to other emissions, so no direct relationship exists between emission rate and activity. The remaining six emission types are generally chained to a single pollutant, so the relation between rate and activity is fairly direct. Table 2 shows the pollutants that are supported in the VISSIM emission module, categorized by their method of application in MOVES.

Table 2: Classification of VISSIM Emission Types by Their Relationship to Activity in MOVES[1]

Direct Rates	**1 Chain**	**2 or More Chains**
CO	CO_2	Benzene
NO_x	NMHC	NMOG
HC	Particulate	Evaporation (VOC)
	SO_2	
	Fuel	
	Soot	

It is possible that chained fractional rates could be used together with parent rates to compute mass per activity emissions rates for chained emissions. However, one may question the value of microscopically modeling chained emissions, when the source rates exist only as fractions of a sum total. That is to say, it may be of little value to go through the effort of creating an engine map file for a chained emission when it can be simply and even more accurately calculated as a fraction of its parent emission after the simulation is run. Post calculating Benzene, NMOG, VOC, and NMHC would actually be possible, because they are all dependent on HC for which a direct rate exists in MOVES. In the following paragraphs, each of the chained emissions is described in terms of its relation to other pollutant quantities and its potential use in developing engine maps for the VISSIM emission module.

CO_2[1]

This pollutant is chained to total energy consumption, and is calculated as total energy*Oxidation fraction*Carbon content in the fuel. It is possible that MOVES default or user supplied fuel data could be used to calculate the oxidation fraction and carbon content of the fuel, from which rates could be extracted in terms of grams/KJ. This would be more useful for HCV rates or possibly sub-operating temperature rates, as there is no energy or work involved in the passenger car or motorcycle warm running emissions calculations in VISSIM. Alternatively, total energy rates may be used to develop a mass/time relationship.

Non-methane hydrocarbons[1]

These emissions are calculated as a fraction of the total hydrocarbons (HC). Default or user supplied fuel supply and market share information is used to determine the non-methane component of total HC. It is possible that MOVES default fuel data could be used to develop a ratio relating total HC emission rates to NMHC, which could then be used for one of the following: 1) calculate adjusted NMHC rates for use in engine map files or 2) post calculate NMHCs as a fraction of total HC.

Particulate matter (PM)[1]

VISSIM designates particulate as a single class of emissions, but in MOVES it is divided into a number of separate components as follows:

- Only elemental and organic carbon PM2.5 is calculated directly from activity in MOVES
- PM10 and sulfate PM2.5 are chained emissions, PM10 is chained to PM2.5 and sulfate is chained to total energy
- The MOVES default database contains separate particulate matter emission rates for brake and tire wear processes, which are calculated directly from activity information (i.e.: not chained)

It is likely that the elemental and organic carbon components of PM2.5 can be transferred directly from MOVES to the VISSIM emission module. It is possible that sulfate PM rates can be calculated similar to CO_2, by extracting rates in units of mass/power for HCV's, or by using total energy rates to compute mass/time.

SO_2[1]

In MOVES, SO_2 emissions are chained to total energy consumption, which is calculated directly from vehicle activity. Like CO_2 and sulfate PM, it may be possible to preprocess the MOVES rates to make them useable to some extent in VISSIM.

Evaporation[1]

MOVES calculates VOC's, which would be considered analogous to the VISSIM classification of evaporative. In MOVES, there are a number of operating modes that are associated with evaporative processes, both running and non-running. Running VOC emissions are chained to non-methane hydrocarbons, which are in turn chained to total gaseous hydrocarbons.

Most non-running evaporative processes are also chained to non-methane hydrocarbons, and are based on soak time with longer soak time being associated with lower emission rates. Both running and parked vehicle evaporative emissions are within the capabilities of VISSIM[3], but the methods used to calculate parked evaporative emissions are not described in any available supporting documentation. In practice, it would be quite challenging to transfer total particulate emission rates from MOVES to VISSIM. It would be much easier (although perhaps of questionable value) to only transfer carbon-based PM2.5 rates, for which a direct relationship between activity and rate exists in MOVES.

Fuel[1]

The MOVES database contains direct rates for brake specific fuel consumption, which is the rate of fuel consumption divided by instantaneous power. This is not technically a chained emission, but would require additional effort to make the rates transferable. Because rates are in terms of mass/power, they may be used to compute fuel use rates for heavy commercial vehicles and for sub-operating temperature emissions. This would be more complicated for passenger car and motor cycle warm running emissions, because rates must not be a function of power in VISSIM.

Soot[1]

Soot likely refers to all carbon-based particulate matter, which means that some MOVES rates are directly applicable and some are not. Direct rates are available for carbon PM2.5, to which PM10 rates are chained. It may be possible to calculate rates for emission type “soot”, but some processing of MOVES rates would be required.

Benzene[1]

Benzene, along with all other pollutants classified as “air toxics” in MOVES, has no direct or secondary mass per activity relationship. Benzene emission rates are chained to VOC’s, which are chained to NMHCs followed by HC. Because all emissions quantities required to calculate Benzene are ultimately chained to HCs, post calculation of this pollutant may be the most viable option.

NMOG[1]

In MOVES, non-methane organic gas is chained to NMHCs, which are chained to HCs. This three part chain of emission quantities would make transferring NMOG rates to VISSIM quite challenging, making post simulation calculation the most feasible option.

2.8.3 Converting MOVES Emission Rates to VISSIM Formatting

This subsection describes some strategies for converting MOVES emission rates to fit the dimensions and formatting required by the layer files in the VISSIM emission module, under the assumption that a direct emission-to-activity relationship can be established. There are two principle technical challenges associated with this process. First, emission rates must be mapped from MOVES VSP and speed-based operating modes to the corresponding operating modes in VISSIM, which vary by vehicle class. Next, HCV and motorcycle rate dimensions must be recalculated to fit the required VISSIM format (light duty/passenger car rates are in terms of mass/time for both software applications). These two challenges are addressed in listed order in the following paragraphs.

For passenger car and light duty vehicle rates, it is possible to back-calculate acceleration from MOVES default vehicle parameters and VSP. This would require that VISSIM vehicle types correspond directly to MOVES source types, and also that grade be eliminated from the VSP equation. If this could be done effectively, only simple unit conversions would be needed to map MOVES rates directly to vehicle engine map files. For HCV's, the vertical axis of the engine map matrix is normalized engine power which translates directly to the MOVES definition of VSP. For the horizontal axis, a method would be required to map speed and/or VSP to normalized engine rotational speed. This would require vehicle gearing and engine power data, neither of which is defined for MOVES source types.

The dimensions for most direct MOVES emission rates are mass/time, which corresponds to passenger car rates in VISSIM. This means that only unit conversions will be required to put rates in the correct format for light duty vehicle warm running engine maps. HCV's require rates to be in terms of mass/power/time. Power can be associated with emission rates by multiplying the VSP designation for each operating mode by the vehicle weight, and then dividing each rate by the power associated with that operating mode. This will result in loss of resolution, because VSP categories contain a range of values instead of a single instantaneous value. Motorcycle rates are required to be in terms of mass/distance. Because operating modes for motorcycles are based solely on speed, each rate is associated with a particular speed category. This means that MOVES's mass/time dimensions can be converted to mass/distance by dividing each rate by its associated speed.

It is clear that mapping rates between MOVES and VISSIM is not a simple process. In some cases it could be done by making some simplifying assumptions such as 1) assume that engine speed is a linear function of vehicle speed and divide the MOVES operating mode speed values by the maximum defined speed to give the horizontal lookup values. 2) Assume that emissions are linear functions of vehicle speed and evenly distribute speed dependent emissions along the rotational speed axis from 0 to 1. Motorcycle rates are a function of speed only in the VISSIM emission module, so mapping MOVES emission rates can be accomplished by averaging VSP across each speed category. The results produced by simplifying in this way would likely be of limited use, as many of the complexities of emissions calculations are ignored completely.

2.8.4 Aggregating MOVES Source Bins to VISSIM Vehicle Types

Each source use type in MOVES is assigned a range of emissions profiles, each with a unique source bin identification code and corresponding to particular class of vehicles that falls under the use pattern designation. For this reason, a direct mapping of a source use type to a VISSIM layer file is impossible. This is not a problem in the MOVES computational structure, because the SBDG (2.4.1) creates a distribution of source bins for each source use type in the operating mode distribution[1]. That is, the distribution of source bins, not the actual source use type, is used with the operating mode distribution and emission rate tables to compute emissions. Thus, a mechanism must be developed to calculate emission rates that are aggregated across all emissions profiles for each vehicle type. If this is done, the following tasks must be completed:

1. Run the source bin distribution generator to produce a source bin distribution table. For every source type model year and pollutant process ID, this table contains a fractional distribution of source bins that sums to 1.
2. Each pollutant may have several processes associated with it, so source bin distribution table rows must be sorted into groups containing a single vehicle type and pollutant. That is, all model years and pollutant processes for each vehicle type/pollutant combination are grouped.
3. Emission rates are associated with the source bin ID numbers in the source bin distribution table, and can be found in the EmissionRate and EmissionRateByAge tables. However, these must be adjusted to account for A/C use and I/M program affects. How this is done varies by pollutant.

Ideally, MOVES adjustment factors would be applied in the preprocessing steps, making it unnecessary to account for these changes within the VISSIM emission module. Most adjustments are functions of scenario-specific environmental conditions, so a software application would most likely be required to recompute and adjust rates on a case-by-case basis.

USE OF ON-BOARD VEHICLE DIAGNOSTICS AND PORTABLE EMISSIONS MEASURING EQUIPMENT

3.1 Overview

Microscopic models produce emissions and fuel consumption estimates with higher temporal resolution than other scales of models. Most emissions and fuel consumption models were developed with data from dynamometer testing which are sufficiently accurate for macroscale emissions inventories. However, these data are not taken at high enough temporal resolution to use for microscopic models. Also the typical laboratory setting does not accurately reflect the temporal and spatial variability of the factors affecting emissions and fuel consumption that the microscopic models are attempting to capture. This has contributed to the need to record real-time engine and emissions data at a high temporal resolution.

Using vehicle OBD, it is possible to record a large number of vehicle operating parameters. These variables represent data needed to run the engine optimally and help in some troubleshooting if there are problems. Some existing vehicles are equipped with O_2 sensors and other sensors that provide emissions data, but primarily these are used to determine engine operating conditions. To gather the data needed for microscopic emission modeling, an OBD reader must be paired with an emissions measurement device. The engine parameters can be used to estimate fuel consumption using engine parameters and emissions data.

This chapter will discuss the validity of using vehicle on-board diagnostics and portable emissions analyzers to collect real-time emissions and fuel consumption data from vehicles operating in the field. Specifically it will review the temporal resolution of the data that can be gathered from each device.

3.2 Vehicle On-Board Diagnostics (OBD)

Engine operational variables may be accessed with a computer via a vehicle’s OBD port. The actual variables that are available depend on the specific vehicle, but typically include variables such as vehicle speed, engine speed, and intake air flow rate. The temporal resolution of the data that can be gathered from the OBD port is dependent on the refresh rate of the vehicle computer.

Vehicle on-board diagnostics have been standardized, and have been required on all vehicles sold in the United States after January 1, 1996. The current standard is OBDII, which included several parameters needed for emissions measurement and control that were not included previously. In general, this means all 1996 and newer model year cars and light trucks can be accessed to record comparable data for emissions modeling.

3.2.1 OBDII Testing Procedures

The variable that needs to be tested is the refresh rate of vehicles on-board computer. This can be dependent of two factors:

1. The rate at which the computer in the vehicle is creating data, and
2. The rate at which the OBDII reader retrieves data.

The relationship between these two factors will be determined by using each OBDII reader on each vehicle tested. This will allow for comparison to determine if the OBDII reader's data retrieval rate affects the perceived on-board computer refresh rate.

The vehicles that were tested in this study included a 1998 Subaru Outback, 2001 Toyota Camry, and a 2008 Ford F150 pickup. These vehicles were chosen to give a range of ages and manufacturers, as well as to test both cars and light duty trucks.

The OBDII readers used were AutoEnginuity® ScanTool OBDII Connector[8] and the Innovate LM-2[9] shown in Figure 4.

Figure 4: Examples of OBDII readers, AutoEnginuity® ScanTool on the left and Innovate LM-2 on the right.

AutoEnginuity's® reader is designed for the home engine enthusiast to record engine data and reset error codes, whereas the Innovate LM-2 is aimed towards tuning engines when a dynamometer is not available. These readers were chosen to represent the range available on the market from ones that only display data to those capable of editing engine tuning maps. Also, AutoEnginuity® represents a reader that requires a computer to display data while Innovate LM-2 is a hand held reader and can display data on its screen, with data downloaded to a computer at a later date.

The temporal resolution was determined by timing the refresh rate of data that was being displayed by the OBDII reader. For AutoEnginuity's® ScanTool this was done by timing the changing of parameters viewed on the computer as shown in Figure 5.

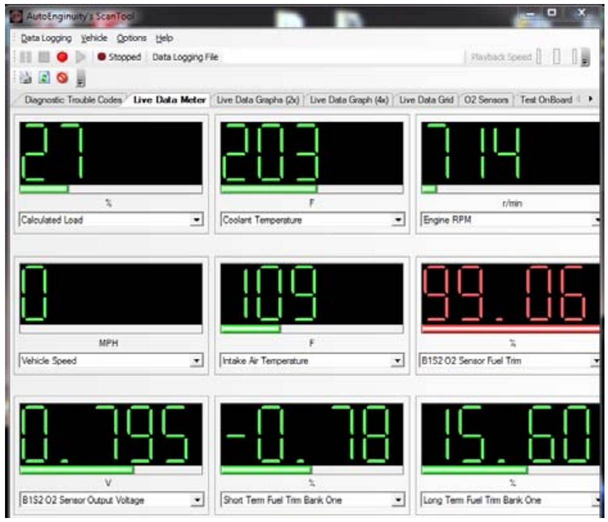

Figure 5: AutoEnginuity's® Scan Tool data display.

The Innovate LM-2 was timed based on the handheld display. It was verified that the timing of the data exported matched the rate of data display. It was confirmed during the tests that the displays were accurately representing real-time vehicle performance with no processing delay.

3.2.2 OBDII Tests Results

The results of testing showed that both OBDII readers had the same display update rate for each vehicle tested. But tests conducted across varying vehicles had different computer refresh rates. The newest vehicle, the 2008 Ford F-150 pickup, updated data approximately ten times per second. The 1998 Subaru and the 2001 Toyota refreshed approximately five times per second.

3.2.3 OBDII Conclusions

The temporal resolution of the data that can be gathered from a vehicles OBDII port is dependent on the refresh rate of the vehicles computer and it not affected by the OBDII reader used. Different aged vehicles do have different refresh rates depending on the make and model, but the most significant contributor is vehicle age.

The computer refresh rates measured were able to capture data that accurately represent the physical changes in the vehicle operating conditions. Figure 6 shows a test of the 2008 Ford F150. The timestep was able to fully capture quick spikes in engine speed from rapidly pressing and releasing the accelerator pedal.

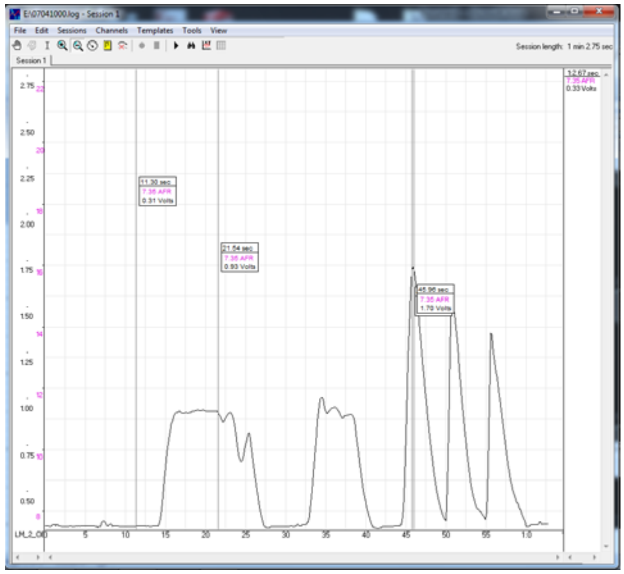

Figure 6: RPMs vs. time for a Ford F150 truck using Innovate LM-2 OBDII reader.

A temporal resolution of five to ten updates per second is adequate to use with microscopic models, which update on an average of three times per second. Thus vehicle on-board diagnostics are able to record data at high enough temporal resolution to use for microscopic models. It is valid to use on-board vehicle diagnostics to collect real-time data from vehicles operating in the field.

3.3 Portable Emissions Measurement Systems (PEMS)

In addition to recording vehicle operating parameters, emissions need to be measured in the field. Emissions may also be measured while a vehicle is being operated using a portable gas analyzer most commonly called a PEMS: portable emissions measurement system. The standard five-gas analyzers measures five components of vehicle exhaust, namely, UHC, CO, CO_2, NO_x, and O_2 (unburned hydrocarbons, carbon monoxide, carbon dioxide, oxides of nitrogen, and oxygen). Tests were conducted using a HORIBA Automotive Emission Analyzer MEXA-584L shown in Figure 7[10].

Figure 7: HORIBA Automotive Emission Analyzer MEXA-584L.

3.3.1 PEMS Testing Procedures

The PEMS was hooked up to a 2001 Toyota Camry that was operated at various engine speeds. The testing included idling the vehicle for a period of time until the emissions readings were constant, and then increasing the engine speed to a setting and holding it constant until the emissions readings again stabilized. The time delay between changing the engine operating conditions changing until the emissions reading changed was noted.

3.3.2 PEMS Testing Results

Emissions are delayed from when they are created in the engine to when they reach the end of the tailpipe. This was shown in the results, with delays as long as a minute between changing the engine operating parameters and seeing a change in the emissions recorded.

3.3.3 PEMS Conclusions

As emission measurements are delayed when changing engine parameters the resolution at which they are measured is not very important as it will not affect the emission prediction capability of a microscopic simulation. It is valid to use portable emissions analyzers to collect real-time data from vehicles operating in the field.

3.4 Measuring Fuel Consumption

While it is possible to estimate fuel consumption using OBDII data, the calculations require assumptions of fuel characteristics and engine efficiency, hence would not be very accurate. It would be far more accurate to install a flow meter in the test vehicles. However, this would require modifying the vehicle, while all other data can be gathered with no vehicle changes required.

This data collection is recommended for future efforts relating fuel use and engine operating conditions. We would need to determine how to best estimate fuel consumption based on OBDII data, and whether the estimate was accurate enough for microscopic modeling.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Microscopic vehicle emissions models are necessary for quantifying the impact of different signal control strategies on air quality. It has been widely recognized that macroscopic models based on the average speed from fixed driving cycles, such as the U.S. EPA MOVES, do not adequately capture the effects of driving and vehicle dynamics on emissions. Therefore, their applicability is limited to estimate and forecast large-scale emissions inventories. In order to predict traffic emissions more accurately and with a higher spatial and temporal detail, microscopic emissions models are necessary. Microscopic traffic simulation modeling provides an accurate and reliable representation of vehicular operations in roadway networks. These models, when integrated with a detailed microscopic emission and fuel consumption use data, can provide a microscopic emission modeling tool suitable for project-level environmental modeling analysis. From the vehicle side, and with the rapid technological changes to vehicle designs that lead to reduction in vehicle emissions and fuel use, it is necessary to develop cost-effective real-time emission and fuel consumption data collection methods for use in the field to support microscopic traffic modeling applications.

The primary goal of this project is to improve the microscopic modeling of emission and fuel consumption by integrating detailed vehicle data into the simulation. The proposed approach combines a microscopic traffic simulation model with detailed emissions and fuel consumption data that is either collected in the field or obtained from an existing emission inventory dataset. The project also examines the possibility of using the vehicle’s OBD to record real-time engine and emissions data at a high temporal resolution suitable for microscopic modeling of vehicle emissions and fuel consumption applications.

In this research project, two basic approaches that may be taken to combine the EPA detailed emissions and fuel consumption data, used in the MOVES model, with microscopic simulation tools, such as VISSIM were introduced. The first approach is to use the microscopic simulation model vehicle specific power trajectory data as source activity input for a MOVES emissions model. This approach has the potential to improve the quality of source activity input to MOVES project scale analysis, as well to make the process of generating activity input simpler for the user. The second approach is to use the emissions and vehicle data contained in the MOVES default database to improve the input to the microscopic simulation emissions module to assist users in developing custom emissions profiles in the emission module in order to more accurately represent the vehicle fleet operating in the U.S. Full description of the two alternatives as well as a case study to illustrate how EPA MOVES' data can be integrated into microscopic simulation are provided in this report.

Most microscopic simulation tools model vehicle operations only from the kinematic point of view with little or no consideration to kinetic components of the motion (drag force, wind resistance, slope resistance, momentums, etc.). The microscopic vehicle trajectories produced by these models show speed and acceleration values that are erratic leading to higher VSPs than observed in the real world. The vehicle speed data generated by the microscopic simulation models should be validated to ensure that the VSP estimated using these trajectories are consistent with field operations.

Using vehicle OBD, it is possible to record a large number of vehicle operating parameters. A discussion of the validity of using vehicle on-board diagnostics and portable emissions analyzers to collect real-time emissions and fuel consumption data from vehicles operating in the field is also presented in this report. Specifically it reviews the temporal resolution of the data that can be gathered from each device.

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