A Simulation Design of an Integrated GNSS/INU, Vehicle Dynamics, and Microscopic Traffic Flow Simulator for Automotive Safety

George Dedes, DGNSS, Columbus, Ohio 43065 USA (phone: 614-937-1993; e-mail: gdedes@dgnsssolutions.com)

Sage Wolfe, Mechanical and Aerospace Engineering, Ohio State University, Columbus, Ohio 43210 USA (e-mail: wolfe.392@osu.edu)

Dorota Grejner-Brzezinska, Civil Engineering SPIN Lab, Ohio State University, Columbus, Ohio 43210 USA (e-mail: dorota@cfm.ohio-state.edu)

Dennis Guenther, Mechanical and Aerospace Engineering, Ohio State University, Columbus, Ohio 43210 USA (e-mail: guenther.1@mecheng.ohio-state.edu)

Gary Heydinger, SEA Limited, Worthington, Ohio 43085 USA (e-mail: gheydinger@sealimited.com)

Kyriacos Mouskos, CUNY Institute of Transportation Systems, New York 10031 USA (e-mail: mouskoskc@gmail.com)

Byungkyu (Brian) Park, Center of Transportation Studies, University of Virginia, Charlottesville, Virginia 22904 USA (e-mail: bpark@virginia.edu)

Charles Toth, Civil Engineering SPIN Lab, Ohio State University, Columbus, Ohio 43210 USA (e-mail: toth@cfm.ohio-state.edu)

Xiankun Wang, Civil Engineering SPIN Lab, Ohio State University, Columbus, Ohio 43210 USA (e-mail: wang.1144@buckeyemail.osu.edu)

Submitted to the 3rd International Conference on Road Safety and Simulation,
September 14-16, 2011, Indianapolis, USA

ABSTRACT

This paper presents the development of a comprehensive, integrated GNSS/INU traffic simulator consisting of a microscopic traffic simulator based on VISSIM, a vehicle dynamics simulator based on CarSim, and a GNSS/INU simulator. This GNSS/INU traffic simulator provides an integrated design, test and evaluation platform for exploring new ideas, developing advanced concept designs, and investigating the impact of existing and emerging Global Navigation Satellite Systems (GNSS) and Inertial Navigation Unit (INU) technologies for enhanced automotive safety at the vehicle and network levels. For the simulation of hazardous conditions, VISSIM identifies situations where safety warning events are generated on the basis of surrogate safety indicators (e.g., time to collision). These events are intercepted by the vehicle dynamics simulator CarSim which generates simulated 'ground truth' vehicle trajectory and orientation information based on VISSIM's

simulated initial driving conditions, vehicle type, driver aggressiveness and road geometry. The simulated 'ground truth' vehicle trajectories and orientation are passed to a GNSS/INU simulator for the computation of the GNSS/INU instrumental, environmental and system errors. The simulated GNSS/INU trajectories in conjunction with the simulated 'ground truth' vehicle trajectories and orientation are processed through a "Driver-Vehicle Control Intervention Module" which simulates the driver and/or automated vehicle response for avoiding potential accidents and crashes. Based on the results of the driver-vehicle simulated response, the individual crashes are estimated through an "Individual Vehicle Crash" estimator. For the estimation of network crashes, a trained Neural Network (NN) is used as a non-parametric crash estimator with input from a Vehicle-2-Vehicle (V2V) and V2I simulators.

Keywords: Micro-simulation, vehicle dynamics simulator, GNSS/INU simulator, driver assistance systems, VISSIM, CarSim, collision avoidance

INTRODUCTION

The modernization of the GPS constellation with modern satellites transmitting new and stronger signals designed for multipath resistance and easier signal tracking are revolutionizing GPS positioning. Russia, Europe and China are racing to develop their own Global Navigation Satellite Systems (GNSS). GLONASS (Russia) has currently 22 fully operational satellites. In the next 1-2 years GLONASS will achieve complete operational status with 24 operational satellites and 2-3 spares. Galileo (Europe) and Compass (China) will be fully operational soon after. The availability of GPS and GLONASS and the soon to follow Galileo and Compass will enable the GNSS receivers to use fast and effective Receiver Autonomous Integrity Monitoring (RAIM) (J.E. Angus, 2006-2007) which will allow robust **sub-decimeter navigation** in rural, suburban and urban environment including many **urban canyons**.

The rapid advancement of Micro Electro Mechanical Systems (MEMS) Inertial Navigation Units (INU) have the potential to provide low-cost (consumer level) sub-meter lane-level positional accuracy for a few minutes when GNSS positions are not available due to signal obstructions occurring in urban canyons and wooded areas. In addition, the INU sensors provide orientation (pitch, yaw and roll) information which is very important for crash prediction and prevention.

The GNSS/INU vehicle location technology is likely to become a standard feature in every vehicle within the next 5 years. This technology will enable vehicles, drivers and transportation operators in the public and private sectors to observe, record and disseminate safety related information to nearby vehicles via Vehicle-2-Vehicle (V2V) and Vehicle-2- Infrastructure (V2I) communications. The V2V and V2I communications are enabled through short-range radio and/or cellular communication technologies including Global System for Mobile (GSM) communications, Code Division Multiple Access (CDMA), and the emerging WiMax and Long Term Evolution (LTE) technologies.

We are developing on behalf of FHWA an integrated GNSS/INU simulator to study the impact of the emerging GNSS/INU and wireless technologies on enhancing automotive safety and related applications. The integrated GNSS/INU simulator consists of a traffic simulator (VISSIM), a vehicle dynamics simulator (CarSim), a GNSS/INU simulator, a "Driver-Vehicle

Control Intervention Module," an individual vehicle crash estimator, a trained neural network for crash estimation, and a V2V/V2I communication simulator.

The traffic simulator generates safety surrogate measures and vehicle initial conditions for road departure, lane changing, passing through signalized intersections, rear-end collisions and sudden stops. This information is transferred to the vehicle dynamics simulator which generates the corresponding 'ground truth' vehicle trajectories. These trajectories are transferred to a GNSS/INU simulator which generates the simulated GNSS/INU trajectories. Both the 'ground truth' and GNSS/INU simulated trajectories are used by the "Driver-Vehicle Control Intervention Module" and crash estimator module to estimate individual vehicle crashes and crash prevention from vehicles equipped with GNSS/INU sensors. The estimated vehicle crashes are used to train a neural network (NN) which together with the V2V/V2I simulator and a traffic simulator are used to estimate vehicle crashes and crash prevention at the network level.

GNSS/INU INTEGRATED SIMULATOR SYSTEM ARCHITECTURE

VISSIM Traffic Simulator

VISSIM is a state-of-the-art microscopic traffic simulator which models a transportation system at the network level. The VISSIM micro-simulator models each individual vehicle driving behavior as follows: (1) each vehicle moves 100 milliseconds from its current position to its next position – the vehicle either moves forward or is changing a lane; (2) each vehicle moves based on Wiedemann's psycho-physical car-following model that often puts the following vehicles at unsafe distances (as if an aggressive driver following too closely); (3) each vehicle makes a lane change when doing so allows the vehicle to achieve its desired speed. As noted in (2), VISSIM models unsafe car-following conditions for which safety warning will be generated on the basis of surrogate safety indicators (e.g., time to collision or safe headway distance). However, VISSIM does not model the vehicle trajectories in a realistic way. For instance, in lane changing scenarios VISSIM's vehicle trajectory does not consider lateral movements within the lane and the lane change happens linearly in two seconds (VISSIM).

For the computation of realistic vehicle dynamics – not possible via VISSIM – trajectories and vehicle orientation, when simulating various hazardous scenarios, we employ CarSim through its Application Programming Interface (API). CarSim is a widely used and extensively validated commercial vehicle dynamics simulator (Kinjawadekar, T., et al., 2009; Deng, J., 2010).

CarSim Vehicle Dynamics Simulator

CarSim is a state-of-the-art vehicle dynamics simulator which can provide the full state of the vehicle motion including position, linear and angular velocities, linear and angular accelerations and vehicle orientation (i.e., pitch, yaw, and roll angles).

CarSim contains full vehicle models for an extensive number of vehicles including passenger cars, light trucks and SUVs. These models contain full descriptions of all important vehicle suspension, geometric, and inertial properties with full non-linear tire response characteristics. CarSim can be invoked using open-loop driver inputs or CarSim driver models for vehicle speed and/or path following control. CarSim includes capabilities to model variations in terrain profiles (road curves, hills and super elevations) and variations in terrain surface types (e.g., high friction asphalt or low-friction wet/icy surfaces).

The simplistic vehicle trajectories from VISSIM are transferred to CarSim for the generation of realistic vehicle trajectories, as for instance, when a vehicle follows another vehicle and the leading vehicle suddenly stops or reduces its speed. CarSim then will emulate the impact of such an action for the following vehicle by: (a) modeling the following vehicle(s) braking motion based on the special characteristics of the vehicle (e.g., weight, ABS or not, truck, bus, passenger car) and (b) modeling the following vehicle(s) lane changing behavior (either left or right), which may in turn lead or not to a crash based on the vehicles that are present in the adjoining lanes.

GNSS/INU Simulator

The GNSS/INU simulator is currently under development as part of this project. The primary reason for integrating an INU sensor with GNSS positioning is to fill in the vehicle positions when the satellite signals are obstructed and enough satellites are not available to compute the vehicle positions. An additional reason for using the INU sensors is to obtain vehicle orientation at all times. GNSS provides yaw information only when the vehicles are in motion. For stopped vehicles single antenna GNSS positioning does not provide orientation information. Vehicle orientation is very important for accident prediction and accident prevention.

The estimation of the GNSS related errors are based on the 'User Equivalent Range Error' (UERE) (Dedes, G., et al., 2002). The UERE is expressed as a standard deviation of all the errors affecting the GNSS positions including internal receiver noise, residual satellite clock errors, satellite ephemeris errors, ionospheric errors, tropospheric errors, multipath and signal obstruction errors. The multipath errors are computed using wavelet analysis of real rata for representative rural, wooded, suburban and urban environments (Elhabiby, M., et al., 2008). The GNSS/INU simulator provides the functionality to compute these errors for a wide range of GNSS sensors ranging from high accuracy cm-level RTK-type to low-accuracy 5-10m smartphone-type GNSS sensors.

The resulting UERE is scaled with the horizontal dilution of precision (HDOP) and the vertical dilution of precision (VDOP) for the estimation of the GNSS position errors (ibid.). The HDOP and VDOP values reflect the influence of the satellite geometry on the accuracy of the estimated vehicle positions, especially when the satellite signals are obstructed. The expected HDOP and VDOP values are computed using the GPS (USA), GLONASS (Russia), Galileo (Europe), and Compass (China) satellite almanacs.

The simulated INU errors are modeled using the IEEE Std 952-1997 for gyros and the IEE Std 1293-1998 for accelerometers (952-1997IEEE). For both the gyroscopes and the accelerometers the noise is modeled as a random walk, the turn-on biases as random constants, the bias-stabilities as first-order Gauss-Markov processes, the g-sensitivities as random constants and the scale factors as constants (Yang, Y., et al., 2007). The simulated GNSS positions and INU measurements are processed through an Extended Kalman Filter (EKF) to simulate the GNSS/INU vehicle positions between the GNSS fixes (Da, R., et al., 1996; Grejner-Brzezinska, D. A., et al., 2008). The accuracy of the simulated INU positions between GNSS fixes depends on the errors affecting the simulated GNSS positions, the time between GNSS fixes, and the accuracy of the simulated INU measurements as dictated by the quality of the INU sensors.

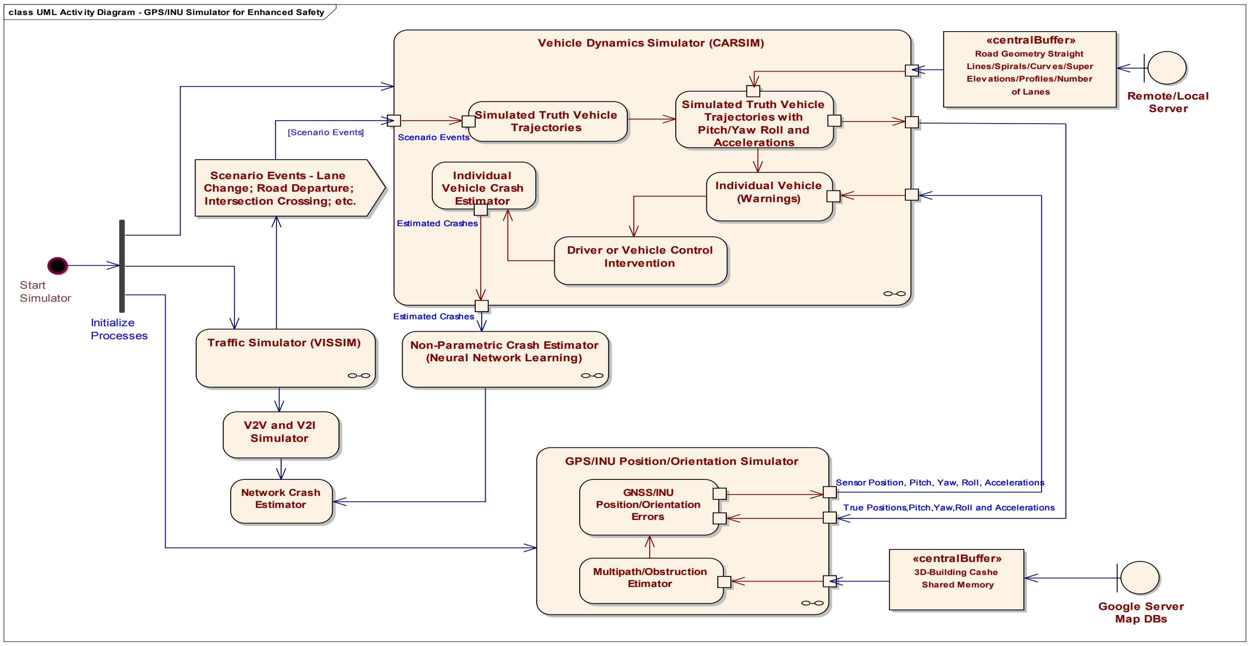

Figure 1. System Architecture of Integrated GNSS/IMU Simulator for Enhanced Safety

Figure 1 shows a Unified Modeling Diagram (UML) activity diagram of the full system architecture for the integrated GNSS/INU simulator. At start-up the integrated simulator spawns the "Traffic VISSIM Simulator" thread, the "Vehicle Dynamics CarSim Simulator" thread, and the "GNSS/INU Position/Orientation" thread.

For the simulation of hazardous conditions, VISSIM identifies situations where safety warning events are generated on the basis of surrogate safety indicators (e.g., time to collision or safe-headway distance). These events are intercepted by the vehicle dynamics simulator (CarSim) which generates simulated 'ground truth' vehicle trajectories and orientation (i.e., pitch, yaw and roll) information based on VISSIM's simulated initial driving conditions (i.e., position/velocity/acceleration/orientation), vehicle type, driver aggressiveness and road geometry.

The simulated 'ground truth' vehicle trajectories and orientation are transferred through inter-thread communications to a "GNSS/INU Position Orientation Simulator" for the simulation of the GNSS/INU instrumental and environmental errors (i.e., atmospheric, ionospheric, signal multipath and signal obstructions) (Figure 1). For the simulation of multipath and satellite signal obstruction errors existing maps or Google maps are used to extract the roadway geometry and to classify the environment as rural, suburban, or urban. The urban environments are further classified as urban canyons, two-way, three-way or four-way road intersections. Based on this environmental classification and the extracted roadway geometry the multipath errors are computed using wavelets (Elhabiby, M., et al., 2008). The satellite obstruction errors are computed using the GNSS satellite almanacs.

The multipath and obstruction errors, together with the rest of the environmental errors (i.e., tropospheric or ionospheric), the GNSS/INU measurement errors (i.e., GNSS/INU instrumental noise) and other system errors (i.e., satellite clock errors and orbit errors) are added to the simulated CarSim 'ground truth' positions and orientation to generate the simulated GNSS/INU vehicle positions and orientation.

The simulated GNSS/INU and 'ground truth' vehicle trajectories and orientation are transferred to a “Driver-Vehicle Control Intervention Module” which simulates driver and/or automated vehicle response for avoiding potential crashes (Figure 1).

The results of the driver-vehicle simulated response are transferred to the “Individual Vehicle Crash Estimator” module which determines if a crash has occurred using either the 'ground truth' or the GNSS/INU simulated trajectories. This module estimates the crash prevention rates at the individual vehicle level.

For the evaluation of accident prevention at the network level a trained NN is employed as a non-parametric estimator. The NNs provide an efficient methodology for evaluating the network crashes because once a NN is trained, the computations are very fast. For the generation of the training data a large number of simulations will be performed using various hazardous scenarios (i.e., lane changing, road departure, intersection crossings, rear-end collisions, etc.) various vehicle types (i.e., cars, trucks, etc.), various GNSS/INU sensors (i.e., low, medium and high accuracy) and various operational environments (i.e., rural, suburban, urban, urban canyons, etc.).

The trained NN crash estimator in conjunction with a “V2V and V2I Simulator” and the VISSIM traffic simulator will provide estimates of network-wide crashes based on various hazardous scenarios, various types of GNSS/INU sensors and various operating environments. Using these results, statistical measures will be computed to evaluate for different hazardous scenarios the effectiveness of using various types GNSS/INU sensors to prevent road accidents and enhance automotive safety.

INTEGRATED GNSS/INU SIMULATOR

The integrated GNSS/INU simulator is developed in C# invoking the VISSIM functionality through VISSIM’s COM interface, the CarSim functionality through CarSim’s API interface, and the GNSS/INU functionality through the GNSS/INU API interface.

VISSIM Integration with CarSim

The integration of VISSIM with CarSim within the integrated GNSS/INU simulator environment is established through VISSIM’s COM interface and CarSim’s API interface (Figure 2).

Hazardous condition triggering is achieved through various scenarios defined at program start-up. For instance, lane changes are triggered for selected vehicle(s) on the basis of user-defined conditions including absolute vehicle position, relative distance and speed between leading and following vehicle(s) or forced lane change at each simulation time step. In addition, we have extended VISSIM’s functionality through its COM interface to enable abnormal lane-changing scenarios such as aggressive lane changes or sudden lane changes.

At start-up VISSIM initializes the required functionality (e.g., simulation road network, hazardous condition scenarios, required vehicle output information, preferred visualizations and functionality). After initialization, VISSIM records to a database the individual vehicle positions, velocities, and accelerations and checks the vehicle's changing status every 100 milliseconds. If a vehicle is in the process of lane changing, VISSIM marks this vehicle to retrieve its trajectory from the database when it completes the lane changing process. When the lane change finishes VISSIM retrieves the vehicle information from the database and passes this information to CarSim (Figure 2).

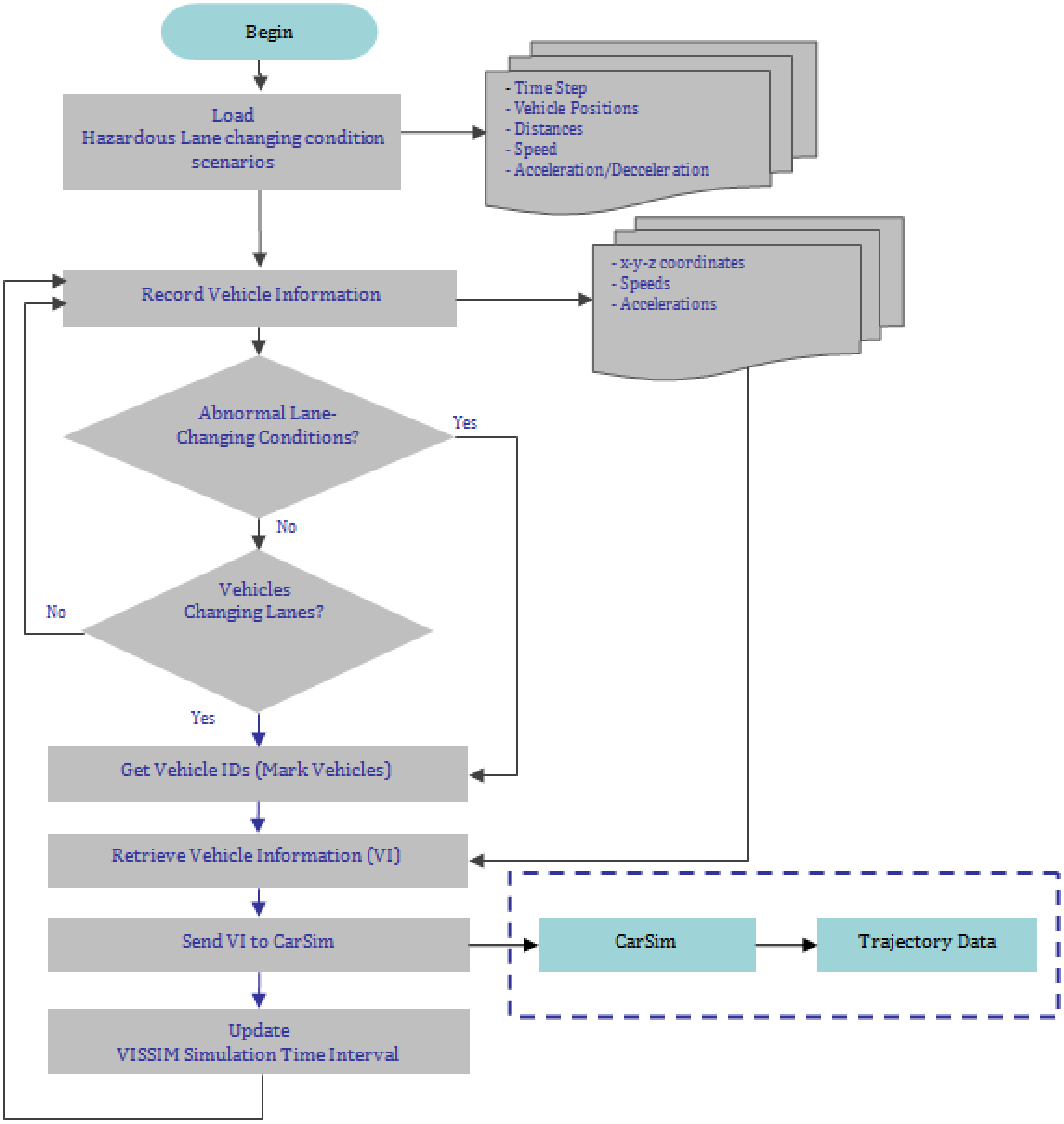

Figure 2. Activity Diagram for VISSIM/CarSim Integration

As mentioned earlier, VISSIM does not model the lane changing behavior in a realistic way. VISSIM's lane changing trajectory happens linearly within two seconds (VISSIM).

For realistic modeling of lane changing and other hazardous scenarios, the integrated GNSS/INU simulator invokes CarSim through its API interface. For initial experiments, CarSim models for a hatchback, a sedan, and a SUV were used. For the lane changing scenarios, speed in CarSim was controlled via a closed-loop throttle control with a constant target speed of 65 mph. Braking was deactivated and steering was controlled via a closed-loop driver path following logic which is built in CarSim's driver models. This means that the desired paths for various aggressiveness levels are programmed in CarSim, and the driver attempts to follow these paths as closely as possible. Since the vehicle speed and lane offset were kept fixed, driver aggressiveness was modeled by varying the distance needed to complete the lane change (shorter distance for a more aggressive driver). The built-in CarSim lane change profile was scaled to create the various severities of lane changing profiles. Peak lateral acceleration was used as a target for scaling lane changing distances, with values of 0.1, 0.3 and 0.5 g used as target values for increasing aggression levels. The lane changing distances were scaled until peak lateral acceleration agreed to within 10% of the target value. Note that due to high levels of lateral acceleration, the more aggressive drivers tended to overshoot their target profiles.

Figure 3 shows three CarSim lane change profiles for a hatchback B-car corresponding to three levels of driver aggressiveness.

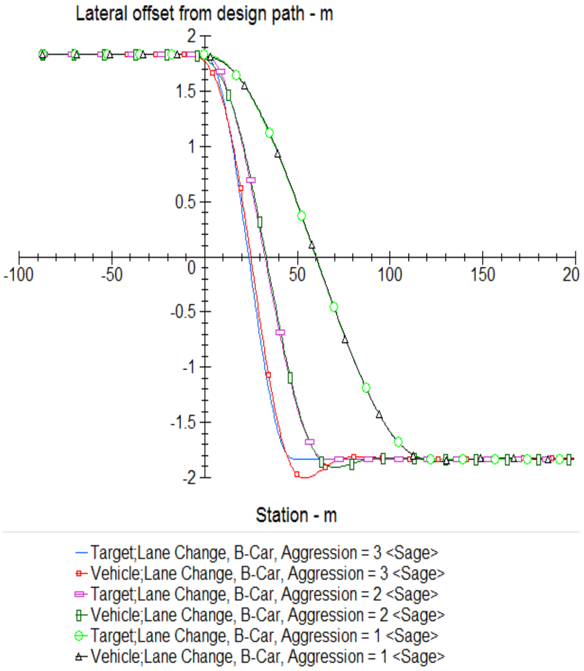

Figure 3. CarSim Lane Changing Paths – Hatchback Vehicle

Driver-Vehicle Control Intervention Module (DVCIM)

The DVCIM simulates the driver type and the vehicle response (in case semi or fully automated features are available) under normal and potentially hazardous conditions. A set of various driver types will be modeled to capture the driving behavior such as aggressiveness (acceleration, deceleration, cruising speed, lane changing, headway, etc.) and response time (i.e., perception and reaction time) under various traffic and environmental conditions.

The following distributions will be determined from the literature and will be modeled into the drivers' profiles:

1. Car following: The time-headway of the following vehicle from the leading vehicle follows a distribution that describes the driver aggressiveness (from safe time-headway to tailgating).
2. Lane changing: Lane changing requires knowledge of the acceptable time-gap from the adjoining lanes. The gap acceptance distribution defines the aggressiveness distribution

(from safe to forceful lane-changing).

3. Desired cruising speed: The drivers' desired speed defines the cruising distribution.
4. Acceleration: This parameter is a combination of the vehicle type and the driver aggressiveness.
5. Deceleration: This parameter is a combination of the vehicle type and the driver aggressiveness.
6. Perception-reaction time: The drivers' perception-reaction time to a stimulus defines this distribution.
7. Environmental conditions: a) Lighting: sunshine, cloudy, dark, etc.; b) Weather: rain, flooding, snow, ice, etc.; c) Pavement: pavement surface, potholes, debris, etc.
8. Traffic control conditions: Signalized intersections, unsignalized intersections, roundabouts, arterials, freeways, urban roadways, rural roadways, speed limit, turning restrictions, etc.
9. Roadway geometry: number of lanes, grade, superelevation, curvature, shoulder, median, runaway clearance, etc.
10. Vehicle types: The integrated simulator will be able to model the dynamics of vehicles that are currently in the CarSim database. The vehicle type will include the capability to model vehicles equipped with sensors that take automated or semi-automated actions such as intelligent adaptive cruise control, electronic stability control, and warnings of vehicle presence at the surrounding area of the vehicle.

The analyst will be able to choose the various driver types prior to the start of the simulation and determine the impacts under various driving experiences such as sudden speed reduction of the leading vehicle, vehicles entering a freeway under various traffic flow and environmental conditions, and vehicles changing lanes under various traffic and environmental conditions (e.g., pothole or debris presence).

The DVCIM will send the driver/vehicle actions into CarSim to produce the realistic vehicle trajectory from the specific traffic flow conditions that were be generated via VISSIM, a microscopic traffic simulator. It is noted that the interface between VISSIM and CarSim is necessary as VISSIM does not simulate vehicular movements required to evaluate safety – for example, VISSIM does not model lateral vehicular movements within the lane and its lane change happens with a fixed amount of time regardless of vehicle type or its speed or acceleration. The following traffic flow conditions will be demonstrated with the proposed integrated GNSS/INU simulator:

Impact of a sudden vehicle stop: The following driver reacts to this event based on his/her driver type, vehicle type, environmental and traffic conditions.

Impact of a lane change: VISSIM produces the vehicle trajectory that includes the lane changing. The vehicles involved in the lane changing are modeled based on their driver/vehicle types which are designated initially under VISSIM (driver aggressiveness). The DVCIM assigns a more detailed driver type for each of the vehicles involved and determines the actions of each vehicle (driver): vehicle waits until a safe gap is found in the adjoining lane or he/she forces his/her entry based on his/her driver type. The vehicle/driver in the adjoining lane drives according to his/her type causing a change to the available gap (an accommodating driver will reduce speed to allow the lane-changing vehicle to enter whereas a non-accommodating driver will try to reduce the gap in order to prevent the other vehicle from entering his/her path). The various traffic flow conditions will also dictate the driving behavior (e.g. under oversaturation conditions many drivers are less accommodating).

Impact of a pothole presence: Under a pothole presence a driver will either go around it or go through it based on his/her perception-reaction time. The DVCIM will send this driver type to CarSim to either model the first or the second reaction and the associated path. Similarly as before all vehicles surrounding the subject vehicle will be modeled based on the DVCIM driver/vehicle type assignment and perception-reaction such that the true impact of either maneuver is modeled: The following vehicles from the subject vehicle will be 'notified' via V2V or V2I communications on the presence of a pothole and its location. The DVCIM will assign various driver/vehicle types to all following vehicles and their potential actions such as changing lane in an aggressive or non-aggressive manner. Similarly, the vehicles in the adjoining lane will react to the maneuvers of the other vehicles trying to change lanes to avoid the pothole based on the assigned driver type.

GNSS/INU Integration with CarSim

Figure 4 shows the activity diagram for the GNSS/INU integration with CarSim. The 'ground truth' vehicle positions, accelerations, pitch, yaw, and roll are available from CarSim for the various hazardous scenarios. The left path of the activity diagram shows the GNSS error estimation and the generation of the simulated GNSS positions. The right path of the activity diagram shows the INU error simulation and the generation of the simulated INU sensor measurements.

Using the vehicle 'ground truth' positions, the corresponding road geometry is extracted for the computation of the multipath errors and the errors due to the obstruction of the satellite signals. These errors together with the GNSS positioning mode errors and receiver noise errors are added to the 'ground truth' positions to generate the simulated GNSS positions (Figure 4 - left path of the activity diagram). The GNSS positioning mode errors are the errors associated with the autonomous positioning (i.e., satellite clock

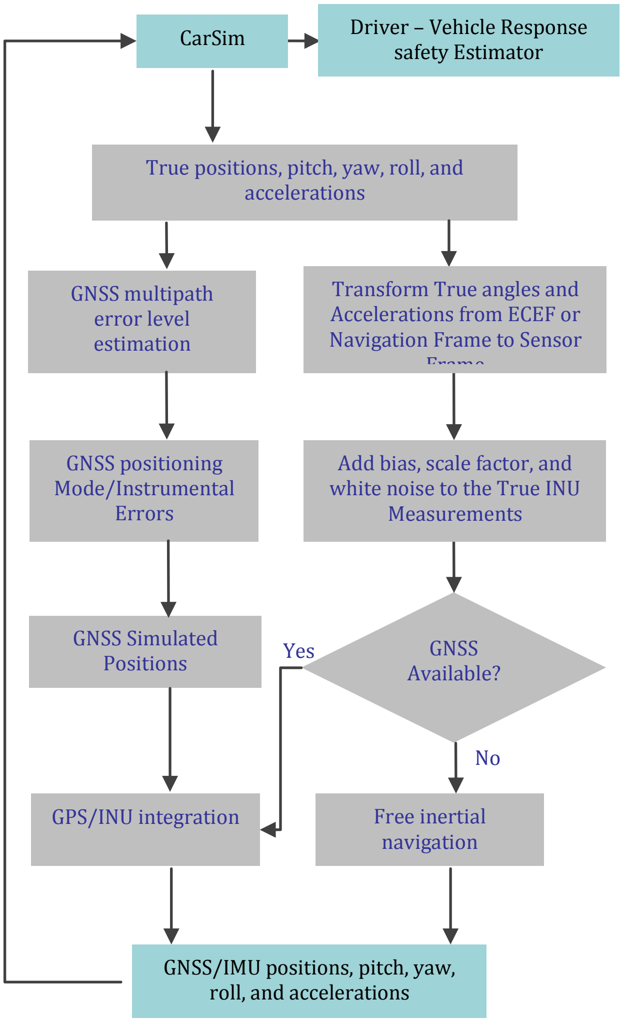

Figure 4. Activity Diagram for GNSS/INU/CarSim Integration

errors, orbit errors, ionospheric errors), code differential GNSS positioning (i.e., ionospheric, tropospheric errors), and carrier-phase differential GNSS positioning (i.e., ionospheric and troposheric errors).

For the generation of the INU simulated measurements the 'ground truth' pitch, yaw, roll and accelerations, generated for the various hazardous scenarios by CarSim, are transformed from the body frame to the sensor frame. The bias, scale factor, and noise errors are computed and added to the CarSim 'ground truth' pitch, yaw and accelerations for the generation of the simulated INU measurements (Figure 4 – right path of the activity diagram).

When the GNSS signals are not obstructed and GNSS positions are available the simulated GNSS positions and the simulated INU measurements are integrated for the generation of the simulated vehicle positions, pitch, yaw, roll and accelerations. When GNSS positions are not available a free-inertial navigation solution is computed using the last available GNSS position and the INU simulated measurements (Figure 4). The resulting simulated GNSS/INU vehicle positions, pitch, yaw, roll and accelerations are transferred back to CarSim and the "Driver-Vehicle Control Intervention" and "Individual Vehicle Crash Estimation" modules to estimate the individual vehicle crashes and to generate the data for the training of the non-parametric neural network crash estimator.

Figure 5 shows the simulated GNSS errors for Autonomous Point Positioning, Wide Area Augmentation System (WAAS) differential positioning and OmniStar HP (High Precision) differential positioning. This "Reference" trajectory (Figure 5) data set was collected along a highway just north of Columbus, Ohio.

The "Reference" trajectory was computed using cm-level GNSS Real-Time Kinematic (RTK) Positioning and the Honeywell H764G Navigation grade (angular bias of 0.0035deg/h; acceleration bias of 25µg) INU unit. This navigation grade INU unit was able to maintain 3-5 cm-level positioning accuracy over a period of 10 seconds without GNSS positioning.

For the "Reference" trajectory the maximum time interval for which RTK GNSS positions were not available was in the order of 10 seconds resulting in a "Reference" trajectory with errors of less than 5cm.

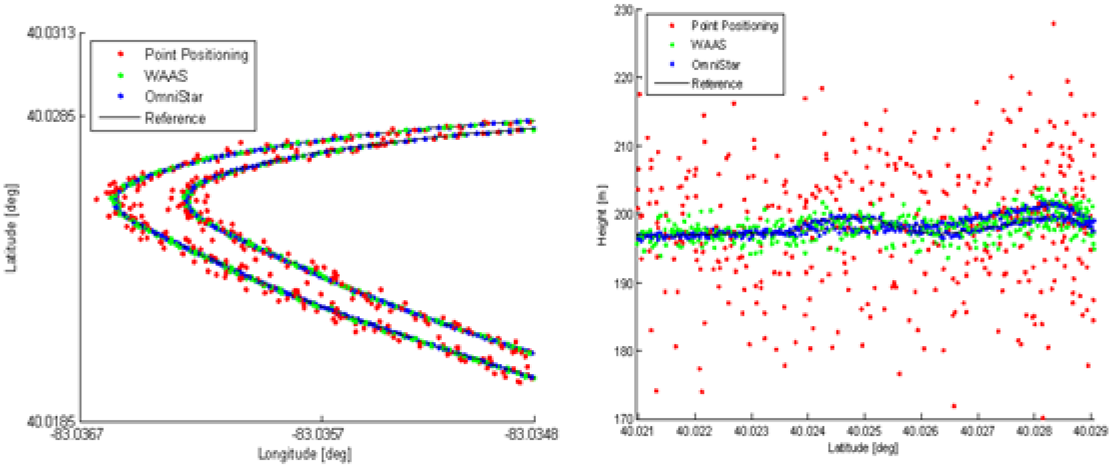

Figure 5. Simulated GNSS Position Errors (Left–Horizontal Errors; Right-Vertical Errors)

Based on this "Reference" trajectory simulated GNSS positions were generated for autonomous positioning (horizontal error 6.0m, vertical error 10.0m), WAAS differential positioning (horizontal error 1.0m, vertical error 1.5m), and OminStar HP (horizontal error 0.15m, vertical error 0.30m) (Figure 5).

Figure 6 shows the GNSS/INU errors with respect to the "Reference" trajectory resulting from the integration of the Autonomous (left) and WAAS (right) GNSS simulated positions with the measurements from a HG1700 Honeywell tactical grade INU (angular bias of 2deg/h; acceleration bias of 1mg).

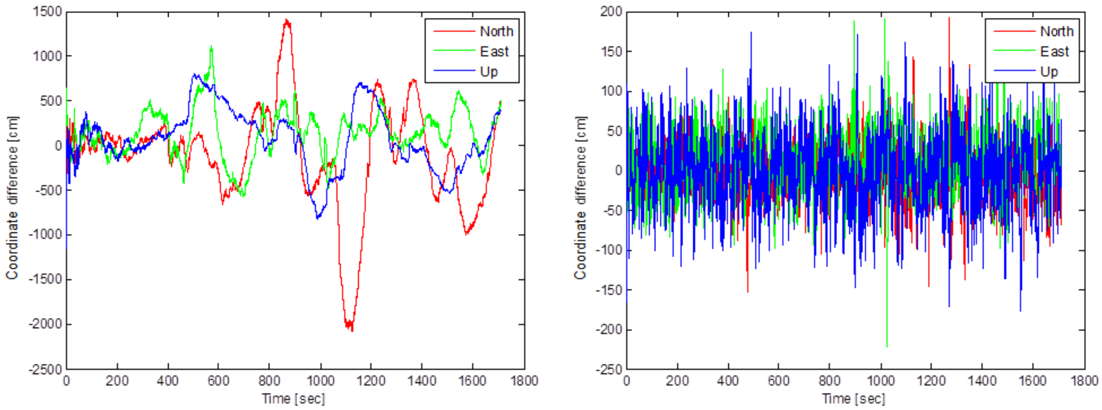

Figure 6. GNSS/INU Errors Using Autonomous (left) and WAAS (Right) Simulated Positions

The GNSS/INU simulator will have the capability to model a variety of GNSS positioning devices ranging from smart phones to high accuracy RTK geodetic GNSS receivers, and a variety of INU units ranging from low-cost MEMS to high performance navigation grade Ring Laser Gyros (RLG) INUs.

Neural Network Design for Network Safety Estimation

For the evaluation of the network safety, a non-parametric neural network (NN) safety estimator is proposed. While every potentially unsafe condition in the VISSIM simulator can be transferred to CarSim to evaluate safety, this transfer process and the CarSim simulation requires an impractical amount of computational run time. The NN has been widely applied to train the relationship between inputs and outputs, and quickly apply such relationship for fast computation. The NN has a capability of developing highly non-linear relationship between inputs and outputs, while typical parametric models often have limitations or less efficient in developing such relationships.

In evaluating safety, FHWA's Surrogate Safety Assessment Model (SSAM) is used. SSAM has been well received among transportation researchers for evaluating safety using traffic simulation models. It is noted that traditional safety evaluations were conducted using post crash analyses on existing facilities and parametric regression type models were developed under roadway characteristics such as existence of shoulder lane, median, or traffic flow characteristic such as number of vehicles, average speeds, and speed variance. However, these traditional approaches are not applicable to new untried conditions including the proposed research.

While microscopic traffic simulators including VISSIM are not perfect for evaluating safety, the transportation research community has reluctantly adopted a safety evaluation methodology using SSAM and a microscopic traffic simulator, as this approach is one of the best available options. Thus, it is clear that the proposed approach utilizes CarSim to expand/overcome those limitations in VISSIM.

As noted, due to the computation time requirements in CarSim and subsequent post-processing, the NN is proposed to establish a 'fast track safety estimation procedure' that would have been estimated by transferring VISSIM status to CarSim, and running CarSim and post processing CarSim vehicular trajectories using SSAM. Although the NN approach requires a sizeable amount of training data to establish the relationship between inputs (i.e., VISSIM unsafe conditions) and safety assessments (i.e., SSAM evaluation results based on CarSim vehicular trajectories), it nevertheless requires much less computations than simulating all possible scenarios through CarSim and transferring its output to SSAM.

As described above, the NN safety estimator, the architecture of which is shown in Figure 7, is based on a Surrogate Safety Assessment model (SSAM). As noted, the use of a NN for the network safety computations is expected to provide an efficient method for the evaluation of network safety because of its computational speed and its ability to model unknown relationships between inputs and outputs.

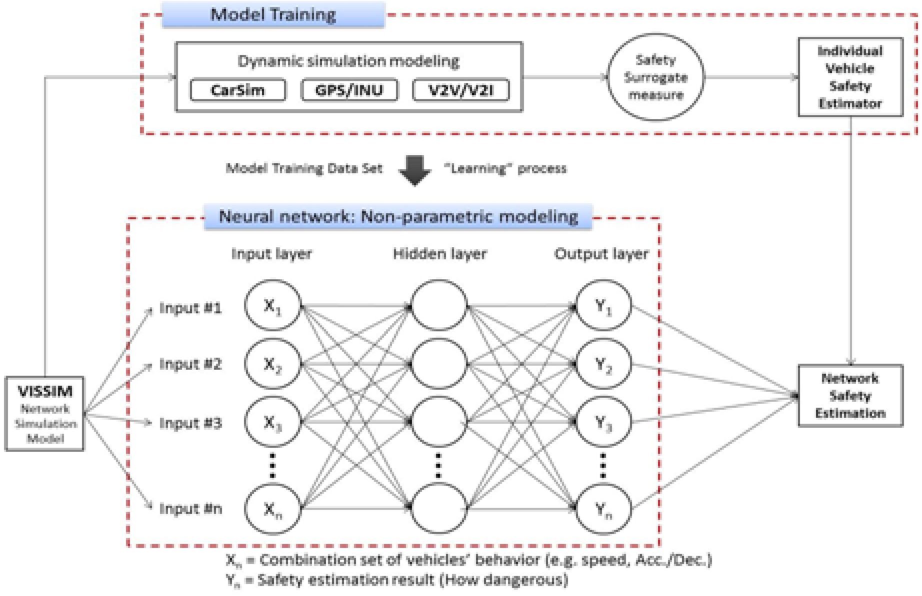

Figure 7. Neural Network Architecture for Network Safety Estimation

The inputs to the neural network are the VISSIM hazardous traffic scenarios realized through various control parameters including vehicle trajectory, vehicle orientation, relative distance and speed from the leading vehicle, vehicle type, driver aggressiveness, road geometry and other parameters depending on the hazardous scenario. The outputs to NN are the safety assessment results obtained from the SSAM program using the following data. 1) the 'ground truth' trajectories and orientation computed by CarSim; 2) the simulated vehicle trajectories and orientation computed by the GNSS/INU simulator; and 3) the V2V and V2I communications delays.

For establishing the expected outputs for the training of the NN, the CarSim 'ground truth' trajectories will be analyzed through the SSAM program to create a safety assessment based on several surrogate safety measures (e.g., minimum time-to-collision, minimum post-encroachment, initial deceleration rate, maximum deceleration rate, classification as lane-change, rear-end or path-crossing event type, etc.). An experimental design approach will be used in developing the inputs and outputs for the NN model. The NN will be developed using MATLAB's Neural Network Toolbox. A simple back propagation neural network will be initially used to develop the relationships.

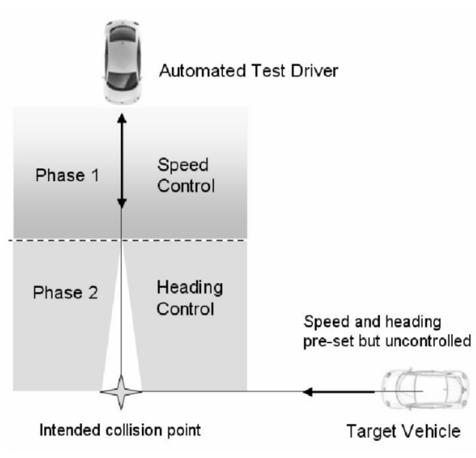

Figure 8. Validation Testing

Demonstration/Validation of the GNSS/INU Simulator

For the validation and demonstration phase, a number of GNSS/INU prototype sensors, ranging high-accuracy to low-cost, low-accuracy will be placed in an actual vehicle and scenario matching to the simulation scenarios (e.g. the lane/road departure maneuver or lane change maneuver) will be executed to validate the simulation environment.

An Automated Test Driver (Mikesell, D.R., et al., 2008) (ADT) will be used to precisely control the path and speed of the actual test vehicle. A commercial vehicle GPS/INU (Oxford Technical Solutions RT2003 (http://www.oxts.com/)) will be used as the reference for ATD control. This sensor, as well as a navigation grade GPS/INU sensor, will be used to accurately define the three-dimensional motions of the vehicle during the field tests. The prototype GPS/INU sensor will also be mounted on the vehicle, and its performance will be evaluated via comparison with the reference motions.

The OSU research team has demonstrated full-scale vehicle-to-vehicle interactive maneuvers using the ATD (Sidhu, A., et al., 2009). Figure 8 shows an example from a demonstration of a vehicle collision scenario. Choreographed lane change maneuvers (vehicle passing/overtaking maneuvers) based on actual vehicle-to-vehicle GPS communication have also been demonstrated. Validation testing will also include a scenario that involves evaluating the prototype GPS/INU in a choreographed maneuver that involves vehicle-to-vehicle communication.

CONCLUSIONS

The integrated GNSS/INU simulator, described in this paper, provides a novel and comprehensive approach for evaluating the impact of the emerging GNSS and INU technologies on automotive safety at the vehicle and network levels. The proposed GNSS/INU simulator will provide the functionality to model a variety of GNSS devices ranging from smart phones to high accuracy cm-level geodetic RTK GNSS receivers and a variety of INU units ranging from low-cost MEMS INUs to high accuracy navigation grade Ring Laser Gyros (RLG).

For the evaluation of the network safety, a non-parametric neural network (NN) safety estimator is proposed. The use of a NN for the safety computations is expected to provide an efficient method for the evaluation of network safety because of its computational speed and its ability to model unknown relationships between inputs and outputs. The inputs to the neural network are the VISSIM hazardous traffic scenarios realized through various control parameters including vehicle trajectory, vehicle orientation, relative distance and speed from the leading vehicle, vehicle type, driver aggressiveness, road geometry and other parameters depending on the hazardous scenario. The outputs to NN are the safety assessment results obtained from the SSAM program (Figure 7).

The integrated GNSS/INU traffic, vehicle dynamics simulator provides the first realistic simulation platform that can be used to model traffic conditions more accurately including crashes which are not available in VISSIM or any of existing traffic microscopic simulators (e.g., PARAMICS, CORSIM).

The results of these investigations will help policy makers to establish policies related to the deployment of GNSS/INU technologies in new vehicles.

A calibrated GNSS/INU integrated simulator could be used within existing driving simulators to produce a more accurate driving environment.

Whereas now the VISSIM, CARSIM and the GPS/INU are integrated via separate software, this platform will generate the need for the development of a new breed of micro-simulators that will have the characteristics of a traffic simulator, a vehicle dynamics simulator and a GPS/INU simulator.

REFERENCES

952-1997IEEE Std http://standards.ieee.org/findstds/standard/952-1997.html; 1293-1998 IEEE Std http://standards.ieee.org/findstds/standard/1293-1998-Cor_1-2008.html.

952-1997IEEE Std http://standards.ieee.org/findstds/standard/952-1997.html; 1293-1998 IEEE Std http://standards.ieee.org/findstds/standard/1293-1998-Cor_1-2008.html.

Angus, J.E., “RAIM with Multiple Faults,” NAVIGATION, Vol. 53, No. 4 Winter 2006-2007, pp. 249-257.

Da, R., Dedes, G., and Shubert, K., “Design and Analysis of a High-Accuracy GPS/INS System,” Proceedings of the 9th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 1996), September 17-20, 1996, pp. 955-964.

Dedes, G. and Rizos, C., “GPS Mathematical Models for Single Point Positioning and Baseline Solutions,” Manual of Geospatial Science and Technology, Edited by John Bossler, 2002, pp 114-126.

Deng, J., Dunn, A.,L., Guenther, D.A., and Heydinger, G.J., "Adaptation of TruckSim Models to Simulate Experimental Heavy Truck Hard Braking Test Data Under Various Levels of Brake Disablement," Society of Automotive Engineers Paper 2010-01-1920, April, 2010.

Elhabiby, M., El-Ghazouly, A., and El-Sheimy, N., “A New Wavelet-Based Multipath Mitigation Technique,” Proceedings of the 21st International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2008), Savannah, Georgia, September 2008, pp. 625-631.

Grejner-Brzezinska, D. A., C. Toth and Sh. Moafipoor, “A Step Ahead: Human Motion, Machine Learning Combine for Personal Navigation,” GPS World, Vol. 19, No.11, 2008, pp. 34-41.

Kinjawadekar, T., Dixit, N., Heydinger, G.J., Salaani, M.K., and Guenther, D.A., "Vehicle Dynamics Modeling and Validation of the 2003 Ford Expedition with ESC using CarSim," Society of Automotive Engineers Paper 2009-01-0452, April, 2009.

Mikesell, D.R., Sidhu, A.S., Heydinger, G.J., Bixel, R.A., and Guenther, D.A., “Portable Automated Driver For Road Vehicle Dynamics Testing”, ASME Paper DSCC2008-14266, ASME Dynamic Systems and Control Conference, October 2008.

Sidhu, A., Guenther, D.A., Bixel, R.A., and Heydinger, G.J., “Vehicle To Vehicle Interaction Maneuvers Choreographed With An Automated Test Driver” SAE Paper 2009-01-0440, April 2009.

SSAM Website: http://www.fhwa.dot.gov/publications/research/safety/08049/index.cfm.

VISSIM – Multi-Modal Traffic Flow Modeling, http://www.ptvag.com/software/transportation-planning-traffic-engineering/software-system-solutions/vissim/.

Yang, Y., El-Sheimy, N., Goodal, C., and Niu, X., “IMU Signal Software Simulator,” Proceedings of the 2007 National Technical Meeting of the Institute of Navigation, January 22-24, 2007, pp. 532-538.

ACKNOWLEDGEMENT

This work is supported in part by the Federal Highway Administration under the Broad Agency Announcement Grant No. DTFH61-09-R-0017.