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Validation of Traffic Simulation Model Output for Work Zone and Mobile Source Emissions Modeling and Integration with Human-in-the-Loop Driving Simulators

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Final Report

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16. Abstract

The next generation motor vehicle emission rate model used in the US, the United States Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES), requires second-by-second vehicle data in order to fully utilize model capabilities. However, field data collection of this type of data is resource intensive and frequently not realistic for local agencies.

Some microsimulation models have the capability of outputting instantaneous speed and acceleration, which can be used in MOVES. With these capabilities, microsimulation offers a valuable tool to conduct analyses requiring a large number of data. However, simulation models usually employ theoretical profiles for the relationship between acceleration and speed. The algorithms were intended to model gross measures of traffic activity, such as changes in cycle length or the effect of an incident. Model output, however, remains unvalidated for predicting the level of vehicle activity output required for MOVES.

Collecting field data to calibrate Vissim models is often expensive and not always feasible. The use of a driving simulator provides an additional way to provide these data. A simulator has advantages over field data in that it can be used to collect data for new projects where field data cannot be collected. Simulators also allow for complete control over interactions between the driver and other vehicles.

Two case studies were used to assess the utility of the microsimulation model, Vissim, in developing output that can be used as input to MOVES. In one scenario, drivers were selected to drive an instrumented test vehicle along a test corridor. In another scenario, five drivers drove through a roundabout in the University of Iowa National Advanced Driving Simulator (NADS).

Models for each scenario were also developed in Vissim. Model output was compared to field collected speed/acceleration profile data to assess the accuracy of microsimulation models in providing realistic estimates of vehicle activity as input to MOVES. Results were summarized to demonstrate the applicability of linking microsimulated vehicle activity data with emissions models to better estimate the emission impacts of different transportation strategies.

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ABSTRACT

The next generation motor vehicle emission rate model used in the US, the United States Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES), requires second-by-second vehicle data in order to fully utilize model capabilities. However, field data collection of this type of data is resource intensive and frequently not realistic for local agencies.

Some microsimulation models have the capability of outputting instantaneous speed and acceleration, which can be used in MOVES. With these capabilities, microsimulation offers a valuable tool to conduct analyses requiring a large number of data. However, simulation models usually employ theoretical profiles for the relationship between acceleration and speed. The algorithms were intended to model gross measures of traffic activity, such as changes in cycle length or the effect of an incident. Model output, however, remains unvalidated for predicting the level of vehicle activity output required for MOVES.

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1. INTRODUCTION

1.1 Background

Project level transportation air quality analyses in the US requires use of the recently developed United States Environmental Protection Agency (EPA)-approved highway emission rate model, Motor Vehicle Emission Simulator (MOVES). Previous transportation emission models relied on aggregate estimates of average speed. The main advantage to MOVES is that it will be able to predict differences in emissions at the project level for different scenarios such as changes in traffic signal timing or implementation of a roundabout, since it has the ability to model emissions based on changes in vehicle mode (acceleration, speed, time spent idling). However, in order to capitalize on this ability, the model requires second-by-second vehicle data (speed, grade, and acceleration). Field data collection of this type of data requires use of chase cars or instrumented vehicles. Collection of even moderate amounts of data using either method is resource intensive and frequently not realistic for local agencies. As a result, this project investigated use of simulation/driving simulator techniques to obtain realistic second-by-second data.

1.2 Literature Review

1.2.1 Integration of Microsimulation into MOVES

Microsimulation models offer a promising alternative to field data collection since many of the models are able to output second-by-second data for individual vehicles. Microsimulation models can also be used to model alternative scenarios. With these capabilities, microsimulation offers a valuable tool to create drive cycles as input to MOVES and are being used increasingly for this purpose. Wang et al. (2013), for instance, used the microsimulation model Vissim to compare emissions for one-way versus two-way streets. Second-by-second speed and acceleration data were binned by operating mode and used to compare differences in emissions.

One of the advantages to microsimulation models is that they have the capability of being calibrated using inputs such as speed distributions, driver factors, fleet distributions, and vehicle characteristics such as acceleration ranges. Simulation models have been calibrated against field conditions for traffic parameters such as delay and level of service (Yin and Qiu 2011, Kim et al. 2005), which are important parameters for emissions. However, simulation models usually employ theoretical profiles for the relationship between acceleration and speed (Hallmark and Guensler 1999, Jackson and Aultman-Hall 2010). The algorithms were intended to model gross measures of traffic activity, such as changes in cycle length or the effect of an incident.

Model output, however, remains unvalidated for predicting accurate second-by-second speed and acceleration for the EPA's MOVES. Jie et al. (2013) found that using default parameters instead of calibrated desired speeds, acceleration, and deceleration in Vissim resulted in over estimating CO_2 and NO_x emissions by 10% using VERSIT+. Ragione and Meccariello (2010) explored output from several simulation models to create drive cycles for emissions estimation. They

suggest further verification of the accuracy of microsimulation acceleration models to replicate actual driving cycles.

Accurate estimates of instantaneous speed and acceleration are important because emissions are correlated to vehicle load, which is a function of speed, acceleration, road grade, and other factors (Barth et al. 1997, Harris et al. 1995, Ramamurthy and Clark 1999, Yanowitz et al. 1999, Fomunung et al. 1999). As a result, ensuring that microsimulation model output adequately represents actual driving behavior is critical for accurate predictions of emissions.

1.2.2 Intergration of Microsimulation Models with a Driving Simulator

Microscopic traffic simulations are often calibrated and validated using real world traffic data (e.g., Punzo et al. 2005), but the use of a driving simulator to provide calibration data is new. Sensitivity analyses to assess the impact of the driver behavior parameters in Vissim have also been conducted (Lownes and Machemehl 2006). Shiraishi et al. (2004) created a traffic simulator model that could take input from a live driver in a simplified driving simulator. This system did not use commercial traffic modeling software and could only update its status once per second.

Previous attempts to integrate microscopic traffic simulation with driving simulation have been made. Jenkins and Rillett (2004) examined passing behavior as a function of lead vehicle size and speed in a DriveSafety simulator and in Vissim. They found the gap at which passing was initiated in the driving simulator two to three times that in the driver behavior models in the traffic model. They attributed these differences to the impaired speed and gap perception in a fixed base driving simulator. The authors also noted the difficulty of integrating the two simulation software components.

1.3 Project Scope

Two case studies were used to assess the utility of the microsimulation model, Vissim, in developing output that can be used as input to MOVES. Speed, acceleration, and vehicle position were collected for two scenarios, one with four different drivers in an instrumented vehicle along a test corridor in Urbandale, Iowa and the other in the National Advanced Driving Simulator (NADS) at the University of Iowa, which utilized five drivers through a roundabout in Scaggsville, Maryland.

A model for each scenario was also developed in Vissim. Model output was compared to field- or simulator-collected speed/acceleration profile data to assess the accuracy of microsimulation models in providing realistic estimates of vehicle activity as input to MOVES. Data were also compared to determine which calibration improves the Vissim output the most. Results were summarized to demonstrate the applicability of linking microsimulated vehicle activity data with emissions models to better estimate the emission impacts of different transportation strategies.

2. MICROSIMULATION MODEL OUTPUT FOR INTEGRATION INTO MOVES

2.1 Scenarios for Case Study

2.1.1 Scenario 1 – Douglas Parkway in Urbandale, Iowa

The study area was a four-lane corridor along Douglas Parkway in Urbandale, Iowa. Urbandale is a suburb in the Des Moines metropolitan area (population ~569,000). The corridor was selected since several types of traffic control along the corridor are present and volumes are relatively consistent (about 4,560 vehicles per day). Since traffic and other conditions are similar along the corridor, it provided the opportunity to study vehicle activity for two different types of traffic control.

The intersection at Northwest 128th Street and Douglas Parkway is signal-controlled and the one at 142nd Street has a two-lane roundabout. Each of the two intersections has four approaches. A map of the area is provided in Figure 1.
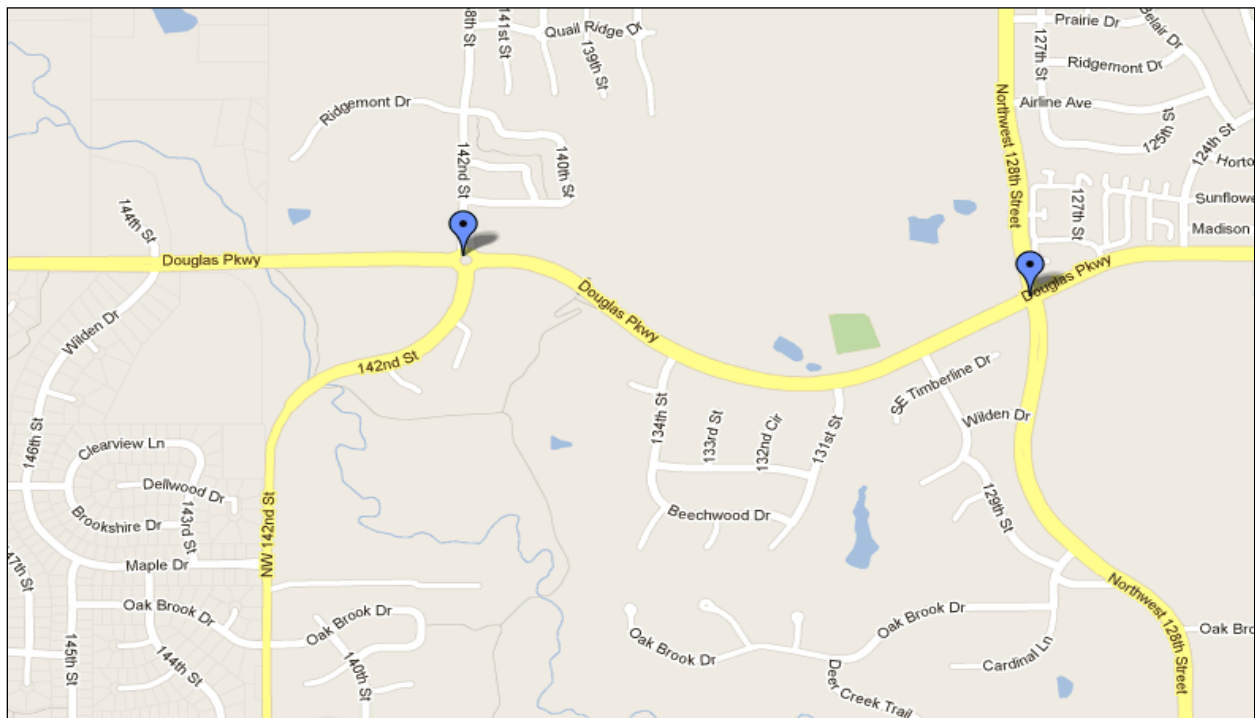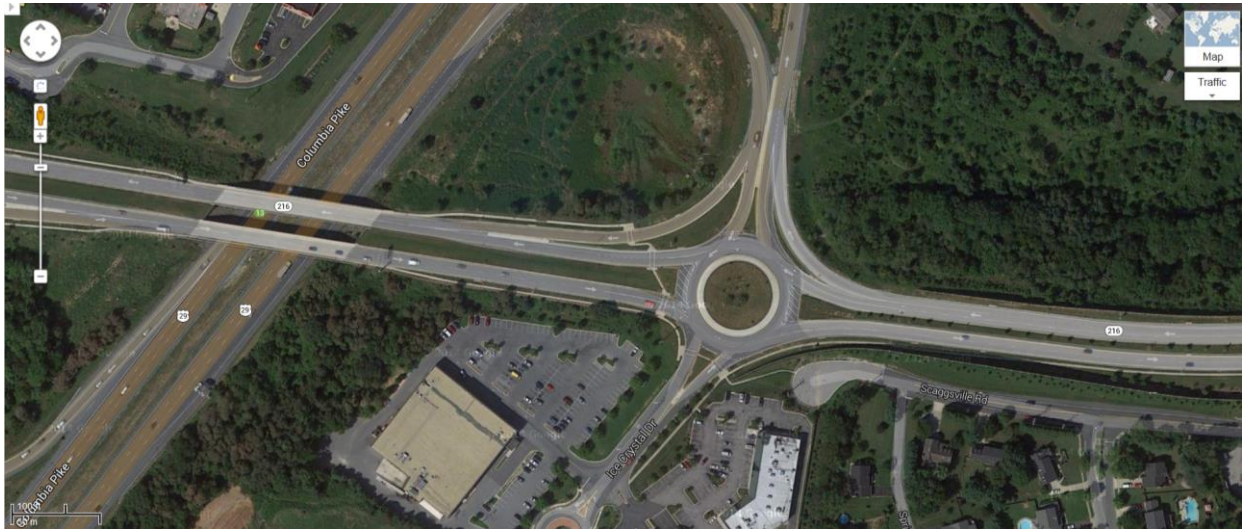

Map data ©2013 Google

Figure 1. Test corridor in Urbandale, Iowa

2.1.2 Scenario 2 – Roundabout in Scaggsville, Maryland

The study area was a roundabout located at the intersection of four-lane Scaggsville Road (Highway 216), which runs east-west, and two-lane Ice Crystal Drive to the south and the ramps to and from northbound Highway 29 (see Figure 2).

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Figure 2. Roundabout in Scaggsville, Maryland

There are two lanes running east and west through the roundabout and one lane running north-south. The westbound to northbound movement along with the southbound to westbound movement have by-pass lanes where drivers do not enter the roundabout.

2.2 Real World Data Collection

2.2.1 Scenario 1 – Douglas Parkway in Urbandale, Iowa

Four drivers (two males and two females aged 20 to 25) were selected to drive an instrumented test vehicle (a 2005 Ford Taurus). The instrumentation included a global positioning system (GPS) that recorded instantaneous speed, acceleration, and position. Drivers were asked to traverse a loop through the test corridor.

Vehicle activity data were collected using the instrumented vehicle and the four drivers. Each driver drove the vehicle through the test corridor along Douglas Parkway and traversed the corridor in each direction. Each driver started upstream of the intersection at 128th Street and traveled at free flow speed when they reached the intersection at 128th Street. The driver then continued along Douglas Parkway to a point west of 156th Street where they turned around and then returned in the same direction. The intersection at 156th Street and Douglas Parkway is approximately 1.25 miles (2.0 kilometers) west of the roundabout at 142nd Street.

Several different drivers were present during each data collection period and were rotated to avoid fatigue. Each driver completed the loop about 14 times. Speed, acceleration, spatial position, and emissions were collected for each run. Data were collected under dry pavement conditions.

Once data were collected, the data were downloaded and integrated into a geographic information system (GIS). Traces for each driver were used as overlays to a map of the study area. The intersection area of influence was determined by examining where most slowing, deceleration, and acceleration occurred. The vehicle area of influence was necessary since the researchers were most interested in comparing vehicle operation at the two intersections where most modal activity occurs.

After reviewing the vehicle traces, it was determined that most of the intersection-related activity occurred within 500 feet (~150 meters) upstream and 500 feet (~ 150 meters) downstream of each intersection. Vehicle activity was extracted for this 1,000 foot (~300 m) are aof influence for each intersection. Data were extracted for these areas for both the instrumented vehicles as well as for simulation model data.

2.2.2 Scenario 2 – Roundabout in Scaggsville, Maryland

Data for this scenario were provided by the University of Iowa and were collected as part of the Federal Highway Administration (FHWA)-sponsored Exploratory Advanced Research Project (FHWA 2010). Output from the NADS simulator was provided for five drivers who took part in the FHWA project. This data included time, position, and speed for each driver at 0.004-second intervals, which was reduced down to 0.1-second intervals. The data were also used to calculate acceleration. Data were extracted for 250 feet upstream of the roundabout, through the roundabout, and 250 feet downstream. More information on how the data were collected is included in the full FHWA report (Lee et al. 2013).

2.3 Model Development and Calibration

2.3.1 Scenario 1 – Douglas Parkway in Urbandale, Iowa

A base model of the corridor was created in Vissim. Volume data in the form of annual average daily traffic (AADT) were obtained from the Iowa Department of Transportation (DOT) for the corresponding study period.

Peak hour volumes were estimated assuming a K factor of 0.12, which assumes that 12% of the daily traffic occurs during the peak hour. This was established using nearby locations where peak hour counts were available.

Intersection turning volumes were determined using entry and exit volumes for corresponding roadway volumes. It was assumed that no traffic entered or exited the roadway between the two

intersections since there were no major traffic generators located along the corridor. Therefore, traffic volume values were balanced to assure volumes were consistent between intersections.

A field observation was used to determine approximate signal phasing, cycle length, and clearance intervals for the signalized intersections. A two-phase, fixed signal was used. Fleet mix was determined by consulting traffic counts from the Iowa DOT for nearby similar facilities. An estimate of 2% heavy vehicles was used.

Default values were used in the initial building of the model for speed. Then, the built-in distribution in Vissim for the speed closest to the speed limit or circulating speed (in the roundabout) were used. Speed distributions from the field data were used to adjust speed profiles in Vissim. Other significant calibrations were not made since the purpose of the study was to compare how well a simulation model could perform without collecting significant field data.

Once the model was coded in Vissim, model parameters were checked to ensure that they were consistent with what data collectors had observed in the field. This included queue length, free-flow speed, roundabout entering speed, etc. In addition, input volumes were compared to simulation output volumes for each of the intersections using the methodology outlined in the Oregon DOT Protocol for Vissim Simulation (Oregon DOT 2011). Capacity was also checked using the methods described in the PTV Group's Vissim training manual (2012) for the roundabout and using the method described in the FHWA Guidelines for Microsimulation (Dowling et al. 2004) and adjusted if necessary to be within appropriate values.

Simulations were run for an hour with a five-minute seeding period at a simulation speed of 1 second. Ten runs of the simulation were completed using 10 different randomly selected seeds. A minimum of 53,000 seconds of data were collected for each study area. Data were output from Vissim for each simulation run for a distance 500 feet upstream and downstream of each intersection. Once data were extracted, data for passenger vehicles and heavy vehicles were separated and only cars were extracted for use in the comparison, since field data were only available for passenger vehicles.

Data were only extracted in Vissim for the east and west approaches for each intersection to match the same locations where field data were collected. Data were also queried so only data for vehicles going all the way through the intersections would be included. Data were combined for all simulation runs and were extracted by intersection approach into a database.

Four additional models were developed based off the base model with a different element or elements being calibrated in each run using real world data. The models followed the path shown in Figure 3 with the elements calibrated also shown in that figure.
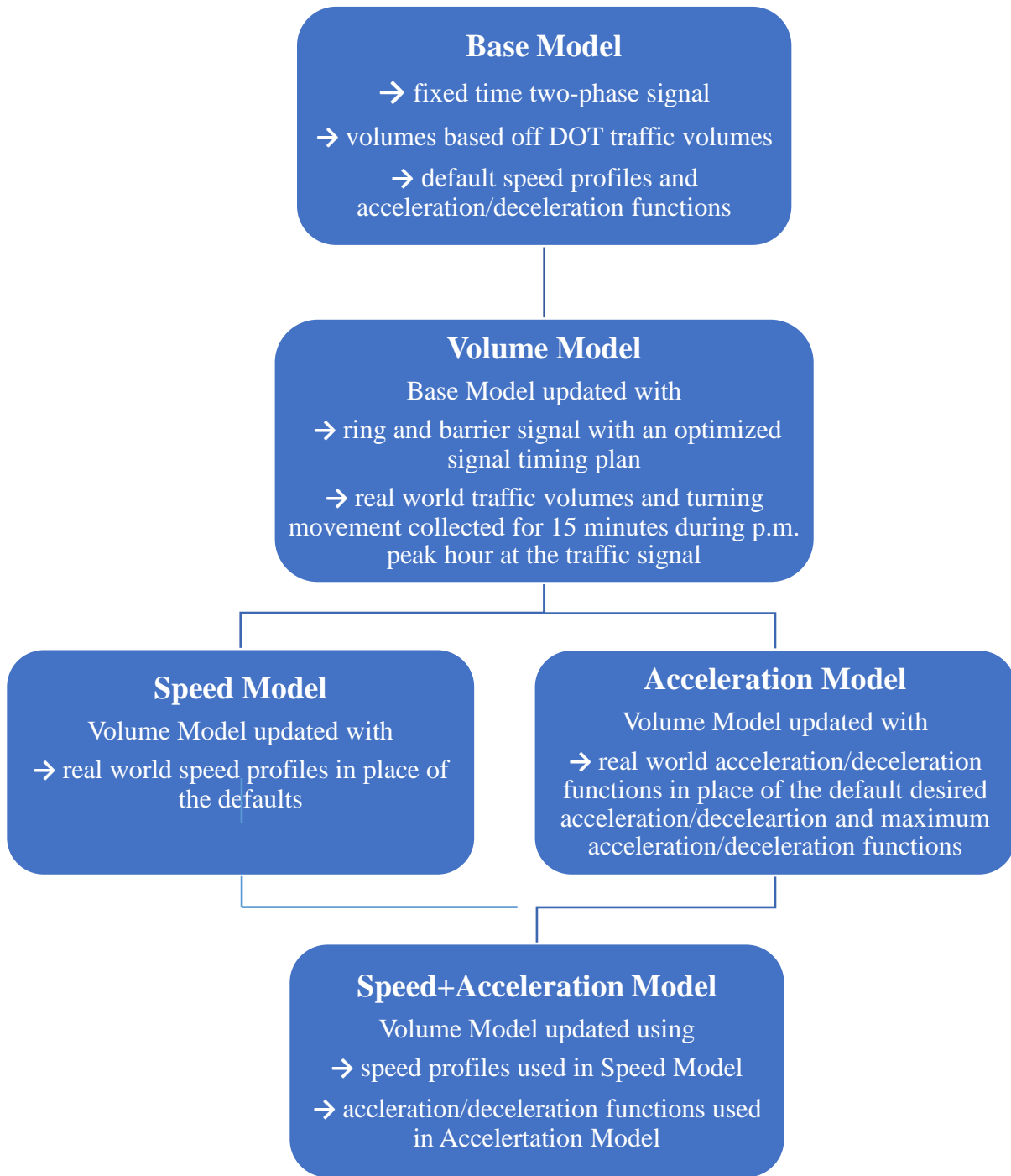
Figure 3. Process used to calibrate Scenario 1 models

2.3.2 Scenario 2 – Roundabout in Scaggsville, Maryland

A base model was developed in Vissim. No traffic data were provided in addition to the fact that simulator traffic is very controlled; therefore, the model was developed and calibrated using

assumed traffic volumes of 250 vehicles per approach. Turning movements utilized were 50 turning left, 50 turning right, and 150 going straight through. Default desired speed distributions were used using those closest to the speed limit on the part of the road. In addition, the default maximum acceleration and deceleration functions along with the default desired acceleration and deceleration functions were used.

Again, the model was calibrated using the process outlined in the FHWA *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software* (Dowling et al. 2004). First, capacity was calibrated using the Transportation Research Board *Highway Capacity Manual* (HCM) capacity method described in the PTV Group's Vissim Training manual (2012). Once the capacity was deemed appropriate, volumes were double checked to make sure simulated values were within 100 vehicles of observed values for greater than 85% of the cases. Visually, flows and queueing areas were double checked to make sure they appeared appropriate. Finally, speeds in the upstream, entering, at the apex of, and exiting the roundabout were compared to the values that were seen in the simulation data provided.

Once the model was calibrated, traffic volumes were adjusted so only through-traffic for the eastbound direction of Scaggsville Road were present. This was done due to the fact that, in the simulation, drivers did not appear to interact with other vehicles based off the speed profiles seen in the data provided.

Simulations were run for an hour with a five-minute seeding period at a simulation speed of 0.1 second. Ten runs of the simulation were completed using 10 different randomly selected seeds. A minimum of 347,208 tenths of a second of data were collected for the study area. Data were output from Vissim for each simulation run for a distance 250 feet upstream and downstream of each intersection, as that were the data available from the simulation. Once data were extracted, data for passenger vehicles and heavy vehicles were separated and only cars were extracted for use in the comparison (since field data were only available for passenger vehicles). Finally, the data from all runs were combined into one file.

The base model was then repeated three additional times with speed, acceleration, and speed+acceleration being calibrated using profiles developed using the simulation data. The process used is shown in Figure 4.
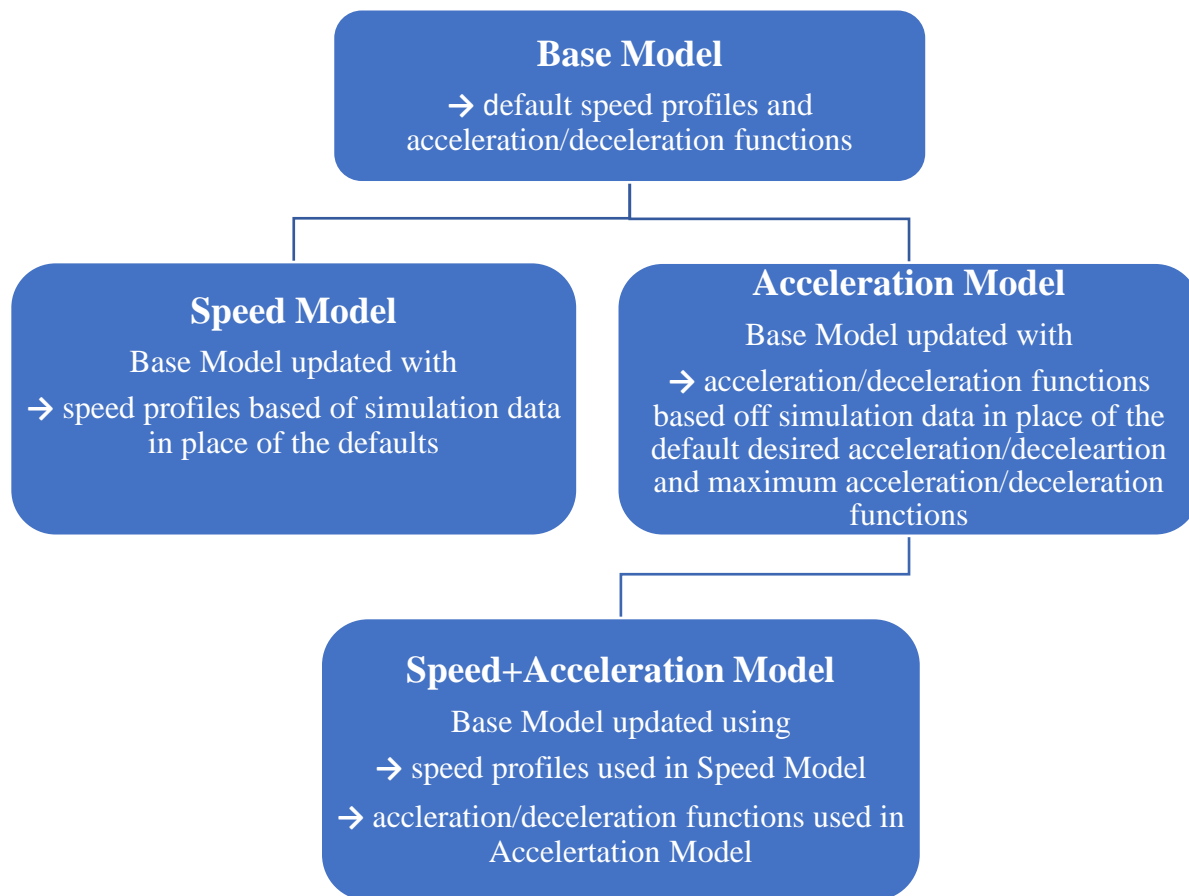
Figure 4. Process used to calibrate Scenario 2 models

2.4 Analysis

Field data and microsimulation output were compared for each intersection in each scenario using vehicle specific power (VSP). Vehicle emissions are correlated to instantaneous engine load demand, which is a function of factors such as speed, acceleration, road grade, and air conditioning use. VSP has been used as a proxy variable for power demand or engine load (Frey et al. 2007, Zhai et al. 2008). VSP is the instantaneous power per unit mass of the vehicle. The second-by-second (Scenario 1) or tenth-of-a-second-by-tenth-of-a-second (Scenario 2) instantaneous speed (m/s) and acceleration (m/s^2) data for both the real world driving and the Vissim outputs were then used to calculate VSP based on the equation and coefficients provided by MOVES (EPA 2010) as follows:

$$VSP = \left(\frac{A}{M}\right) \times v + \left(\frac{B}{M}\right) \times v^2 + \left(\frac{C}{M}\right) \times v^3 + (a + g \times sin\,\theta) \times v$$

where:

A   = road load coefficient for rolling resistance (kW-s/m)
B   = road load coefficient for rotating resistance (kW-s^2/m^2)
C   = road load coefficient for drag resistance (kW-s^3/m^3)
M   = fixed mass factor for the source type (metric tons)
g   = acceleration due to gravity (m/s^2)
v   = vehicle speed (m/s)
a   = vehicle acceleration (m/s^2)
sin θ = fractional road grade

The coefficients for *A*, *B*, *C,* and *M* were extracted from the *MOVES 2010 Highway Vehicle Population and Activity Data* guide for the passenger car source type (EPA 2010). The values used were *A* = 0.156461 kW-s/m, *B* = 0.002002 kW-s^2/m^2, and *C* = 0.000493 kW-s^3/m^3. The estimated passenger vehicle weight was 1.479 metric tons. Road grade was not collected and could not be included in the calculations.

VSP was calculated for each row of data, which represents one second of data for Scenario 1 and 0.1 second of data for Scenario 2. Once the VSP was calculated, the data were placed in bins and the percentage in each bin was calculated to determine the distributions. Data were disaggregated into the following VSP bins:

- < -20
- < 0 to -20
- 0 or idling
- 0 to 10
- > 10 to 20
- > 20

The chi-squared error was used to determine how well the bins of the simulation and real world data matched. Due to the strict nature of these tests, statistical significance was not achieved in any case; however, the test was used to determine which calibration factors improved the models most.

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where:

O_i = the observed frequency for bin i
E_i = the expected frequency for bin i

2.5 Results

2.5.1 Scenario 1 – Douglas Parkway in Urbandale, Iowa

Data for the simulation runs were compared against the field data by VSP bin as follows for each intersection.

Roundabout

Figure 5 shows results for the roundabout both by bin and cumulative percent**.**
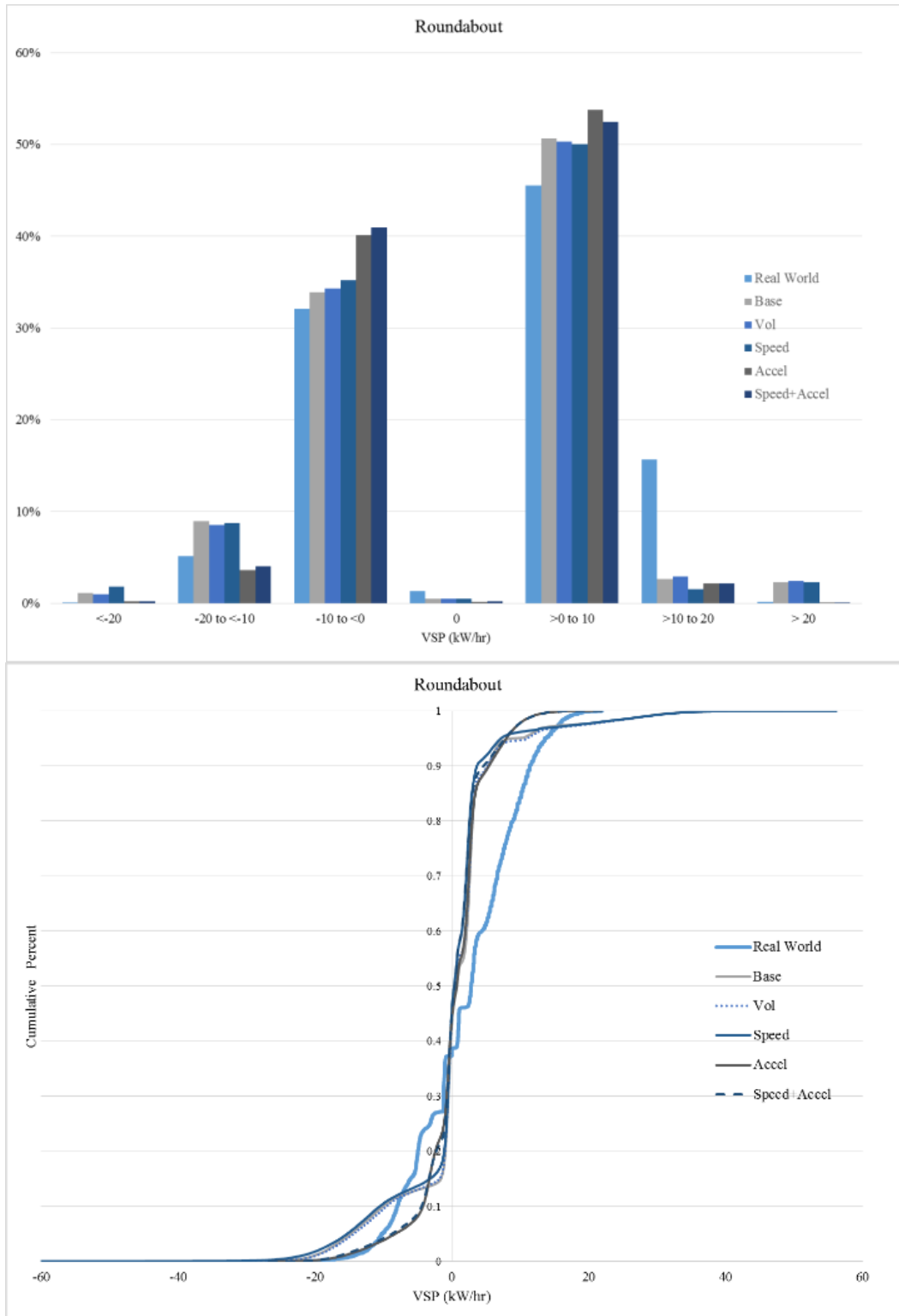
Figure 5. VSP distribution at roundabout

As shown, the distribution of time spent in individual VSP bins were similar for the microsimulation models and field data**.** The base, volume. and speed models all over estimated

all of the negative bins along with the > 0 to 10 and > 20 bins, while it under estimated the 0 and > 10 to 20 bins. The Acceleration and Speed+Acceleration models slightly overestimated the < -20 bin and overestimated the -10 to < 0 and > 0 to 10 bins. The -20 to < -10, 0, and > 10 to 20 bins were underestimated, while the > 20 bin was slightly underestimated.

As seen by the cumulative percentage chart in Figure 5, the Acceleration and Speed+Acceleration models were similar to the real world data near 0 and 1, but differed greatly in the middle, especially near VSP equal to 10, which corresponds to the large difference seen in the > 10 to 20 bin. For the Base, Volume, and Speed models, all overestimated the greater magnitude VSPs, which can be seen in both charts in Figure 5.

The three models estimated the < -20 bin to be 1.1, 1, and 1.77%, respectively. compared to 0.09% seen in the field. Additionally, for the > 20 bin, the Base Model bin was estimated to be 2.29%, the Volume Model was estimated to be 2.45%, and Speed Model was estimated to be 2.28%, versusthe 0.12% seen in the field. While these values account for less than 1% of the VSP distribution, they fall into the larger VSP bins, which are associated with much higher emissions and therefore could skew results. This was due mainly to the higher or lower accelerations than were seen in the field.

Again, all models underestimated the 0 VSP bin. This may be due to the fact that the drivers in the field data collection were not as used to the roundabout as the model assumes and are more likely to be more cautious than drivers in the model.

The χ^2 test found that none of the results were statistically significant, but did find that using the calibrated volumes, speed, and acceleration (Speed+Acceleration Model) provided the best results. Using only the calibrated speed was found to actually decrease the fit of the VSP distribution, as it increased the number of larger magnitude VSPs seen. Overall, it was found for roundabouts that calibrating using real world acceleration/deceleration profiles provided the best increase in obtaining VSPs close to real world data.

Traffic Signal

The results for the traffic signal demonstrated some weaknesses in the microsimulation model as seen in Figure 6.
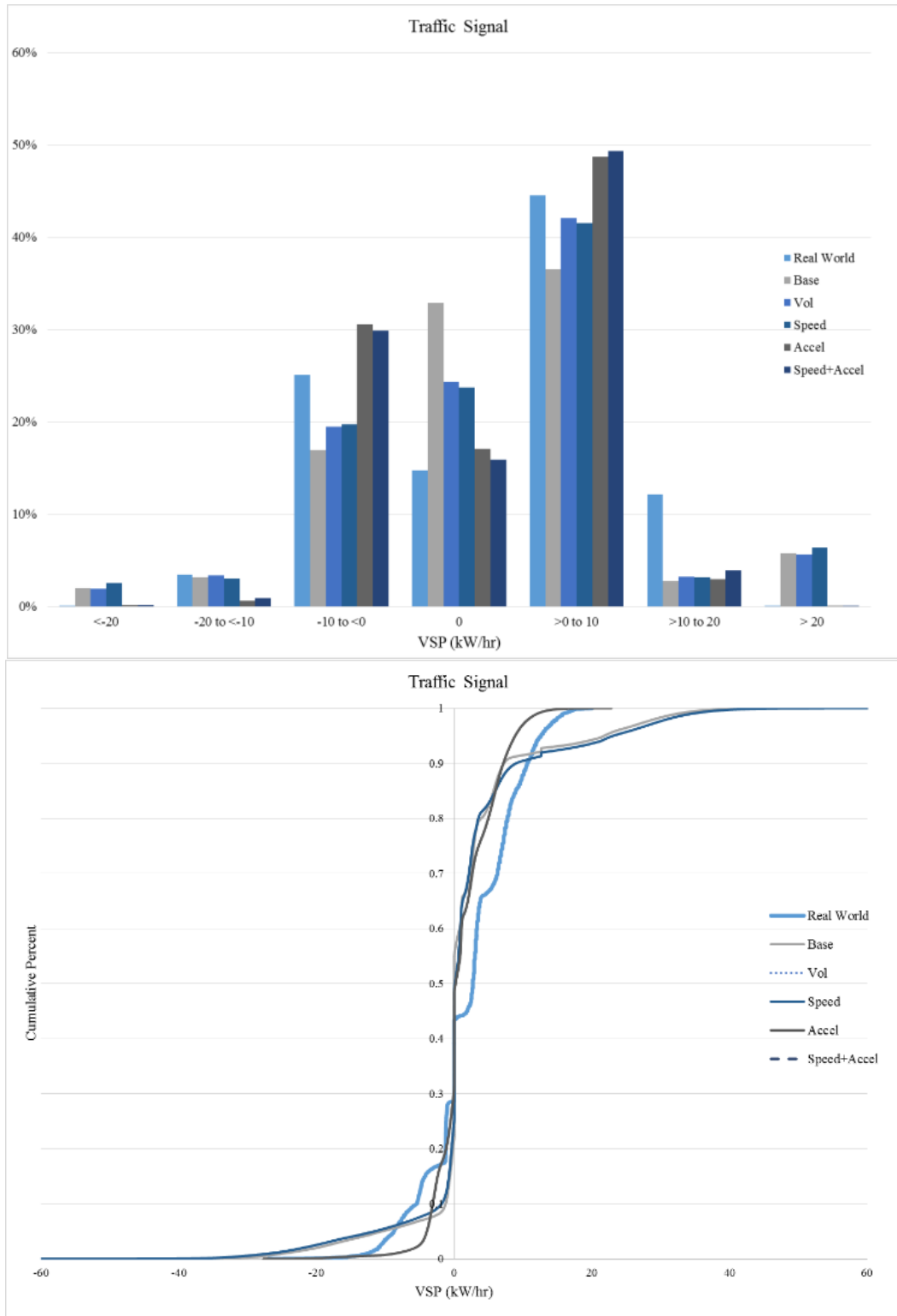
Figure 6. VSP distribution at traffic signal

The Base, Volume, and Speed models all overestimated the larger magnitude VSPs with them having 1.98, 1.92, and 2.53%, respectively, in the < -20 bin and 5.73, 5.63, and 6.39% in the >

20 bin, respectively, compared to the 0.09% seen in the real world for the < -20 bin and 0.03% in the > 20 bin. As mentioned earlier, these may be small percentages, but as they are larger values, they may skew results. All three models also overestimated the amount of idling traffic and underestimated the - 20 to < -10, < -10 to < 0, > 0 to 10 and > 10 to 20 bins.

The Acceleration Model and Speed+Acceleration Model greatly improved these results, which can be seen in the cumulative percentage chart in Figure 6. These models only slightly overestimated the < -20 bin by 0.02 and 0.04%, respectively, and underestimated the > 20 bin by 0.03 and 0.01%., respectively The 0 bin also improved greatly, which can be seen in Figure 6. These models underestimated the -20 to < -10 and > 10 to 20 bins, but the Speed+Acceleration Model was the best fit of the five models for the > 10 to 20 bin.

The results of the χ^2 test were similar to those of the roundabout analysis. Calibrating acceleration/deceleration profiles provided the greatest increase in producing real world like results. However, using calibrated volume, speed, and acceleration resulted in the most real world like model. Again, no results were found to be statistically significant and calibrating speed provided the least real life like results as it increased the larger magnitude VSPs seen.

2.5.2 Scenario 2 – Roundabout in Scaggsville, Maryland

The results for the Scaggsville roundabout demonstrated similar weaknesses in the microsimulation model as the previous models as seen in Figure 7.

Figure 7. VSP distribution at Scenario 2 roundabout
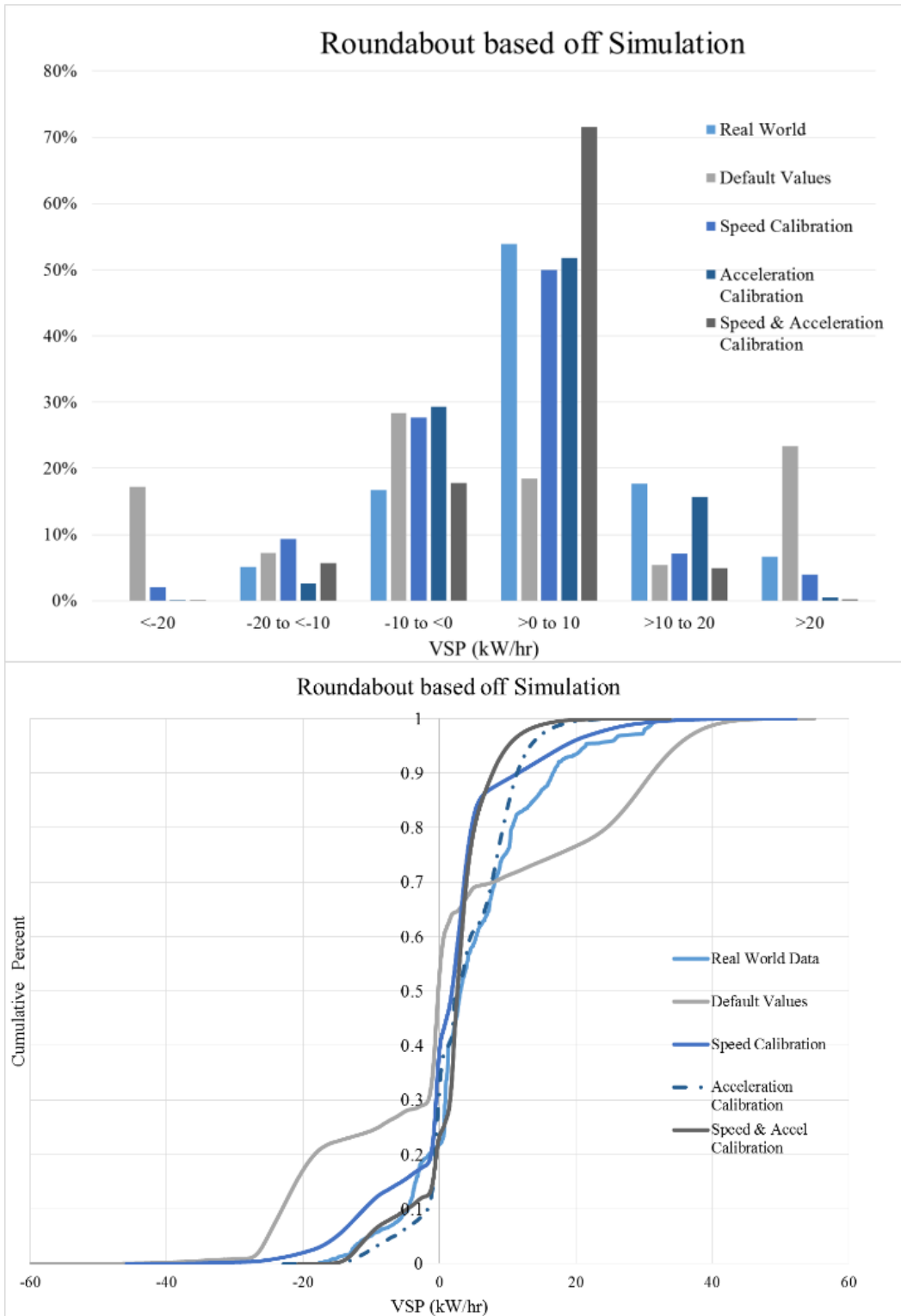
In this scenario, there were no drivers in the 0 bin, as the model ensured no driver stopped and therefore is not included in the figure. The default model overestimated the larger magnitude

VSPs with 17.17% for the < -20 bin compared to 0% in the real world and 23.38% in the > 20 bin compared to 6.60% in the real world. The speed model overestimated the < -20 bin with 2.02% the real world being 0%. These two models also all overestimated the -20 to < -10 and -10 to <0 bin and underestimated the > 0 to 10 and > 10 to 20 bins.

The Acceleration Model and Speed+Acceleration Model greatly improved these results.

These models were the same as the real world data for the < -20 bin. The Acceleration Model overestimated the -10 to < 0 bin by 12.62%, but underestimated the others by 2.47% for the -20 to < -10 bin, 2.10% for the > 0 to 10 bin, 1.98% for the > 10 to 20 bin, and 6.07% for the > 20 bin. The Speed+Acceleration Model saw the -20 to < -10 bin overestimated by 0.54%, the -10 to < 0 bin overestimated by 1.01%, and the > 0 to 10 bin overestimated by 17.63%. The > 10 to 20 and > 20 bins were underestimated by 12.80 and 6.39%, respectively.

The results of the χ^2 test were similar to those of the results from Scenario 1. Calibrating acceleration/deceleration profiles provided the greatest increase in producing real world like results and resulted in the best representation of real world VSPs. Again, no results were found to be statistically significant and, in this case, it was found that using default values provided the least real life like results.

2.6 Conclusions

2.5.1 Summary of Results

Microsimulation models offer a powerful tool to output instantaneous speed and acceleration data for current and future conditions. The speed and acceleration outputs of these models can be implemented in MOVES to conduct project level air quality analyses. However, these models often need to be calibrated based on real world speed and acceleration profiles, traffic and turning volumes at intersections, and signal timing plans. These data are not always easily or economically collected and are at times unknown when modelling future conditions.

Case studies were used to develop models in Vissim to examine how varying amounts of calibration using limited real world data affected the VSP distribution, which was calculated based on instantaneous speed and acceleration output from Vissim.

The results showed that Vissim was able to output models that were similarly shaped to the VSP distributions seen in the field, especially for the traffic signal in Scenario 1 and the roundabout where vehicles didn't encounter other traffic in Scenario 2. However, models were not able to output distributions that were statistically significant.

In all scenarios, it was found that calibrating the acceleration and deceleration profiles improved the results more than any other calibration and, at a minimum, this calibration should be conducted.

2.5.2 Limitations

The limitations of this study are limited sample sizes for both scenarios. Scenario 1 had only four drivers and one vehicle was used due to cost constraints. Scenario 2 had only five drivers worth of data.

3. INTEGRATION OF HUMAN-IN-THE-LOOP DRIVING SIMULATOR WITH MICROSCOPIC TRAFFIC SIMULATION

In parallel with the Iowa State University (ISU) Vissim integration project, the University of Iowa performed work to connect the Vissim microscopic traffic simulation with the driving simulator software used by NADS. The objective of this integration was to enable Vissim models to control the behavior of ambient traffic in a driving simulator scenario, thus providing realistic levels and patterns of traffic flow for research subjects driving the scenario. A secondary objective was to enable the use of driving simulator data to be fed into the Vissim model to provide headway and speed data from actual drivers for the Vissim behavioral model systems.

Due to key staff departures and changes on the University of Iowa portion of this work since it began, the planned software integration was not entirely completed. The architecture for the integration was developed and is presented in this chapter.

3.1 Background

Driving simulators have long been a major tool for researchers in the areas of cognitive science, psychology, neuroscience, civil engineering, and many other disciplines. Driving simulators provide a realistic, fully controllable, and repeatable environment for human subjects to perform driving maneuvers and provide subjective feedback in response to particular designs in vehicles, roadway infrastructures, or driving scenarios. F

or many studies, the presence of realistic traffic with the desired density surrounding the test subject is highly beneficial in eliciting genuine driver response. However, the highest priority for scenario vehicle generation using a driving simulator is usually the precise control of the predefined sequence of events that can be repeated exactly in multiple runs.

Ambient traffic is included in these scenarios and this traffic is traditionally generated by the simulator software using simple "rules of the road" that the autonomous ambient traffic vehicles follow. It is possible to program the behavior of each vehicle individually in the ambient traffic stream, but this is generally difficult and tedious, particularly at moderate to high throughput levels. Even though a stochastic process is introduced in Vissim in order to increase variations in behavior, it still cannot account for the eccentricities that individual drivers might manifest.

The two key elements from driving simulators, human-in-the-loop simulation and the inclusion of precisely controlled event sequences involving multiple vehicles, which introduce perturbations to the microsimulation process, can benefit transportation system studies tremendously.

3.2 Scenario for Case Study

A driving simulator scenario consists of two parts: the roadway network and the scenario control, which dictates the rules of the road for vehicles traveling that network. To integrate the NADS

miniSim™ software with Vissim, a common road network first needed to be established. Creating a correlated scenario required understanding both the miniSim™ and Vissim scenario syntaxes.

The PTV Group's Vissim software includes a driving simulation module that allows very simple driving of scenarios within Vissim. The User's Manual from the PTV Group for Vissim 5.40 provided detailed information on how to use the simulator, how to create a scenario, and how those options work in Vissim, mostly from the graphical user interface (GUI) design view of the software. The most commonly used approach for building a network is to put an image of the real world road network as the background and finish (or draw) the scenario on top of the image. This approach is simple and fast and serves sufficiently in macro traffic simulation where concern to precise road position is not critical. However, for the purpose of this project, that was not precise enough to make the integration work well.

The Vissim road network consists of links and connectors. A link can be understood as a road in real world. It contains name, length, direction, lane number, lane width, positions, and other information about a road. A connector is used to connect links. More specifically, a connector connects lanes from different links. It also has several properties such as position, direction, and length. This road network approach allows travel origin-destination type analyses to be done, but not measurement of driving performance along those links nor through the connectors.

The miniSim™ roadway network is really two layers: the visuals and the logical road information (LRI) layer. This LRI layer allows driving performance measures to be collected relative to the centerline of the road and allows events to be triggered as a vehicle crosses pre-defined points or "road pads" along the LRI.

3.3 Methodology

A simple intersection was created, first, to initially test the integration of both roadway and scenario software components. After this test, a more complicated scenario was developed.

The project was divided into two main efforts. The first effort was establishing a method to create identical roadway networks in the two software environments. The second effort focused on scenario control, whereby behavior of ambient traffic was controlled by miniSim™ and passed to Vissim.

After analyzing the scenario and roadway definition features of Vissim V. 5.40, it became obvious that duplicating a scenario from a miniSim™ scenario (.scn) file to a Vissim input (.inp) file would be more expedient instead of the other way around. Using a miniSim™ road network and scenario file is more beneficial since we have conducted many studies associated with existing miniSim™ scenarios. If this was accomplished, we could easily port study data from previous projects into the new integration of miniSim™ and Vissim.

Both Vissim and miniSim™ scenarios are coordinate-based. It is intuitive to use coordinates to do a point-to-point duplicate between those two, but there are differences. For the miniSim™ logical road information (.lri) file, a road can be a two-way road. Thus, the coordinate represents the point in the middle of a road. While in the Vissim .inp file, links are directional (i.e., roadways that are single-lane for both directions of travel require two links, with one for each direction). So, in Vissim, we needed to create one direction of travel of the road, and then generate the other side of the road. Also, adjustment based on lane width, road layout, and some other factors (e.g., conversion from feet to meters) was required. With these differences in mind, we were able to parse the .lri source code and port the road network data into an .inp file by modifying the source code.

After the development of the integrated Vissim-miniSim™ system, we created a simple, imprecise scenario including only one intersection to verify the system's functionality (see Figure 8).
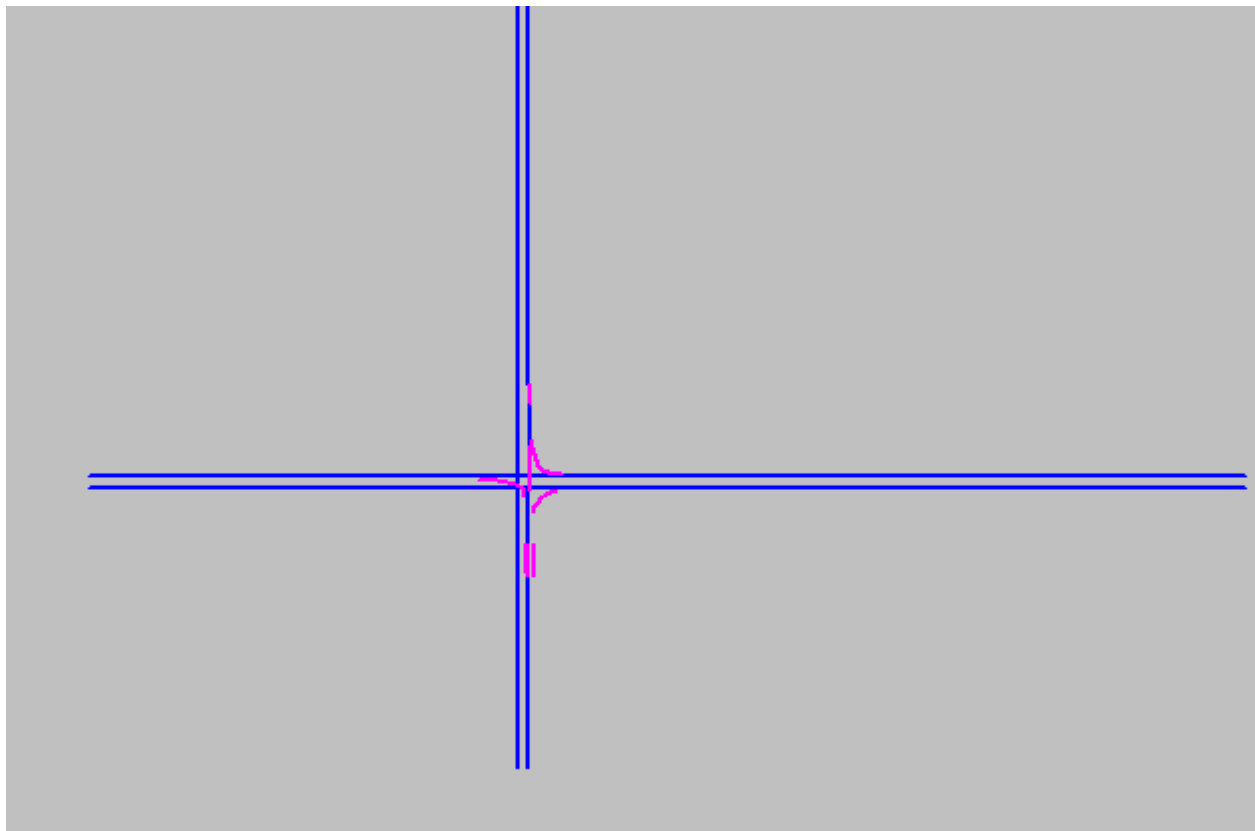

Figure 8. Simple intersection scenario created to verify integrated system

We then created a Vissim scenario based on a more complex urban area (CityDemo.scn, which is a base scenario that we have for the simulator). The Vissim scenario was created by working with the source code. A simple virtual world consisting of three intersections with some tangent and curve connectors was created in the NADS Iowa Scenario Authoring Tool to test the integration (see Figure 9).
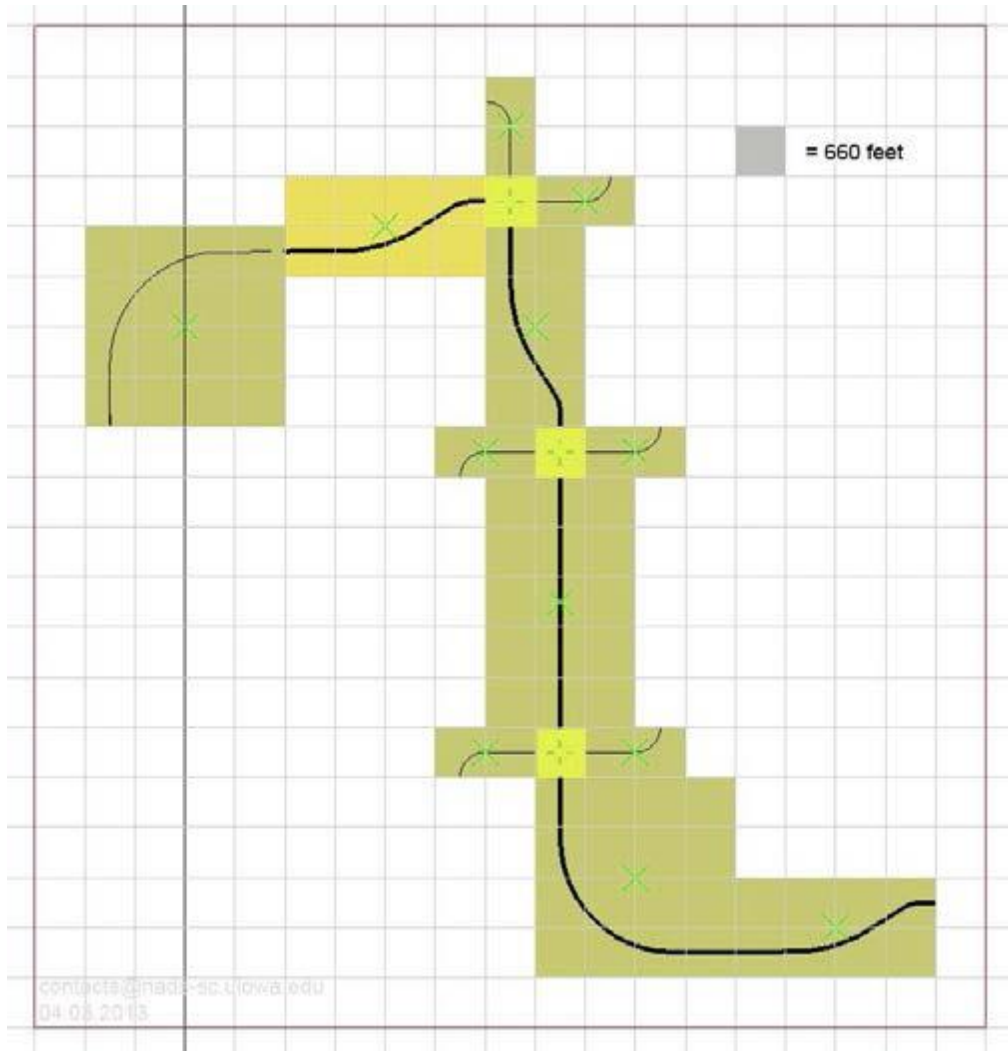
Figure 9. City Demo urban roadway network developed in miniSim™ to test integration

For this scenario, all urban roads were defined with 12-foot lanes. Roadways were two-lane with one lane in each direction, single lane for both directions of travel and two lanes for both directions of travel, with the outer lanes restricted to parking only. There were transition regions near the four-way intersections that change road profiles. Crossroads and alleys were present in the visual model only and were spaced throughout the urban area. Lane markings were double-yellow, no-passing for the urban area. The turning radius was 60 feet for all turning corridors.

3.4 Results

Using the simple scenario, software was developed to allow the scenario control portion of miniSim™ to talk to Vissim. A batch file created environmental variables to indicate where all the input (.inp) files for Vissim and other associated files were located and then started the Vissim server with command-line arguments of local and remote internet protocol (IP) addresses. The system architecture for the software integration is shown in Figure 10.
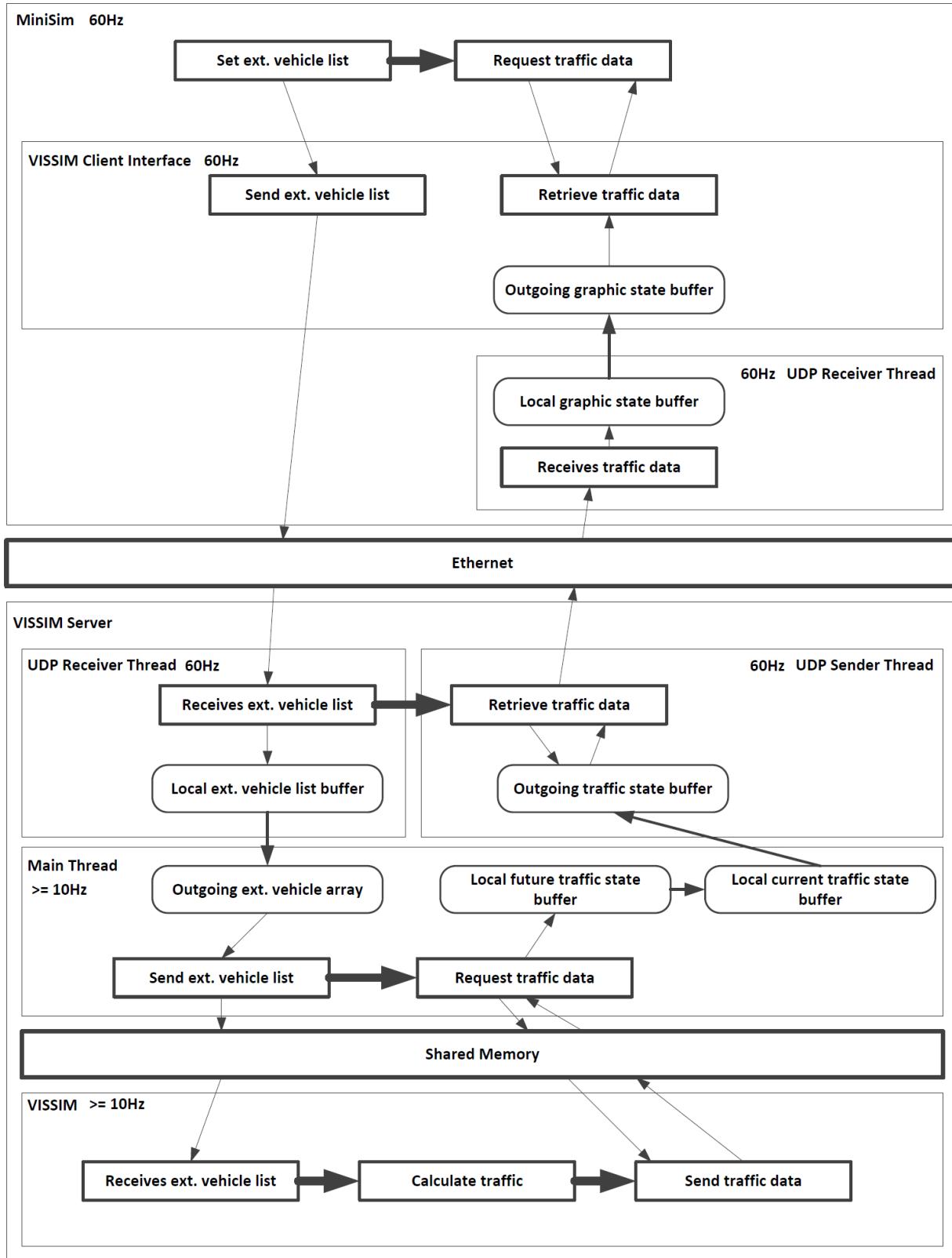
Figure 10. Software integration architecture

Because the interface did not function as expected and due to this failure and departure of key staff, the plan to coordinate with ISU efforts was modified. Driving performance data gathered as part of an FHWA-sponsored Exploratory Advanced Research Project was provided to ISU. These data were collected on the full-motion NADS-1 simulator and included several roundabouts (Lee et al. 2013).

Five traces of drivers driving through a roundabout in Maryland were provided and used to explore the use of simulation data as a source to calibrate microsimulation models for vehicle emissions modeling. The process used and results can be seen in Chapter 2 Scenario 2.

The roadway definition portion of the integration of the simple scenario worked fine. A duplicate of the miniSim™ urban City Demo scenario was created in Vissim by using separate links for each lane of travel (see Figure 11).
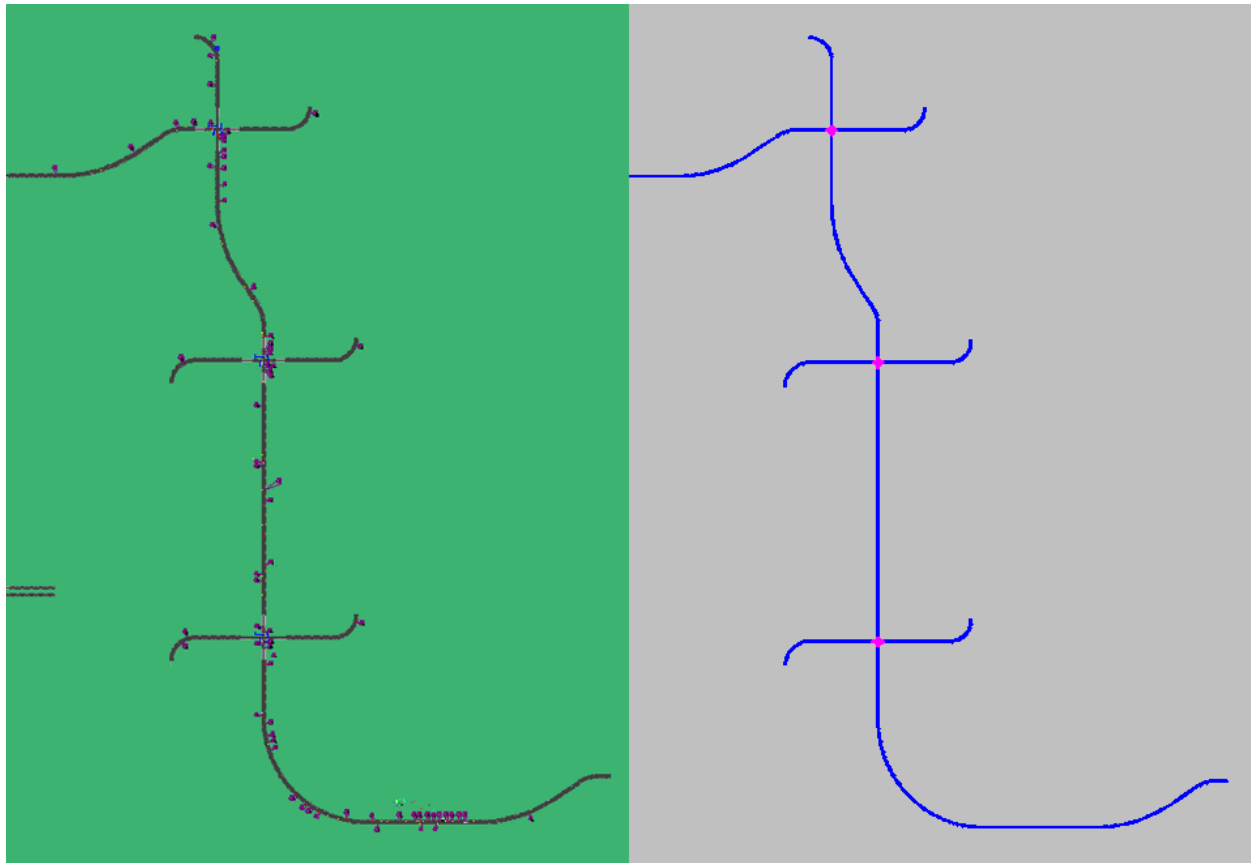

Figure 11. Vissim roadway network (left) and corresponding miniSim™ roadway network (right)

Unfortunately, the scenario control portion was not as successful. We did find that as of January 2013, there was a bug in Vissim 5.40 that makes the traffic vehicles unaware of any of the external vehicles except the first one in the list, which is the township vehicle as set by the miniSim™ software. This resulted in miniSim™ continuing to send headway and speed

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information for additional vehicles in the scenario, but Vissim could not index them and only accepted the first item on the list. The PTV Group acknowledged the bug and has released a new version of Vissim. However, we have not verified this with the newer Vissim.

3.5 Conclusions and Lessons Learned

The integration of two software systems developed for different purposes posed unique technical challenges. Ultimately, we were unsuccessful in getting the scenario control to operate in both environments. The project team is aware of at least two other driving simulator systems that have successfully integrated microscopic traffic simulation models. The FHWA Highway Driving Simulator, which uses custom software, is currently capable of having Vissim generate ambient traffic. Simulators manufactured by Realtime Technologies, Inc. also have the capacity to communicate with Vissim's driving simulator interface.

During the time of this project, the team was using Vissim Version 5.40, which was one of the earliest versions to include a driving simulator interface. The project team discovered bugs in the PTV Group's interface and was provided with excellent technical support by their technicians. However, the current version of the PTV Group's Vissim product (Version 7) does not include an updated driving simulator interface, which is noted as a feature set to be included in service pack updates for Version 7 (PTV Group 2014).

REFERENCES

Barth, M., T. Younglove, T. Wenzel, G. Scora, F. An, M. Ross, and J. Norbeck. Analysis of Modal Emissions from a Diverse In-Use Vehicle Fleet. 1997. *Transportation Research Record: Journal of the Transportation Research Board*, 1587: 73-84.

Dowling, R., A. Skabardonis, and V. Alexiadis. 2004. Traffic Analysis *Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*. Publication FHWA-HRT-04-040. FHWA, U.S Department of Transportation.

EPA. 2010. *MOVES2010 Highway Vehicle: Population and Activity Data*. EPA420-R-10-026. U.S. Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality.

FHWA. 2010. *Driving Simulation Forward: Making Driving Simulators More Useful for Behavioral Research (Fact Sheet)*. FHWA-HRT-10-060.

Fomunung, I., S. Washington, and R. Guensler. 1999. A Statistical Model for Estimating Oxides of Nitrogen Emissions from Light-Duty Motor Vehicles. *Transportation Research Part D*, 4(5): 333-352.

Frey, H. Christopher, Nagui M. Rouphail, Haibo Zhai, Tiago L. Farias, and Concalo A. Goncalves. 2007. Comparing Real-world Fuel Consumption for Diesel and Hydrogen-fueled Transit Buses and Implications for Emissions. *Transportation Research Part D*, Vol. 12, pp. 281-291.

Hallmark, S. L., and R. Guensler. 1999. Comparison of Speed-Acceleration Profiles from Field Data with NETSIM Output for Modal Air Quality Analysis of Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 1664: 40-46.

Harris, D. B., F. G. King, and E. Brown. 1995. *Development of On-Road Emission Factors for Heavy-Duty Vehicles*. US Environmental Protection Agency Report EPA/600/A-95/138.

Jackson, E., and L, Aultman-Hall. 2010. Analysis of Real-World Lead Vehicle Operation for Integration of Modal Emissions and Traffic Simulation. Presented at 89th Annual Meeting of the Transportation Research Board, Washington, D.C.

Jenkins, J. M., and L. R. Rilett. 2004. Application of Distributed Traffic Simulation for Passing Behavior Study. *Transportation Research Record: Journal of the Transportation Research Board*, 1899(1): 11-18.

Jie, Lie, H. Van Zuylen, Y. Chen, F. Viti, and I. Wilmink. 2013. Calibration of a Microscopic Simulation Model for Emission Calculation. *Transportation Research Part C: Emerging Technologies*, Vol. 31, pp. 172-184.

Kim, S., W. Kim, and L. R. Rilett. 2005. Calibration of Microscopic Models Using Non-Parametric Statistical Techniques. *Transportation Research Record: Journal of the Transportation Research Board*, 1935: 111-119.

Lee, J. D., N. Ward, E. Boer, T. L. Brown, S. A. Balk, and O. Ahmad. 2013. *Exploratory Advanced Research: Making Driving Simulators More Useful for Behavioral Research – Simulator Characteristics Comparison and Model-Based Transformation*. FHWA-HRT-13-073.

Lownes, N. E., and R. B. Machemehl. 2006. Sensitivity of Simulated Capacity to Modification of VisSim Driver Behavior Parameters. *Transportation Research Record: Journal of the Transportation Research Board*, 1988(1): 102-110.

Oregon DOT. 2011. *Protocol for VisSim Simulation*.

PTV Group. 2012. *PTV Vissim Advanced: Specialized Applications Classroom Training*. PTV America, Inc. Oregon.

PTV Group. 2014. PTV Vissum 7 Highlights. http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/release-highlights/. Accessed September 16, 2014.

Punzo, Vincenzo, and Fulvio Simonelli. 2005. Analysis and Comparison of Microscopic Traffic Flow Models with Real Traffic Microscopic Data. *Transportation Research Record: Journal of the Transportation Research Board,* 1934(1): 53-63.

Ragione, L. D., and G. Meccariello. 2010. The Evaluation of a New Kinematic Emission Model on Real and Simulated Driving Cycles. *SAE International Journal of Fuels*, 2010-01-1564, 3(2): 521-531.

Ramamurthy, R., and N. N. Clark. 1999. Atmospheric Emissions Inventory Data for Heavy-Duty Vehicles. *Environmental Science and Technology*, 33(1): 55-62.

Shiraishi, T., H. Hanabusa, M. Kuwahara, E. Chung, S. Tanaka, H. Ueno, and T. Yamamoto. 2004. Development of a Microscopic Traffic Simulation Model for Interactive Traffic Environment. *Proc. 11th World Congress on Intelligent Transport Systems and Services (ITSWC),* Nagoya, Japan.

Wang, J., L. Yu, and F. Qiao. 2013. Micro Traffic Simulation Approach to the Evaluation of Vehicle Emissions on One-way vs. Two-way Streets: A Case Study in Houston, Downtown. *Proc., 92nd Annual Meeting of the Transportation Research Board,* Washington, DC.

Yanowitz, J., M. S. Graboski, L. Ryan, T. L. Alleman, and R. L. McCormick. 1999. Chassis Dynamometer Study of Emissions from 21 In-Use Heavy-Duty Diesel Vehicles. *Environmental Science and Technology,* 33(2): 290-216.

Yin, D., and T. Z. Qiu. 2011. Comparison of Macroscopic and Microscopic Simulation Models in Modern Roundabout Analysis. *Transportation Research Record: Journal of the Transportation Research Board*, 2265: 244-252.

Zhai, Haibo, Christopher H. Frey, and Nagui M. A. Rouphail. 2008. Vehicle Specific Power Approach to Speed- and Facility-Specific Emissions Estimates for Diesel Transit Buses. *Environmental Science and Technology*, Vol. 42, pp. 7985-7991.