ECO-DRIVING MODELING ENVIRONMENT

Final Report
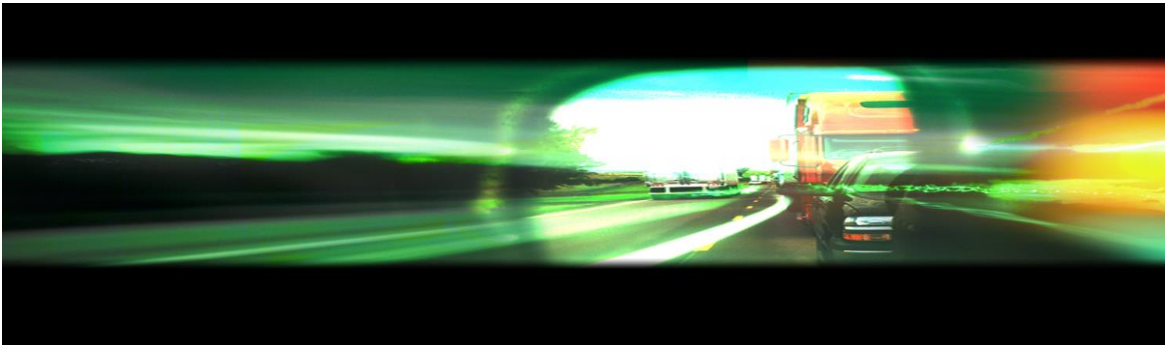
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16. Abstract

This research project aims to examine the eco-driving modeling capabilities of different traffic modeling tools available and to develop a driver-simulator-based eco-driving modeling tool to evaluate driver behavior and to reliably estimate or measure fuel consumption and emissions. The proposed driver-simulator eco-driving modeling tool consists of a driving simulator integrated with an advanced engine modeling software in a hardware-in-the-loop modeling environment. The high-fidelity driving simulator has the advantages of being able to accurately simulate multiple driving environments and provide real-time feedback to the driver. A simplified fuel efficiency model based on a generic brake-specific fuel consumption (BSFC) map for an inline 4-cylinder has been developed and tested. By using the engine RPM and engine torque variables provided by the NADS MiniSim with the generic BSFC model, power and approximate engine efficiency, fuel consumption, and fuel economy are estimated within the MIniSim simulation environment. Using Windows Presentation Foundation (WPF) an EcoDash is created. The developed EcoDash overlays on top of the existing MiniSim Dashboard that include a speedometer, a tachometer, and in the center of the speedometer cluster is an acceleration display.

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EXECUTIVE SUMMARY

The U. S. Department of Transportation (USDOT) has been working on several initiatives to reduce traffic-related vehicle emissions and fuel consumption to help the nation's transportation activities become more sustainable and cost-effective. In recent years, eco-driving has been identified as one promising solution to palliate environmental and fuel consumption issues. Eco-driving is a collection of driving techniques designed to reduce fuel consumption and emissions in existing vehicles. Drivers are slowly becoming educated on the techniques of eco-driving but currently few tools exist to educate and train drivers about eco-driving practices. This research project aims to examine the eco-driving modeling capabilities of different traffic modeling tools available and to develop a driver-simulator-based tool to evaluate driver behavior and to reliably estimate or measure fuel consumption and emissions.

The proposed driver-simulator eco-driving modeling tool consists of a driving simulator integrated with an advanced engine modeling software in a hardware-in-the-loop modeling environment. The high-fidelity driving simulator has the advantages of being able to accurately simulate multiple driving environments and provide real-time feedback to the driver. A simplified fuel efficiency model based on a generic brake-specific fuel consumption (BSFC) map for an inline 4-cylinder has been developed and tested. By using the engine RPM and engine torque variables provided by the NADS MiniSim with the generic BSFC model, power and approximate engine efficiency, fuel consumption, and fuel economy are estimated within the MIniSim simulation environment. Using Windows Presentation Foundation (WPF) an EcoDash is created. The developed EcoDash overlays on top of the existing MiniSim Dashboard that include a speedometer, a tachometer, and in the center of the speedometer cluster is an acceleration display. A SimLink interface between the GT-Suite Software and the NADS MiniSim Model is developed and validated. The interface facilitates the integration of the two models to create an Eco-Driving model-training tool.

CHAPTER 1: INTRODUCTION

1.1 Overview

The U. S. Department of Transportation (USDOT) has been working on several initiatives to reduce traffic-related vehicle emissions and fuel consumption to help the nation's transportation activities become more sustainable and cost-effective. In recent years, eco-driving has been identified as one promising solution to palliate environmental and fuel consumption issues. Eco-driving is a collection of driving techniques designed to reduce fuel consumption and emissions in existing vehicles. Drivers are slowly becoming educated on the techniques of eco-driving but currently few tools exist to educate and train drivers about eco-driving practices.

The characteristics of eco-driving are generally well defined and easily characterized. The advantages of eco-driving go beyond CO2 reductions. They include reducing the trip cost to the individual and producing tangible and well-known safety benefits, with fewer accidents and traffic fatalities, through the harmonization of operating speeds on different roadway segments. The little public understanding of the nature of eco-driving, however, limits the potential operational benefits of eco-driving practices. Many vehicles are now equipped with tools to help drivers choose the best compromise between safety and CO2 reduction driving techniques (Eco-Driving Assistance Systems – EDAS). Additionally, several GPS-based smartphones applications provide a dynamic fuel efficiency indicator, while some software are specifically dedicated to eco-driving and are able to deliver tips to help decrease fuel consumption. However, the fuel consumption and emission models used in these tools are generally macroscopic in nature with little or no calibration and validation. This research project aims to examine the eco-driving modeling capabilities of different traffic modeling tools available and to develop a driver-simulator-based eco-driving modeling tool to evaluate driver behavior and to reliably estimate or measure fuel consumption and emissions.

1.2 Report Organization

This report is organized in four chapters. After the introduction, chapter 2 documents the eco-driving modeling capabilities of different traffic modeling tools covering the availability of

fuel consumption and emission data and the modeling capabilities of microscopic, mesoscopic, and macroscopic modeling tools. Chapter 3 provides a brief summary of the development and design architecture of the driver-simulator-based eco-driving modeling tool developed as part of this project. Chapter 4 includes the study conclusions and recommendations.

CHAPTER 2: ECO-DRIVING MODELING CAPABILITIES

2.1 Introduction

The main goal and contribution of this work is to document current practices used to model eco-driving, fuel consumption, and emissions. The work in this chapter is divided into two main sections. The first section focuses on sources of vehicle emissions and fuel consumption data. The second section addresses eco-driving, fuel consumption, and emission modeling capabilities of different simulation modeling tools covering three analysis levels: microscopic, mesoscopic, and macroscopic. For each of the models, details are provided on how both the kinetics and kinematics components of vehicle motion are being represented and modeled. "Kinetics" refers to the movements of various bodies and the forces that can act on both bodies in motion and bodies at rest. "Kinematics" focuses only on the movement of various bodies, but does not address forces that can influence movement.

2.2 Sources of Vehicle Emissions and Fuel Consumption Data

2.2.1 Emission Inventories

An emission inventory is a "database that lists, by source, the amount of air pollutants discharged into the atmosphere during a given period from a certain activity." It is an important component in the air quality management process and is used to determine sources and quantities of different air pollutants and to build emission trends over time (EPA, 2012a). Some of the methods of collecting vehicle emissions and fuel consumption data to build emission inventories include: 1) continuous monitoring of actual emissions measurements, 2) extrapolating the results from short-term source emissions tests, and 3) merging available activity levels data with associated emission factors.

2.2.2 Emission Factors

An emission factor is defined as a value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors are typically expressed as the weight of a specific pollutant divided by the

unit weight, volume, distance, or duration of the activity emitting the pollutant (Office of Air Quality Planning and Standards, 2012).The general equation for emissions estimations is:

$$E = A * EF * (1 - ER/100)$$

Where:

- E = emissions;
- A = activity rate;
- EF = emission factor, and
- ER = overall emission reduction efficiency (%).

There are several emission inventories and factors' databases. An example is the Emission Factors (EMFAC) database that includes emission rates for different types of motor vehicles (passenger cars and heavy-duty trucks) operating on highways, freeways and local roads in California. EMFAC-2014 is the most recent version of this model. Data from 25 million registered vehicles in the vehicle registration data were used to update the populations in each vehicle class for 59 geographical areas. Travel activity data are provided by regional transportation planning agencies, while Vehicle Miles of Travel (VMT) and speed data are obtained from the Southern California Association of Governments, Bay area Metropolitan transportation commission, San Diego association of governments, and San Joaquin Valley councils of government (California Environmental Protection Agency - Air Resources Board, 2014).

Another extensive source of emission factors is the EPA's Air Pollutant (AP) -42 Documentation. This documentation was developed by the Emission Factor and Inventory Group (EFIG). It addresses ozone-related pollutants (like total Organic Compounds, Oxides of Nitrogen (NO_x), and Carbon Monoxide (CO)), hazardous pollutants, and global warming gasses. (Office of Air Quality Planning and Standards, 2012) and (EPA, 2012b). Examples of emission inventories and their available resources are listed below.

- National Emission Inventory (NEI): NEI is a comprehensive and detailed estimate of air emissions and hazardous air pollutants from all air emissions

sources. It is developed and maintained by the U.S. Environmental Protection Agency (EPA). NEI is updated every three years based on emission estimates and emission model inputs provided by state, local, and tribal air quality agencies from sources in their jurisdictions. The database is supplemented by data developed by the US EPA. (EPA, 2012a) and (EPA, 2013).

- EPA Clearinghouse for Inventories & Emission Factors: This database contains information on emissions inventories, emission factors, software and tools used for emissions inventories, and emissions modeling. All emission inventory data, tools, and resources could be downloaded from the EPA website (EPA, 2012c).

- Biogenic Emissions Inventory System (BEIS): The Biogenic emissions come from natural sources and need to be accounted for in photochemical grid models. These photochemical grid models could be defined as a large-scale air quality models that use a set of mathematical equations characterizing the chemical and physical processes in the atmosphere to simulate the changes in pollutant concentrations in the atmosphere. Often only the emissions from vegetation and soils are included, but other relevant sources include volcanic emissions, lightning, and sea salt. Biogenic emissions are typically computed using a model that includes spatial information on vegetation and land use and environmental conditions of temperature and solar radiation. The model inputs are typically horizontally allocated (gridded) data, using a fixed coordinate system with respect to the ground, and the outputs are gridded biogenic emissions that can then be speciated and used as input to photochemical grid models (EPA, 2013).

- Emissions Modeling System for Hazardous Pollutants (EMS-HAP): The Emissions Modeling System for Hazardous Pollutants (EMS-HAP) is an emissions processor that performs the steps needed to process an emission inventory for input into the Assessment System for Population Exposure Nation-wide (ASPEN) model or the Industrial Source Complex Short Term Model, Version 3 (ISCST3) model. EMS-HAP is written in the SAS

programming language and is designed to run on any UNIX workstation. The user will need a SAS license and some knowledge of SAS to use this program (EPA, 2012d).

- NONROAD Vehicle & Engine Emission Modeling: The primary use of the NONROAD Model is for estimating the air pollution inventories by professional mobile source modelers, such as state air quality officials and consultants. NONROAD2008 updates NONROAD2005 to include new non-road emission standards promulgated in 2008 related to small gasoline engines and pleasure craft (EPA, 2012e).

- Sparse Matrix Operator Kernel Emissions (SMOKE): It is a Linux software supported by the "Center for Environmental Modeling for Policy Development (CEMPD) at the University of North Carolina at Chapel Hill. SMOKE is an active open-source development project supported and distributed through the Community Modeling and Analysis System Center. All required information could be obtained from this following source (SMOKE version 3.1, 2012).

- International Vehicle Emissions (IVE) Model: The International Vehicle Emissions (IVE) Model is a computer model designed to estimate emissions from motor vehicles. The model is intended to help cities and regions develop emissions estimates to focus control strategies and transportation planning on those that are most effective; predict how different strategies will affect local emissions; and measure progress in reducing emissions over time. The model makes estimates of local air pollutants, greenhouse gas emissions, and toxic pollutants (ISSRC, 2012).

- Comprehensive Modal Emissions Model (CMEM): CMEM is a microscopic emission rate database. The model is based on a total of more than three hundred tested vehicles. These vehicles were tested using three primary driving cycles: 1) The EPA Federal Test Procedure (FTP); 2) the US06, Supplemental Federal Test Procedure (SFTP); and 3) the Modal Emission Cycle (MEC01). During the tests, second-by-second tailpipe and engine-out emissions data (gram emission/gram fuel) were

collected [38](Barth et al., 2000a) and (Barth et al., 2000b). CMEM uses a physical, power-demand modal modeling approach based on the vehicle physical characteristics to generate emission tables. The vehicle emissions testing procedure was based on a second-by-second performance measurements of Carbon dioxide (CO_2), Nitrogen Oxides (NOx), Hydrocarbon (HC), and Carbon Monoxide (CO) over three separate driving cycles. The complete modal emissions model is composed of six modules. These models are: Engine power demand; Engine speed; Fuel/air ratio; Fuel-rate; Engine-out emissions; and Catalyst pass fraction (a function primarily of fuel/air ratio and engine-out emissions, and defined as the ratio of the tailpipe to engine-out emissions) (Barth et al., 2000a), and (Barth et al., 2000b)

- Emission Inventory Guidebook: This emission inventory is prepared by the United Nations European Environment Agency (EEA) and the Task Force on Emissions Inventories and Projections (TFEIP). This guidebook provides a comprehensive guide to state-of-the-art atmospheric emissions inventory methodology. The guidebook also supports the efforts of reporting under the United Nations Economic Commission for Europe (UNECE) Convention on Long- Range Trans-boundary Air Pollution and the European Union (EU) directive on national emission ceilings (United Nations Economic Commission for Europe, 2012), and (TFEIP, 2012).

2.3 Vehicle Emissions and Fuel Consumption Modeling Capabilities of
Simulation Modeling Tools

2.3.1 Overview

In this part of the work, different simulation modeling tools are presented. Traffic simulation models were divided, based on the level of analysis into these three categories: microscopic, mesoscopic, and macroscopic (Yue, 2008). In the following sections, a brief summary of the characteristics of different models, as they relate to modeling fuel consumption and vehicle emissions will be presented and discussed. The reviews presented include the model's emission modeling capabilities, how vehicle kinematics and kinetics are being represented in the model, and how it could be used for research related to emissions and fuel consumption. "Kinetics" is a mechanics branch that focuses on the movements of various bodies and the forces that can act on both bodies in motion and bodies at rest; however ,"kinematics" is solely focused on the movement of various bodies, without addressing the forces that can influence movement.

2.3.2 Microscopic Simulation Models

Microscopic simulation tools model the movement of individual vehicles on the basis of car-following and lane-changing theories. They describe both the system entities and their interactions at a high level of detail. These models are also designed for operations analyses of systems of road facilities (Lieberman and Rathi, 1997), (Dowling et al., 2002), and (Alexiadis et al., 2004). Using instantaneous speeds and acceleration of individual vehicles, microscopic models can calculate fuel consumptions. These models are usually used to evaluate individual transportation projects. There are several microscopic simulation models currently available. Examples of these models include: Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN2), Corridor Simulation (CORSIM), INTEGRATION, MICSTRAN (Microscopic Simulator Model for Traffic Networks (MicroSim), Microscopic Traffic Simulator (MITSIM), Probabilistic Adaptive Simulation Model (PADSIM), PARAMICS, SimTraffic, VISSIM, and Wide Area Traffic Simulation (WATSim).

VISSIM

VISSIM is a stochastic, microscopic, time step, and behavior based traffic simulator. VISSIM's traffic model is based mainly on the psychophysical driver behavior model of R. Wiedemann, in which the driver's reactions are in response to the relative speed and distance of the preceding vehicle. VISSIM can simulate multi-modal traffic flows, including passenger cars, buses, light rail, trucks, pedestrians, and others. VISSIM was originally developed at the University of Karlsruhe, Germany in the early 1970s, while the commercial distribution, development, and maintenance started in 1993 by PTV Transworld AG and is still done by them today (Loren Bloomberg and Dale 2000), and (Gomes et al., 2004).

VISSIM is formed mainly from two main parts; the first one is the simulator generator part, in which the user can import aerial photos and schematic drawings and can begin to build the simulation network graphically. The second main part is the signal state generator (SSG), in which the logic of the signal control exists, and in which the user can define lots of different signal operations like fixed time, and ramp metering (Loren Bloomberg and Dale 2000), and (Gomes et al., 2004).

VISSIM was used in several of the research work related to emissions. In one paper, researchers proposed a real-time signal control method to minimize CO_2 emissions (Umedu et al., 2012). This method integrated arrival times from the information that consists of position and speed from the vehicle to vehicle and vehicle to infrastructure communications. The paper speculates that the more signals that are controlled together, the more efficient control can be and thus the authors have decided to use this specification in their system. The process of analyzing emission used mathematic calculations of exhaust output and VISSIM simulation to provide travel times of a corridor.

VISSIM is supporting an add-on called EnViVer. Using the vehicle record data, EnViVer can calculate different types of emissions like CO_2, NO_x, and PM_{10}. The emission model in EnViVer is the microscopic exhaust gas/emission model VERSIT+ which is based on emission measurements for about 2,800 vehicles under different driving conditions. The

main idea of EnViver is based on importing the VISSIM record files and then calculating the emissions at spatial detail, and finally getting the output tabulated or graphed (PTV Group, 2012).

CORSIM

CORSIM is a microscopic simulation program developed by the Federal Highway Administration (FHWA), and part of the Traffic Software Integrated System (TSIS) which offers a window-based interface for running the model. CORSIM mainly includes two traffic simulation predecessor models, NETSIM, and FRESIM. NETSIM is concerned with arterials with at-grade intersections (urban street traffic); while FRESIM models uninterrupted facilities including interstate freeways and grade separated expressways (freeway traffic). CORSIM executes the simulation and measures the network efficiency to the user in predetermined Measures Of Effectiveness (MOEs) (Minnesota Department of Transportation, 2008), (Bloomberg and Dale, 2000), and (Park et al., 2004).

When combined with NETSIM and FRESIM models, CORSIM is capable of simulating a large set of systems. These systems include freeways, urban streets, corridor or networks, different intersection control (e.g. pre-timed signals and actuated ones), almost any surface geometry, including turn pockets and the number of lanes, weaving sections, work-zones, and bus operations (Minnesota Department of Transportation, 2008), (Bloomberg and Dale, 2000), and (Park et al., 2004).

CORSIM is mainly based on a link-node structure network model, where links characterize roadway segments, and the nodes represent intersections, entry and exit points. CORSIM is a stochastic simulation model, which means it uses random processes to model drivers' behavior, vehicle characteristics, and interactions into each run. Multiple runs may be required to get a true picture of the network because one run might be not representative. CORSIM creates tabulated data for fuel consumption and environmental emissions. It can also tabulate and graph the effect of traffic different control strategies on acceleration and fuel consumption. Because CORSIM's data was not updated for many years, FHWA recommends using the data for comparison analysis only and not as absolute indications

(Minnesota Department of Transportation, 2008), (Bloomberg and Dale, 2000), (Park et al., 2004), and (FHWA, 2010).

The newer versions of CORSIM have adopted the Vehicle Transient Emissions Simulation Software (VeTESS) for the process of calculating fuel consumption and emissions. VeTESS was developed as a vehicle level tool for the simulation of fuel consumption and emissions for real traffic transient vehicle operation within the EU 5th framework project DECADE (2001-2003). VeTESS is capable of calculating emissions and fuel consumption made by a single vehicle during a defined "drive-cycle." For a given drive-cycle, VeTESS uses simple mathematical calculations to determine the engine's operating conditions from the force on the vehicle. These calculations involve gear ratios and their efficiencies. Using the equation of motion, Equation 2, VeTESS calculates the total force on the vehicle.

$$F_{total} = F_{accel} + F_{grad} + F_{roll} + F_{aero} \qquad \text{Equation 2}$$

Where:

- F_{total} = The total force acting on the vehicle,
- F_{accel} = The force required in order to cause an acceleration of the mass of the vehicle,
- F_{grad} = The component of the weight force of the vehicle acting parallel to the slope,
- F_{roll} = The rolling resistance,
- F_{aero} = The aerodynamic resistance.

The engine provides the force required to overcome the motion resistances as a torque. After that, driven wheels convert this torque from rotational to linear motion. VeTESS then evaluates the engine speed and engine torque from the forces acting on the vehicle and references the corresponding values for the emission components using emission maps. These maps are generated by operating the engine in a series of steady-state conditions (Beckx et al., 2007).

CORSIM was used in many research works related to emissions. One example of this type of research is Kosman et. al. who evaluated both CORSIM and VISSIM for project-level emission modeling (Kosman et al., 2003). The studied project-levels included the impacts of traffic flow improvements resulting from changes in signal timing or other roadway improvements. CORSIM was compared to VISSIM for two different scenarios.

In the first scenario, outputs from the two models were compared to spot speed and average speed data collected from the field. Average speed, includes the total travel time along a link including idling, and this is why average speeds generated by simulation models depend on the effectiveness of queuing and delay prediction.

In the second scenario, the models' predicted emission reductions were compared to three Congestion Mitigation and Air Quality (CMAQ) projects. In the first scenario, researchers found both CORSIM and VISSIM under-predicted the mid-block spot speed, with mixed results for the average speed. Overall predicted emissions (VOC and NO_x) in the first scenario from CORSIM, VISSIM, differed the field studies by less than 7%. In the second scenario, researchers found CORSIM predictions differences in pre- and post-project speeds are greater than VISSIM predictions for all three projects. This resulted in causing greater reductions in emissions.

CMEM

The Comprehensive Modal Emissions Model (CMEM) is published by the Center for Environmental Research and Technology (CE-CERT) in Riverside, California. Development of CMEM began in the late 1990s with support from the Cooperative Highway Research Council and continued until the final phase was completed in 2005. CE-CERT has also received some support from the Environmental Protection Agency (EPA). CMEM is not a traffic simulator, which means all vehicle activity data must come from another source. Because of this, microscopic traffic simulation software is often used to generate traffic network and activity data, and input to CMEM to calculate emissions. Several interface applications used to link CMEM with microscopic simulation software have been developed and used with success (Barth et al., 2005). CMEM is an open source and is available free for download.

CMEM is based on a deterministic physical power demand model, which is based on a parameterized analytical representation of emissions production. Emission rates depend on causal variables such as fuel delivery system, inspection maintenance effects, and vehicle age. Second-by-second vehicle tailpipe emissions are modeled as the product of three components: Fuel Rate (FR), engine-out emission indices (gram $_{emission}$/gram $_{fuel}$), and time-dependent catalyst pass fraction (M. Barth et al., 2006). Because the rates contained in CMEM are based on physical parameters, in theory it could be adapted to represent new vehicle technologies. The most recent major changes, however, to the CMEM emission rate database took place in 2005, which suggests the emissions data contained in this software could be outdated.

CMEM data properly incorporate the physical variables that contribute to emission rates. Existing emission inventories were deemed too generalized by vehicle category and not detailed enough for this purpose. Instead, emission rates were developed "in-house" from tests conducted on several hundred recruited vehicles at the University of California Riverside Center for Environmental Research and Technology. CMEM is based on a simple parameterized physical approach.

This approach uses six modules that predict engine power, engine speed, air/fuel ratio, fuel use, engine-out emissions ($g_{emission}$/g_{fuel}), and the catalyst pass fraction. All emission data used in CMEM were collected in the USA, mostly at the Riverside facility. For the most part, emission data were collected on dynamometer tests, using a number of different drive cycles with the intent to capture the full range of operation in the resulting emission rates. Much of the data used in CMEM were collected before 1998, with additional low emitting vehicle data collected in 2002-2003 (M. Barth et al., 2006). The input operating variables in CMEM have some variables such as; (acceleration, air/fuel equivalence ratio, and fuel rate), second-by-second speed, road grade angle, and accessory use (such as air conditioning).

The main output of the CMEM model is the instantaneous emission. This instantaneous emission could be calculated as the product of three components:

- Fuel rate,

- Mass of engine-out emissions per grams of fuel consumed, and

- The catalyst pass fraction which is the ratio of tailpipe emission to engine-out emission (An et al., 1997).

The instantaneous emissions equation is shown in Equation 3:

$$\text{Tailpipe emissions} = \text{FR.} \left(\frac{g_{emission}}{g_{fuel}} \right) . CPF$$

Equation 3

Where:

- FR = fuel-use rate in grams/s,

- $g_{emissions}/g_{fuel}$ = grams of engine-out emissions per grams of fuel consumed, and

- CPF = the catalyst pass fraction, defined as the ratio of the tailpipe to engine-out emission.

The total tractive power requirements (in KiloWatt-KW) placed on the vehicle (at the wheels) is shown in Equation 4:

$$P_{tract} = A \cdot v + B \cdot v^2 + C \cdot V^3 + M \cdot a + M \cdot g \cdot v \cdot \sin \theta$$

$$P = \frac{P_{tract}}{\eta_{tf}} + P_{acc}$$

Equation 4

Where:

- M = the vehicle mass with the appropriate inertial correction of rotating and reciprocating parts (kg),

- v = speed (m/sec.),

- a = acceleration (m/s^2),

- g = the gravitational constant (9.81 m/s^2), and

- θ = the road grade angle.

- P = the engine power output,

- η_{tf} = the combined efficiency of the transmission and final drive,

- P_{acc}= the engine power demand associated with the operation of vehicle accessories.

The fuel rate in any driving cycle for any vehicle model could be calculated using Equation 5:

$$FR \approx \left(KNV + \frac{P}{\eta}\right)\frac{1}{44}$$

Equation 5

Where,

- k   = the engine friction factor,
- N   = engine speed (revolutions per second),
- V   = engine displacement (liter),
- $\eta \approx 0.4$ = a measure of indicated efficiency.

And finally the engine-out emission module could be calculated using Equation 6:

$$ECO \approx [C_0(1 - \phi^{-1}) + a_{co}]FR$$
$$EHC \approx a_{HC}FR + \gamma_{HC}$$
$$ENO_x = a_{1NOX}(FR - FR_{NOX}) \text{ If>0 and 0 otherwise, for } \phi<1.05$$
$$ENO_x = a_{2NOX}(FR - FR_{NOX}) \text{ If>0 and 0 otherwise, for } \phi\geq1.05$$

Equation 6

Where:

- C_0, a_{CO}, a_{HC}, and γ_{HC} are calibrated constant coefficients that are slightly different from vehicle to vehicle,
- a_{1NOX} and a_{2NOX} are engine-out NO_X emission indexes in grams of emissions per gram of fuel use under optimum and enrichment conditions, respectively, and
- FR_{NOX} is fuel rate thresholds.

One of the examples of using CMEM in the emissions research work is Xia et al. (2012) that discussed the use of the ECO-Signal Operations approach technology. The ECO-approach technology means a traffic signal broadcasts its signal phase and timing, and Geometric Intersection Description to the vehicle. An on-board system takes this information along with vehicle position and speed and provides speed recommendations to the driver. This speed would be an emission reducing optimal speed. Field tests were conducted using a test vehicle equipped with the optimal speed algorithm. Based on the vehicle speed trajectories during the

test, vehicle fuel consumption was calculated using CMEM. During the two tested scenarios, vehicle emissions were reduced compared to the control, an uninformed driver (Xia et al., 2012).

INTEGRATION

INTEGRATION is a trip-based microscopic traffic and emissions simulation model. It was developed in its current version under the direction of Dr. Hesham Rahka at Virginia Tech. The software includes a traffic assignment tool, in which Origin-Destination (O-D) matrices are entered along with departure time series histograms for each O-D pair. The INTEGRATION framework can model a range of on-road vehicle types and supports a total of 25 default options including passenger cars, light-duty trucks, and heavy-duty trucks. Similar to most industry standard traffic simulation software, vehicle operation is governed by proprietary car following, lane changing and gap acceptance models (Rakha, 2013).

INTEGRATION was designed with a strong basis in vehicle operation dynamics and is intended to represent acceleration and velocity accurately at high temporal resolution. In addition, the model is designed to offer flexibility in estimating acceleration rates of both large and small vehicles on varying road types and conditions. This accuracy and flexibility are a necessity for microscopic power-based emissions modeling (Rakha, 2013). INTEGRATION allows the user to specify time series histograms for departures for each origin-destination pair in the simulation. The software generates individual vehicle departure time schedules from this information before the simulation is run. Departures can be fully random or any combination of random and uniform. Calibration of the O-D demand is achieved using a maximum likelihood approach (Rakha and Ahn, 2004b).

Pipes and Greenshields car-following and traffic stream models were combined into a single regime model, based on desired speed and proximity to followed vehicle. This is referred to as Van Aerde's model after Michael Van Arde, the original developer of INTEGRATION. The model is calibrated using four parameters based on field data: free-speed, speed-at-capacity, capacity, and jam density. Position, headway, and speed are computed in 0.1 second time steps (Rakha et al., 2004c), (Rakha et al., 2001b), and (Rakha et al., 2004e).

INTEGRATION uses a separate acceleration and deceleration logic. Deceleration is computed based on the existing speed, the speed of the vehicle or object that is necessitating the deceleration, and the time available to decelerate. According to the developers, this can lead to an asymptotic deceleration of a vehicle following another vehicle that is traveling at a constant speed. In any case, a vehicle will not continue to decelerate once it reaches the speed of the vehicle ahead of it (Rakha et al., 2004c).

Vehicle acceleration in INTEGRATION is simulated with the vehicle dynamics model, as opposed to the more common kinematic acceleration models. One of the problems identified with the state of practice models is in their ability to represent the speed/acceleration relationship at low vehicle speeds. Most models allow acceleration to vary as a function of speed, with higher acceleration in general associated with lower travel speeds. A number of different ways of modeling this exist, however, with no definitive relationship between these two parameters. According to the developers of INTEGRATION, industry-standard traffic models tend to overestimate acceleration at low speeds, which makes them poorly suited for emissions modeling (Rakha et al., 2004e), (Rakha et al., 2004c), (Rakha et al., 2001b). INTEGRATION addresses this issue by constraining vehicle acceleration to the physical limitations of the vehicle as described below.

In the INTEGRATION model, power is computed as the minimum of 1) maximum tractive effort based on tire/road surface friction and vehicle weight and 2) engine power, corrected for transmission efficiency and accessory power use. In addition to power, rolling resistance, aerodynamic drag, grade, and vehicle mass are all considered in acceleration computations. The model also accounts for the fact that drivers do not typically use the maximum power available in their vehicles. The configuration differs somewhat for light-duty and heavy-duty vehicles (LDV's and HDV's). The HDV model accounts for the loss of power at low speeds due to gear shifting (Rakha et al., 2001b). The LDV model is very similar but assumes the low-speed power loss effect is negligible for passenger vehicles (Rakha et al., 2004e). Both the LDV and HDV models were calibrated using field data collected at Virginia Tech's Smart Road test facility in Blacksburg, Virginia.

For the HDV model, four heavy-duty diesel trucks of model years, ranging from 1990 to 1998 were driven over the test course in the spring of 2001. Ten different load cases were tested for each vehicle. By changing the loading, researchers hoped to incorporate the range of power to weight ratios that would typically be observed in practice. This data was used to calibrate the power adjustment factor, which is a linear function relating engine power to vehicle speed. This factor is intended to capture the average power reduction due to gear shifting as a function of speed, as actual power fluctuates between the maximum value and zero as gear shifts take place (Rakha et al., 2001b).

Vehicle acceleration data were collected in the summer of 2001 using 13 test vehicles ranging from subcompact to light duty trucks. This data was used to calibrate and compare several state of practice vehicle acceleration models, including the dynamics model used in INTEGRATION. Comparisons were made for speed and acceleration versus time and distance, as well as acceleration versus speed. The results of the comparison, strongly supported the vehicle dynamics model over the other state of practice models. This was a relatively simple validation and did not involve any real world vehicle interaction or complex maneuvers (Rakha et al., 2004e).

The emissions model incorporated into INTEGRATION is the Virginia Tech Microscopic energy and emission model (VT-Micro). While a full discussion of the model structure is outside the scope of this report, the model will be described as it relates to INTEGRATION. Based on the instantaneous speed and acceleration levels of individual vehicles, VT-Micro, predicts the instantaneous fuel consumption and emission rates of HC, CO, NOX and CO2 (Ahn, 1998), (Rakha et al., 2000), and (Ahn et al., 2002c).

One important thing to note is that when the performance characteristics like acceleration characteristics of the VT-Micro data are exceeded in the input speed and acceleration data, emissions will be computed at the boundary of the VT-Micro data. That is to say, the performance envelope of the VT-Micro data determines the maximum possible emission rates (Rakha et al., 2004c). Although INTEGRATION computes speed and acceleration in

0.1 second-time steps, these values are averaged over one second time steps for emission calculations. According to supporting documentation, this reduces the accuracy of the emissions estimates and is done to reduce the computational load.

Emission rates were collected using dynamometer tests and standardized drive cycles. The first study to develop non-high emitting vehicle emission rates was conducted in 1996 at the Oak Ridge National Laboratory (ORNL). Test vehicles included five light-duty automobiles and three light-duty trucks and were selected to be representative of the sales proportion in terms of engine displacement, based on sales data from 1995 and 1996. The vehicles used in the emission rate development were subjected to driving tests in order to develop practical performance limits that correlate to the actual vehicle capabilities (Rakha and Ahn, 2004b). The general VT-Micro equations used to calculate the instantaneous fuel consumption and emission rates of individual vehicles could be seen in Equation 7.

$$MOE_e = \sum_{i=0}^{3}\sum_{j=0}^{3} exp\left(k_{i,j}^e * v_{VT}^i * a^j\right), for\ a \geq 0$$

Equation 7

$$MOE_e = \sum_{i=0}^{3}\sum_{j=0}^{3} exp\left(l_{i,j}^e * v_{VT}^i * a^j\right), for\ a < 0$$

Where:

- MOE_e = Instantaneous fuel consumption or emission rate (Liter Per Second or milligram per second),
- a = Instantaneous acceleration of vehicle (km/h/s),
- v = Instantaneous speed of vehicle (km/h),
- $k_{i,j}^e$ = Vehicle-specific acceleration regression coefficients for MOEe, and
- $l_{i,j}^e$ = Vehicle-specific deceleration regression coefficients for MOEe.

Since the initial release, the VT-Micro model has been updated to include emissions data from 87 additional cars and trucks. This update is described in the documentation related specifically to VT-Micro, but it is stated that the updated model has been included in the current release of INTEGRATION (Rakha and Ahn, 2004b). This data was gathered by the

EPA using dynamometer tests at the Automotive Testing Laboratories, Inc., in Ohio and EPA's National Vehicle and Fuels Emission Laboratory (NVREL) in Michigan in the spring of 1997.

Vehicles of model years 1986 to 1996 were drafted at random from inspection and maintenance lanes in Ohio. Vehicles were screened to separate high emitting from non-high emitting vehicles, and separate rates developed for each group. In the screening process, 60 vehicles were identified as non-high emitters and 37 as high emitters. Each vehicle was tested in 14 to 16 different drive cycles to insure the full range of acceleration/speed combinations was captured. In addition to the typical vehicle categories of light duty and heavy duty, statistical methods were used to define five LDV and two light-duty truck (LDT) categories.

Emission rates were developed from test data using the methods described in the VT-micro model supporting documentation (Rakha et al., 2004c). Regression equations were developed to represent emission rates as functions of speed, power, and acceleration. Separate regression equations were developed for positive and negative acceleration because engine power is exerted in positive acceleration while none is exerted in negative acceleration. An optimal temporal shift of approximately six– eight seconds was computed to deal with the time lag between acceleration and tailpipe emissions.

Aggregate and instantaneous emission rates were validated using a number of drive cycles, but no validation was performed (at least in the rate development studies) using microsimulation versus real world data. The documentation of the rate development studies is focused primarily on the emission vs. acceleration and speed relation, as opposed to the simulated versus real world relationship.

PARAMICS

Paramics is a microscopic traffic simulation software package published by Quadstone in Edinburgh Scotland. Interestingly, there are two similar microscopic traffic simulation software titles published by the SIAS company in Edinburgh under the name Paramics: the

Quadstone product and "S-Paramics". According to the SIAS company website, the similarity in both name and underlying model is the result of a partnership between Quadstone and SIAS that was dissolved in 1998 (SAIS, 2012), and (Mahfoudh-Boussaid et al., 2012). Here the focus is on the Quadstone product for several reasons. First, Quadstone Paramics has more functionality in terms of emissions modeling. S-Paramics does have a built in emissions model, but it is out of date and has limited functionality. In addition, Quadstone Paramics contains "Paramics API", which is a tool for creating and utilizing added functionality, such as integrating Paramics with external emissions models (Quadstone, 2012).

Paramics allows a good deal of user flexibility in terms of vehicle behavior, signal timing, and data collection (Speirs and Braidwood, 2004). Paramics is advertised as "fully scalable", which means a broad range of network scales can be modeled, from a single intersection to an entire city (Quadstone, 2012). Simulated vehicles are represented as "Driver-Vehicle units" (DVU's), each of which is assigned a number of physical and decision characteristics, including vehicle geometry and performance parameters, familiarity with the traffic network, aggressiveness, and origin-destination information. DVU route selection can be made in three different ways, including deterministic, stochastic cost weighting, and dynamic feedback that is a real-time decision structure based on driver familiarity and traffic conditions.

The "Advanced" version of the software also contains an OD estimating tool (Quadstone UGM, 2009). Vehicle movement across a network is determined by Quadstone's proprietary car-following and lane-change models (Speirs and Braidwood, 2004). For signal timing, Paramics can model fully actuated and demand responsive signal plans, with the option to change signal parameters as the model is running. This allows the user to make changes to signal timing and immediately observe the effect on traffic flow. Paramics apparently does not include an automatic traffic signal optimization application, but does include a number of up to date tools designed to aid the user in visualizing and optimizing signal timing and other traffic control mechanisms (Quadstone, 2012).

One notable component of Quadstone Paramics is Monitor, a proprietary emission modeling tool. Little documentation was found, however, that describes either the methodology or underlying data used in this application. Based on the limited documentation available, it is clear Monitor utilizes tables that contain vehicle exhaust emissions and fuel consumption rates as a function of vehicle type, speed, and acceleration (Barth et al., 2000a). The software simply looks up the values for each second in the analysis to compute pollutant quantities and fuel consumption. It is likely in most cases, the emission rates will be provided by the user because of the inadequacy of emission data contained in Monitor. In one study, emission rates were computed for each second in the analysis using a CMEM plug-in developed in the Paramics API, which demonstrates the flexibility the API tool provides (Barth et al., 2000a).

Another example of using PARAMICS in the emissions related research work is (Boriboonsomsin and Barth, 2008) who studied the impact of freeway High-Occupancy Vehicle (HOV) lane configuration, continuous access HOV and limited access HOV, on vehicle emissions. In this paper, the authors used an emissions modeling methodology that integrates PARAMICS, a microscopic traffic simulation model, with CMEM, a modal emissions model to estimate vehicle emissions from these two types of HOV lane configurations. Their research found the emissions in freeways with continuous access HOV lane are consistently lower than emissions from freeways with limited access HOV lane. This result was justified by mentioning the dedicated ingress/egress sections of the freeway with limited access HOV lane are having highly concentrated weaving maneuvers, which cause acceleration/deceleration events to occur with higher frequency and magnitude.

2.3.3 Mesoscopic Models.

Mesoscopic models combine the properties of microscopic and macroscopic simulation models. They represent most entities at a high level of detail but describe their activities and interactions at a much lower level of detail than would a microscopic model. They provide more coverage with less modeling detail than microscopic simulation. Similar to microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. However, the movement of these vehicles in mesoscopic models follows the approach of the macroscopic

models and is governed by the average speed on the travel link (Lieberman and Rathi, 1997), (Dowling et al., 2002), (Alexiadis et al., 2004).

The MEASURE Model

Researchers at The Georgia Institute of Technology developed the Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURE). MEASURE is a GIS-based emissions model. It can calculate estimates of HC, CO, and NO_x. Two major modules are included in MEASURE. The first one is the start emissions module while the second one is the on-road emission module (Bachman et al., 2000). Refined tree-based regression analysis of vehicle emission test data was used to calculate the emission rates in MEASURE. In MEASURE, emission rates are a function of pollutant, vehicle model year, vehicle fuel delivery technology, high or normal emitter vehicle, and modal variables. Source of data is from EPA and California Air Resource Board.

Vehicle emissions for the On-Road Emission module are estimated based on different operating modes. These modes are idle, cruise, acceleration, and deceleration. Average travel speed, roadway characteristics, traffic flow, and volume to capacity ratio are used to build the vehicle operating modes. Vehicle registration data were used to get vehicle cold and hot-start characteristics distribution, and then estimate the start emission model. The start emission estimates will be based on start characteristics distribution and start emission rates (Bachman et al., 2000).

DYNASMART-P:

DYNASMART (DYnamic Network Assignment-Simulation Model for Advanced Road Telematics) is currently supported by the Federal Highway Administration through McTrans. DYNASMART-P provides lots of features like: the capability of modeling big networks, importing of network and demand data from other planning models, enhanced loading and display speed for large-scale network datasets, and emissions models for light-duty vehicles (Mehta et al., 2003).

The emission models used in DYNASMART-P are adapted from the lookup tables for fuel consumption and emissions developed at the Oak Ridge National Laboratory (ORNL) in the mid-1990s (ORNL models). These fuel consumption and emissions models are based on functions of vehicle speed and acceleration. DYNASMART-P is using ONROAD models developed at Texas Southern University for heavy-duty vehicles. EPA also accepted MOBILE 5 to be also interfaced with DYNASMART-P for additional analysis. More details of the development methodology of these used models, the look-up tables, and their evaluation of other emission models like INTEGRATION could be found in these resources: (West et al., 1997), and (FHWA, 1999).

2.3.4 Macroscopic Models

Macroscopic simulation models are designed for operations analyses of systems of road facilities. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. In these models, entities and their activities and interactions are described at a low level of detail, while minor details, like the lane change maneuvers, would not be present at all (Lieberman and Rathi, 1997), (Dowling et al., 2002), and (Alexiadis et al., 2004).

MOVES (Motor Vehicle Emission Simulator)

The most recent release, MOVES2014, is the EPA's newest multi-scale on-road emissions model. It has replaced MOBILE 6 as the preferred software for State Implementation Plans and Transportation Conformity Analyses. Although it is considered by the EPA to be capable of modeling at macro, meso, and micro scale, it is not a traffic simulator and vehicle activity data must be input by the user for smaller scale modeling.

In macro scale computed vehicle activity is based on nation-wide vehicle miles traveled data, which is not precise enough for mesoscopic and microscopic scale analysis (EPA, 2012f). Despite this lack of precision, MOVES contains an impressive amount of emissions and vehicle data, and can be used with a microscopic traffic simulator to model system-level

changes. Emissions data for light-duty passenger vehicles is based largely on inspection maintenance test data from the Phoenix, Arizona area. This data dates from 1995 to 2005 and was collected from approximately 62,500 vehicles (EPA, 2011a), and (EPA, 2011b). Heavy-duty and additional light duty vehicle and emissions data are based on a number of different studies, all using American vehicles and driving conditions.

In general, the EPA loosely based data requirements for each vehicle subgroup of the population of that vehicle type currently on the road. As a result, some emission rates (such as those for heavy duty gasoline vehicles) are based on a comparatively small quantity and range of actual data (EPA, 2011a). Some emission rates were determined using on-road vehicle operation; others were simply calculated from dynamometer tests using EPA standard drive schedules.

Over 60 different pollutants can be modeled separately in MOVES, which is likely the most of any emission model currently available. Basic emission rates in MOVES such as fuel consumption, NO_x, and CO are a function of vehicle specific power (VSP) and are in units of mass/time (EPA, 2011a), and (EPA, 2011b). Many minor pollutants and all air toxics are computed as fractions of major pollutant quantities. The software corrects for a number of scenario variables, including meteorological conditions, startup emissions, and local inspection and maintenance program effects. Simulation is conducted in one second-time steps and generates output in the form of MySQL database tables.

At the micro scale, there are two preferred methods to input vehicle activity information. The first method is to input data for each link in the modeling area in the form of a second-to-second vehicle velocity profile. This input can come from actual vehicle travel logs, EPA standard drive cycles, or from microscopic simulation output. This is used along with default vehicle characteristics to generate a time distribution of vehicle operating modes differentiated according to the MOVES classification system by VSP. Alternatively, the user can provide the operating mode distribution directly as an input table. Total activity is computed in units of time based on average speed and link geometry, and this is used by the

operating mode distribution to compute the time spent in each emission rate-specific operating mode (EPA, 2011a), and (EPA, 2011b).

MOVES was used in many studies in the last ten years. In one example of these studies researchers reviewed a study conducted to compare the vehicle activity of a roundabout to other intersections based on testing the hypothesis that roundabouts are more efficient (Hallmark and Mudgal, 2012). The study used on-road instrumentation to record second by second vehicle activity, i.e. instantaneous speed and acceleration. This vehicle activity data were inputted into MOVES, and mathematical equations for the vehicle specific power (VSP) bins were used to estimate the emissions for the three different traffic controls. VSP is a variable for engine load shown to be highly correlated with emissions. The VSP bins separated emissions rates and data was placed into bins based on the emissions rate recorded. With these bins, researchers were able to see where the majority of the data points lie. The data showed roundabouts have higher vehicle emissions through the intersection however they are not in the "system" as long. This means more experimentation needs to be completed for vehicle emissions over a time period.

Another example for using MOVES is when Qiao et al. (2012) who evaluated the concept that if vehicles can communicate with stop signs, drivers will start to slow earlier without physically seeing the stop sign. Preemptively locating stop signs can result in more fuel-efficient stopping (Qiao et al., 2012). In order to communicate with the vehicles the authors of this study analyzed the use of Radio Frequency Identification (RFID) devices. RFIDs have already been implemented in the transportation discipline. MOVES was used alongside incorporated VSP bin distributions and their related emissions rates. Average emissions were found from the MOVES binning and PEMS emissions data. Emissions rates were estimated for vehicles with and without the RFID. The vehicle with the RFID had lower emission rates no matter which direction the driver chose to go once leaving the intersection.

Watson Model

A fuel consumption model was developed by Watson et al. (1979) using average speed data. The changes in the positive kinetic energy during acceleration were used as a predictor

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variable in this model, But the effects of speed changes during the deceleration phase were not included (Watson, 1979). Also, the effect of aerodynamic drag on fuel consumption becomes significant at higher average speeds (at average speeds over 55 km/h), and this is also is not included in the study (Evans and Herman, 1978).

The fuel consumption-space mean speed relationship is in Equation 8:

$$F = K_1 + \frac{K_2}{V_s} + K_3 V_s + K_4 PKE$$

$$PKE = \sum (V_f^2 - V_i^2)/(12.960 X_s)$$

Equation 8

Where,

- F = fuel consumed (L/km),
- V_s = space mean speed (km/hr),
- PKE represents the sum of the positive kinetic energy changes during acceleration in m/s^2,
- V_f = final speed (km/hr),
- V_i = initial speed (km/hr),
- X_s = total section length (km),
- $K1$: parameter representing idle flow rate ,
- $K2$: parameter representing fuel consumption to overcome rolling resistance,
- $K3$: parameter representing fuel consumption to overcome air resistance,
- $K4$: parameter related to fuel consumption due to positive acceleration.

2.3.5 Summary and Conclusion

This work is directed to researchers and transportation engineers who would like to get one organized document as a resource for information about transportation emissions sources and modeling tools. The main goal and contribution of this work is to synthesize and document current practices in modeling fuel consumption and emissions models in a synthesis format, which is presenting different facts in an organized, and reasonably objective manner instead of arguing a particular point.

The synthesis work presented in this work focuses on two main areas: fuel consumption and emission modeling tools, and sources of emissions inventory and data used in the models. In the first part of this work, the authors started providing some details about the definition, importance, and methods of calculation of emission inventories, emission factors, and some of the currently available emission inventories. In the second part, the authors reviewed currently available fuel consumption and emission models suitable for modeling traffic operations. The review in this second part included three different analysis levels: microscopic models, mesoscopic models, and macroscopic models. The organization of this section consisted of techniques that utilize mathematical models, simulation packages, and in-the-field systems.

CHAPTER 3 DRIVER-SIMULATOT ECO-DRIVING MODELING ENVIRONMENT

3.1 Driver Simulator Modeling Environment

A seven video channel National Advanced Driving Simulator (NADS) MiniSim is used in the Eco-Driving modeling environment to render the simulations and collect our performance and behavioral data. The driving interface for the simulations is an instrumented cab based on a 2001 Chevrolet S10 pick-up truck (Figure 1).

Figure 1 Overhead view of the Driver Simulator Chevy S-10 cab with the 3 Main forward displays and right-side mirror display

3.2 Characteristics of Driver-Simulator Eco-Driving Modeling System

The Driver-Simulator Eco-Driving Modeling System is developed using the following characteristics:

- The system has several vehicles that have validated dynamics models
- The vehicle dynamics models have several sub models that run concurrently – engine, transmission, tire, steering, brakes, aero, etc. The specific data for each vehicle are integrated in the NAD model via a text input files.
- The MiniSim records all the driver inputs and many of the vehicle dynamics outputs
- All the vehicle dynamics input data files are viewable and modifiable

- Hills and wind to impact the vehicle performance, meaning the mass of the vehicle is part of the model so road geometry does definitely impact performance.

- There is an aerodynamics model to model drag

- There is a wind effect (wind gusts, side winds, etc) that is basically an external force that can be applied to the model in scenario. It is not calibrated, but its based on a physics model and not a 'special effect'.

- The dynamic model is a high-fidelity multi-body modeling environment. All aspects of terrain interaction will affect the model as expected.

- Autonomies models could be integrated into the simulation, as they are Simulink based and can be compiled into C++ so they could run in a subsystem in real-time with MiniSim.

3.3 Driver-Simulator Eco-Driving Modeling- System Architecture

The developed driver-simulator-based tool consists of a driving simulator integrated with an advanced engine modeling software in a hardware-in-the-loop modeling environment. The high-fidelity driving simulator has the advantages of being able to accurately simulate multiple driving environments and provide real-time feedback to the driver. A simplified fuel efficiency model based on a generic brake-specific fuel consumption (BSFC) map for an inline 4-cylinder has been developed and tested. By using the engine RPM and engine torque variables provided by the NADS MiniSim with the generic BSFC model, power and approximate engine efficiency, fuel consumption, and fuel economy are estimated within the MIniSim simulation environment. Using Windows Presentation Foundation (WPF) an EcoDash is created. The developed EcoDash overlays on top of the existing MiniSim Dashboard that include a speedometer, a tachometer, and in the center of the speedometer cluster is an acceleration display. A SimLink interface between the GT-Suite Software and the NADS MiniSim Model is developed and validated. The interface facilitates the integration of the two models to create an Eco-Driving model-training tool.

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

This research project aims to examine the eco-driving modeling capabilities of different traffic modeling tools available and to develop a driver-simulator-based tool to evaluate driver behavior and to reliably estimate or measure fuel consumption and emissions.

The proposed driver-simulator eco-driving modeling tool consists of a driving simulator integrated with an advanced engine modeling software in a hardware-in-the-loop modeling environment. The high-fidelity driving simulator has the advantages of being able to accurately simulate multiple driving environments and provide real-time feedback to the driver. A simplified fuel efficiency model based on a generic brake-specific fuel consumption (BSFC) map for an inline 4-cylinder has been developed and tested. By using the engine RPM and engine torque variables provided by the NADS MiniSim with the generic BSFC model, power and approximate engine efficiency, fuel consumption, and fuel economy are estimated within the MIniSim simulation environment. Using Windows Presentation Foundation (WPF) an EcoDash is created. The developed EcoDash overlays on top of the existing MiniSim Dashboard that include a speedometer, a tachometer, and in the center of the speedometer cluster is an acceleration display. A SimLink interface between the GT-Suite Software and the NADS MiniSim Model is developed and validated. The interface facilitates the integration of the two models to create an Eco-Driving model-training tool.

Traffic simulation and optimization models use different methods and data sets to estimate the fuel consumption and emissions that result from vehicular traffic. Microscopic traffic simulation models that take into consideration the vehicle kinetics (drag force, wind resistance, grade effect, etc.) estimate fuel consumption and emissions more accurately than models that do not take into consideration this aspect of vehicle motion. To improve the accuracy of the model estimates, the mathematical models that relate the engine VSP to fuel consumption and emission rates should be calibrated and validated to reflect field conditions at different sites.

REFERENCES

Ahn, K., 1998. Microscopic Fuel Consumption and Emission Modeling. Virginia Polytechnic Institute and State University.

Ahn, K., Rakha, H., Trani, A., Van Aerde, M., 2002. Estimating Vehicle Fuel Consumption and Emissions Based on Instantaneous Speed and Acceleration Levels. Journal of Transportation Engineering 128, 182–190.

Alexiadis, V., Jeannotte, K., Chandra, A., 2004. Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer (No. FHWA-HRT-04-038). FHWA, Washington, DC.

An, F., Barth, M., Norbeck, J., Ross, M., 1997. Development of Comprehensive Modal Emissions Model: Operating Under Hot-Stabilized Conditions. Transportation Research Record: Journal of the Transportation Research Board 1587, 52–62.

Bachman, W., Sarasua, W., Hallmark, S., Guensler, R., 2000. Modeling Regional Mobile Source Emissions in a Geographic Information System Framework. Transportation Research Part C: Emerging Technologies 8, 205–229.

Barth, M., An, F., Younglove, T., Scora, G., Levine, C., Ross, M., Wenzel, T., 2000a. Comprehensive Modal Emissions Model.

Barth, M., An, F., Younglove, T., Scora, G., Levine, C., Ross, M., Wenzel, T., 2000b. Development of a Comprehensive Modal Emissions Model.

Barth, M., Collins, J., Scora, G., Davis, N., Joseph, N., 2006. Modeling Extremely Low Emitting Vehicles.

Barth, M., Younglove, T., Scora, G., 2005. Development of a Heavy-Duty Diesel Modal
    Emissions and Fuel Consumption Model. California Partners for Advanced Transit and
    Highways, Research Reports 125.

Beckx, C., Int Panis, L., Torfs, R., Janssens, D., Broekx, S., 2007. The Application of the
    Simulation Software VeTESS to Evaluate the Environmental Impact of Traffic
    Measures. Presented at the 10th International Conference on Computers in Urban
    Planning and Urban Management, Iguassu Falls, Brazil.

Bloomberg, L., Dale, J., 2000. Comparison of VISSIM and CORSIM Traffic Simulation
    Models on a Congested Network. Transportation Research Record: Journal of the
    Transportation Research Board 1727, 1–23.

Boriboonsomsin, K., Barth, M., 2008. Impacts of Freeway High-Occupancy Vehicle Lane
    Configuration on Vehicle Emissions. Transportation Research Part D: Transport and
    Environment 13, 112–125. doi:10.1016/j.trd.2008.01.001

California Environmental Protection Agency - Air Resources Board, 2014. EMFAC 2014-
    Technical Documentation.

Dowling, R., Holland, J., Huang, A., 2002. California Department of Transportation
    Guidelines for Applying Traffic Microsimulation Modeling Software.

EPA, 2013. Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel
    Economy Trends: 1975 - 2013 [WWW Document]. URL
    http://darwin.phyloviz.net/ComparingPartitions/index.php?link=References

EPA, 2012a. Compilation of Air Pollutant Emission Factors, Modeling and Inventories
    [WWW Document]. URL http://www.epa.gov/otaq/ap42.htm

EPA, 2012b. EPA - Air Quality Management (AQM) - Emissions Inventory [WWW Document]. EPA - Air Quality Management (AQM) - Emissions Inventory. URL http://www.epa.gov/air/aqmportal/management/emissions_inventory/

EPA, 2012c. EPA-Nonroad [WWW Document]. URL http://www.epa.gov/oms/nonrdmdl.htm

EPA, 2012d. MOVES2010b User Guide.

EPA, 2012e. Related Programs, TTN, Support Center for Regulatory Atmospheric Modeling [WWW Document]. URL http://www.epa.gov/scram001/dispersion_related.htm#ems-hap

EPA, 2012f. Technology Transfer Network Clearinghouse for Inventories & Emissions Factors [WWW Document]. URL http://www.epa.gov/ttnchie1/eiinformation.html

EPA, 2011a. Development of Emission Rates for Heavy-Duty Vehicles in the Motor Vehicle Emissions Simulator MOVES2010 Final Report.

EPA, 2011b. Development of Emission Rates for Light-Duty Vehicles in the Motor Vehicle Emissions Simulator (MOVES2010) Final Report.

Evans, L., Herman, R., 1978. Automobile Fuel Economy on Fixed Urban Driving Schedules. Transportation Science 12, 137–152. doi:10.2307/25767904

FHWA, 2010. Introduction to CORSIM Theory [WWW Document]. Appendix A: Introduction to CORSIM Theory. URL http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol4/app_a.htm

FHWA, 1999. Development and Validation of Light-Duty Vehicle Modal Emissions and Fuel Consumption Values for Traffic Models (No. FHWA-RD-99-068).

Gomes, G., May, A., Horowitz, R., 2004. A Microsimulation Model of a Congested Freeway Using VISSIM, in: Transportation Research Board Conference.

Hallmark, S., Mudgal, A., 2012. Comparison of VSP Profiles for Three Types of Intersection Control and Implications for Emissions, in: 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC). Presented at the 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC), pp. 415 –420. doi:10.1109/ITSC.2012.6338862

ISSRC, 2012. The International Vehicle Emissions (IVE) Model [WWW Document]. URL http://www.issrc.org/ive/

Kosman, K., Hallmark, S., Poska, S., 2003. Evaluation of Simulation Models for Project-Level Emissions Modeling, in: Transportation Research Board, Annual Meeting.

Lieberman, E., Rathi, A., 1997. Traffic Simulation. Traffic flow theory.

Mehta, T., Kottapalli, A., Mahmassani, H., Bhat, C., 2003. Assessing The Environmental Benifits of intelligent Transportation Systems Measures: Methodologies and Applications. Work 4197, 3.

Minnesota Department of Transportation, 2008. Advanced CORSIM Training Manual- Final Corsim Manual (No. SEH No. A-MNDOT0318.00).

MSU, 2014. Introduction to Synthesis [WWW Document]. Introduction to Synthesis. URL https://www.msu.edu/~jdowell/135/Synthesis.html

Office of Air Quality Planning and Standards, U.E., 2012. Emissions Factors & AP 42 [WWW Document]. URL http://www.epa.gov/ttnchie1/ap42/

Park, B., Yun, I., Choi, K., 2004. Evaluation of Microscopic Simulation Tools for Coordinated Signal System Deployment. KSCE Journal of Civil Engineering, Transportation Engineering 8, 239–248.

PTV Group, 2012. VISSIM and Enviver [WWW Document]. Common Add-ons - EnViVer. URL http://www.ptv-vision.com/en-uk/products/vision-traffic-suite/ptv-vissim/modules/

Qiao, F., Wang, J., Wang, X., Jia, J., Yu, L., 2012. A RFID Based E-STOP Sign and its Impacts to Vehicle Emissions, in: 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC). Presented at the 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC), pp. 206 –211. doi:10.1109/ITSC.2012.6338899

Quadstone, 2012. Quadstone Paramics | Traffic and Pedestrian Simulation, Analysis and Design Software [WWW Document]. URL http://www.paramics-online.com/

Quadstone UGM, 2009. Paramics North American Update 2009.

Rakha, H., 2013. INTEGRATION © Release 2.40 for Windows: User's Guide – Volume I: Fundamental Model Features. Virginia Tech.

Rakha, H., Ahn, K., 2004. Integration Modeling Framework for Estimating Mobile Source Emissions. Journal of transportation engineering 130, 183–193.

Rakha, H., Ahn, K., Trani, A., 2004a. Development of VT-Micro Model for Estimating Hot Stabilized Light Duty Vehicle and Truck Emissions. Transportation Research Part D: Transport and Environment 9, 49–74.

Rakha, H., Lucic, I., Demarchi, S., Setti, J., Van Aerde, M., 2001. Vehicle Dynamics Model for Predicting Maximum Truck Acceleration Levels. Journal of transportation engineering 127, 418–425.

Rakha, H., Snare, M., Dion, F., 2004b. Vehicle Dynamics Model for Estimating Maximum Light-Duty Vehicle Acceleration Levels. Transportation Research Record: Journal of the Transportation Research Board 1883, 40–49.

Rakha, H., Van Aerde, M., Ahn, K., Trani, A., 2000. Requirements for Evaluating Traffic Signal Control Impacts on Energy and Emissions Based on Instantaneous Speed and Acceleration Measurements. Presented at the Transportation Research Board 79th Annual Meeting, Washington D.C.

SAIS, 2012. SIAS Transport Planners [WWW Document]. Paramics Microsimulation. URL http://www.sias.co.uk/ng/sparamicshome/sparamicshome.htm

SMOKE version 3.1, 2012.

Speirs, E., Braidwood, R., 2004. Quadstone Paramics V5.0 Technical Notes 15.

TFEIP, 2012. Task Force on Emission Inventories and Projections (TFEIP) [WWW Document]. URL http://tfeip-secretariat.org/

Umedu, T., Togashi, Y., Higashino, T., 2012. A Self-Learning Traffic Signal Control Method for CO2 Reduction using Prediction of Vehicle Arrivals, in: Intelligent Transportation Systems (ITSC), 2012 15th International IEEE Conference on. IEEE, pp. 421–426.

United Nations Economic Commission for Europe, 2012. TF Emission Inventories and Projections [WWW Document]. URL http://www.unece.org/env/lrtap/taskforce/tfeip/welcome.html

Watson, H., 1979. A Simplified Method for Quantifying Fuel Consumption of Vehicles in Urban Traffic. Presented at the Automotive Engineering Conference, 4th, 1979, Melbourne, Australia.

West, B., McGill, R., Hodgson, J., Sluder, S., Smith, D., 1997. Development of Data-Based Light-Duty Modal Emissions and Fuel Consumption Models (No. 972910). SAE International, Warrendale, PA.

Xia, H., Boriboonsomsin, K., Schweizer, F., Winckler, A., Zhou, K., Zhang, W.-B., Barth, M., 2012. Field Operational Testing of ECO-Approach Technology at a Fixed-Time Signalized Intersection, in: 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC). Presented at the 2012 15th International IEEE Conference on Intelligent Transportation Systems (ITSC), pp. 188 –193. doi:10.1109/ITSC.2012.6338888

Yue, H., 2008. Mesoscopic Fuel Consumption and Emission Modeling. Virginia Polytechnic Institute and State University.