Directions for Next Generation Microscopic Traffic Simulation Modeling Tool under the IntelliDrive environment

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Abstract

Microscopic traffic simulation models have been widely accepted in the evaluations of new treatments in the surface transportation system. These include new highway, lane usage (e.g., high occupancy vehicle lane or high occupancy toll lane), speed limits (e.g., variable speed limit, and uniform or differential speed limits), etc. Additional needs such as considering lateral movements within the lane made researchers develop plug-in modules on the basis of application programming interface (API). With a recent initiation of IntelliDrive or cooperative vehicle infrastructure system, a traffic simulation research community has faced to consider directions for the future microscopic traffic simulation modeling tools.

This paper conducted comprehensive assessments on the existing practices in the microscopic simulation modeling and future modeling needs, and recommended that the development of traffic simulation model independent plug-in modules. Additional recommendations including short-term and long-term approaches were discussed.

Introduction

Traffic simulation models have been widely used in the evaluations of new traffic operations and management strategies including the intelligent transportation systems, in part because actual field implementations are costly and risky. However, it is understood that the developments in the traffic simulation models often do not cope with the technology advancements. Consequently, the simulation tool needs significant enhancements by the end users. This is in part why many research institutes developed enhancements to existing off-the-shelf products. For example, researchers developed additional modules such as actuated signal controller or ramp metering in evaluating new/untried technological enhancements as well as traffic operational strategies (Park et al., 2004, Liu et al., 2001, Faber et al., 2008). However, the capabilities of these plug-in modules are limited by the choice of existing simulation models such as PARAMICS, AIMSUM, VISSIM, etc. That is, these plug-in modules still have to work with the black-box simulation tools as the developers do not open their source codes.

This paper explores options for next generation microscopic traffic simulation modeling tool especially for the cooperative vehicle infrastructure system (CVIS) or IntelliDrive environment. Given that researchers already have developed plug-in tools, there exist many options such as (i) integrating existing plug-ins to open source microscopic simulation tools (e.g., MITSIMLab, SUMO, TRANSIMS, etc.), (ii) keeping the current architecture (i.e., continue to use plug-ins with commercial microscopic simulation tools), and (iii) making the existing plug-ins independent to work with any microscopic simulation modeling tools. This exploration should consider future needs in the simulation modeling applications and stakeholders. One of the most important considerations would be the modeling of cooperative vehicle infrastructure systems (CVIS) or IntelliDrive environment. This opens up many questions including how the communications network, driver support systems, traveler responses, etc. should be considered. This paper discusses various aspects that need to be carefully considered in the development of future simulation modeling tools.

Current Approaches in the Microscopic Traffic Simulation Modeling

This section discusses current state-of-the-practice in the use of microscopic traffic simulation models in terms of traffic, vehicle, human factors, sensors, communications, and control point of view.

Traffic Modeling

Traffic simulation can be categorized into microscopic, mesoscopic, and macroscopic depending on the model fidelity. In a microscopic simulation, the traffic movements are mainly governed by car-following and lane changing models. Core algorithms in car-following and lane changing behavior models have been developed/enhanced using limited data sources including the next generation simulation (NGSIM) data and other vehicle trajectory data. The origin-destination information is often estimated using somewhat limited sensor counts and assumed to be perfect during the simulation model calibration. Additional information such as automated vehicle location or identification (AVL or AVI) has helped estimating better OD tables.

Vehicles Types
Traffic simulation models can accommodate a variety of vehicle types including passenger cars, trucks, light rail transit, bicycles, pedestrians, etc. Physical characteristics of these vehicles have been adequately defined on the basis of maximum acceleration and deceleration rates, vehicle weights, turning radius, etc. Traffic simulation models have not well accommodated advanced vehicle technologies such as adaptive cruise control and electronic stability control, while such advanced vehicle control technologies can be realized via application programming interface (API), or even hardware in the loop simulations.

Human Factors
Microscopic traffic simulation models consider human factors based on drivers' aggressiveness in response to traffic control, interactions with adjacent vehicles, etc. In practice, human behaviors on route and departure time selections, and response to guidance information are not properly captured, in part due to limited data. Driving workload and potential misconduct (or driving errors) are hardly considered in the traffic simulation models. Driving simulators have been widely used in the analyses of human factors in response to traffic control. Recently, a few studies have integrated a driving simulator and a microscopic simulator (e.g., Turner Fairbank Highway Research Center). It has been reported that the deceleration rates measured in the driving simulator were much lower than those normally observed in real world driving conditions. This certainly indicates observed human behaviors via driving simulators should be used with caution.

Sensors
The current state of the practice microscopic traffic simulation tools directly model fixed point sensors (e.g., loop detectors), while any errors associated with communication and detector malfunctions are not explicitly modeled. It is possible to model advanced sensors such as lidar or radar through an application programming interface. A few studies have used microscopic traffic simulation in modeling wireless location technologies. An example is a traffic monitoring application using cell-phone locations and their errors (Fontaine and Smith, 2007).

Communications
Communications network simulation has not been fully integrated into microscopic traffic simulation models. This is in part due to the difference in simulation modeling specifications (i.e., one being event-based while the other being time-scan based). In general, basic communications needs (e.g., required bandwidth, communication ranges, optimal hub locations, etc.) can be easily realized by post processing of the traffic simulation output. For example, the amount of messages communicated by a given time interval (to gauge bandwidth requirement) can be easily measured by analyzing the microscopic traffic simulation model output (Tanikella et al., 2007).

Traffic Controls
Microscopic traffic simulation models have embedded control engines such as traffic signal controller, ramp meter, etc. Even though these 'simulated' controllers mimic basic features, they hardly replicate vendor added proprietary features. To overcome such limitations, hardware in the loop (HIL) simulation has been used to allow integrations between traffic simulation model and actual vehicle, actual traffic signal

controller, etc. As the HIL simulation requires real clock run time, software in the loop simulation has emerged to speed up the simulation run time.

Key Challenges in Microscopic Traffic Simulation Models

This section discusses several key challenges in microscopic traffic simulation modeling.

Validity of the simulation models

This is an issue on the microscopic simulation model calibration and validation. While the importance of calibration/validation is well recognized, lack of procedure, necessary data (or efforts to obtain such data) and time/efforts to do so have kept end users from conducting proper microscopic simulation model calibration/validation. Instead, simulation model calibration has been exercised ad-hoc basis by simply observing animations or checking traffic volume. The calibration and validation of the traffic simulation model is the first step to achieve reliable outputs in support decision making process.

Computation time

Unlike macroscopic or mesoscopic simulation, microscopic simulation is computationally extensive in nature. When extensive API applications interrupting computer simulation every tenth of seconds are used, the computation time can be a significant burden. In addition, if a communications network simulator is to be integrated into a microscopic simulation model, it would further slow down the computation. While a distributed computing environment – a software system allowing the development of client/server applications – has been already adopted in microscopic traffic simulations, the computation time can still be a challenge for a sizable network modeling. Hopefully, computation technology can be enhanced to achieve acceptable computation time. The computation time requirement largely depends on the applications – real time implementation vs. off-line evaluations.

Data sources

It is generally understood that various traffic and behavior data are essential in the development of traffic simulation models. For example, to establish a simulation model for a study network, end users need to input, at least, the following data: dynamic origin-destination, drivers' aggressiveness, infrastructure control settings (e.g., traffic signal timing plan, sensor locations, VMS locations, etc.), vehicle mix, etc. Unfortunately, state-of-the-practice is still far removed from automated data collection. For example, dynamic OD tables are estimated from historic OD tables and limited actual sensor counts, while drivers' aggressiveness has been appropriately captured – mostly updated on the basis of preferred preferences. Additional data sources, such as vehicle trajectory data for the development/calibration of the car-following and lane changing models, are fairly scarce. Even though a recent NGSIM project (http://www.ngsim.fhwa.dot.gov/) established high fidelity individual vehicular trajectory data from several freeway and arterial networks, and developed a few core logics in lane changing behaviors, these data are still limited to less than an hour worth of data from a few miles on a freeway or 4 to 5 signalized intersections.

What will be the Future?

To prepare functional requirements for next generation traffic simulation modeling tool, this section presents the anticipated arrival of future intelligent cars and their characteristics based on the 5G model.

Sol et al. (2008) has presented an interesting vision of five generations of intelligent cars. The majority of cars including those equipped with GPS navigation system, automatic payment system, etc. are considered to be 1G, while some vehicles with modern advanced technologies such as adaptive cruise control, lane departure warning, etc. are 2G. The 3G cars will have car-to-car and car-to-infrastructure communications, and a selective automated driving function to lighten drivers' workload. The 4G cars will have fully automated driving at uncongested roadways, and automated steering wheel control at congested conditions. The 5G will have autonomous vehicle control.

The arrival of future intelligent cars can be affected by many factors including technology development, policy decision, human acceptance, etc. Based on Sol et al. (2008) and two other studies (Vreeswijk et al. 2008; Wilmink et al., 2008), the 1G and 2G cars are to achieve sufficient market penetrations by 2015, and 3G cars would rapidly arrive to the market within another seven years.

Assuming the next generation traffic simulation tool targets 15 years ahead, 3G cars as well as mix of up to 2G cars are likely being presented. It is expected that communications infrastructure (i.e., road side equipment) would be deployed in major urban areas and critical segments on motorways. Furthermore, vehicle communication devices (i.e., on board units) would be readily available on all 3G, most of 2G and some 1G (through after market installations) cars. Thus, it is a no-brainer to develop a next generation traffic simulation tool that can adequately model cooperative vehicle infrastructure systems or the IntelliDrive environment.

Communications Technologies

This section provides the current status in communications standards for the cooperative vehicle infrastructure systems.

With the advances in communications technologies, vehicles can communicate with near-by vehicles as well as infrastructure. The U.S. Department of Transportation has initiated vehicle infrastructure integration (VII) and already dedicated 75 MHz wireless communications bandwidth at 5.9 GHz (Sharafsaleh et al., 2008). The European Union as well as Japan have started similar systems, and are in the process of allocating dedicated communications bandwidth. For example, the European Commission will allocate 30 MHz of spectrum at 5.9 GHz band for CVIS.

In terms of standard architecture for the cooperative vehicle infrastructure systems communications, the US has decided on IEEE 802.11p, while the European Union has started two architectures: one is called car-to-car communication consortium (C2C-CC) and the other is called Continuous Air interface for Long and Medium distance (CALM). Figure 1 shows an example of a cooperative vehicle infrastructure systems communications environment.

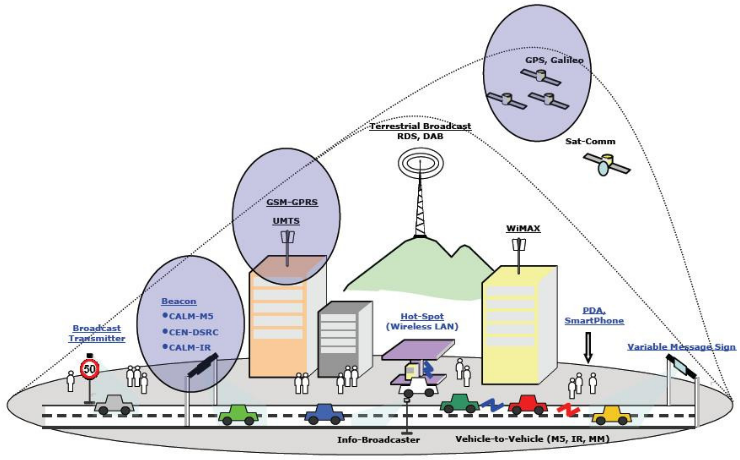

Figure 1. Example of cooperative vehicle infrastructure communications system
(Source: http://www.cvisproject.org/en/news/cooperative_systems_at_london.htm)

Just like traffic engineers simulate cars and infrastructure using microscopic traffic simulation models, communications engineers do use simulation models. There exist many communications network simulation modeling tools. However, the following four models are widely used for the applications of mobile communications (e.g., V2V and V2I) that are necessary for the proposed cooperative vehicle infrastructure systems.

NS-2, an open source program, is a discrete event-based simulation modeling tool providing simulation of TCP, routing, and multicasting protocols over both wired and wireless communications networks. It is written in C++ and an object oriented version of Tcl. It supports various platforms including Linux, OS X, and Windows (with Cygwin). The network animation is also supported by the network animator, called nam, via a Tcl/Tk based tool. Further information can be found at http://www.isi.edu/nsnam/ns/.

OPNET, originally developed as a graduate project for a networking course at MIT, stands for optimized network engineering tool. It is a commercial product – costly but it provides a more reliable and user-friendly interface than NS-2. Additional information can be found at http://www.opnet.com/.

OMNeT++ is a public source – free for academic and non-profit use. It provides a modular and open-architecture simulation environment with a graphic user interface and an embeddable simulation kernel. It supports the simulation of communications networks including internet protocols, mobility and ad-hoc networks. More information can be found at http://www.omnetpp.org/.

NCTUns is an open-source communications network simulator that only runs on Linux platform. The most unique feature of NCTUns is the capability of modeling the U.S. IntelliDrive communication standards, dedicated short range communication (DSRC) incorporating the IEEE 802.11p and IEEE 1609 family (NCTUns, 2009).

Future Simulation Needs

Based on the goals and visions of potential stakeholders, Table 1 presents next generation simulation modeling requirements for the implementation of the cooperative vehicle infrastructure systems. These requirements were identified through a series of conversations with experts as well as a brainstorming session by the authors.

Table 1. Future Simulation Modeling Requirements for Cooperative Road Vehicle Systems

Stakeholder	Future Simulation Modeling Needs
Auto manufacturers	Vehicle dynamics realizing unmanned vehicle and other advanced driver support systems, Performance (e.g., safety and mobility) assessments with enhanced vehicle control devices (e.g., ACC, C-ACC, collision warnings, collision avoidance, etc.) including drivers' acceptance rates, interaction between manned and unmanned vehicles, etc.
Entrepreneurs	Impacts of e-service and/or entertainment system in terms of driving performance, travelers' responses/acceptances, service quality, etc.
Road authority and government	Quantifying (societal) benefits of CVIS, and synergy with combined deployments, On-line monitoring and prediction capability, integrated corridor management (freeway, arterial, transit, para-transit, bike and pedestrian), fuel consumption and emission impacts of various policies, etc.
Traffic industry	Modeling of advanced sensing technology, realistic representation of traffic control devices (either via SILS or HILS)
Traffic simulation model developers	Integration with real-time sensors, automated online calibration and validation, automated interface with various data sources including inputs/outputs of other models (e.g., emission estimator, driving simulator, etc.), interface/integration with communications network simulator
Communications industry	Realistic representation of traffic behavior for evaluating communications control logics, integration with traffic simulator for developing/testing adaptive communications control, etc.
Information providers	Accurate driver behavior model, route guidance algorithm, impacts of navigation guidance, drivers acceptance and compliance rates, benefits/costs of centralized vs. decentralized guidance systems, etc.
Drivers and Travelers	Hardly use simulation modeling tools
NGO seeking sustainable society	Accurately estimating sustainability measures and assessing impacts of various technology improvements toward sustainable transportation system

Functional Requirements

Based on the functions requirements presented in Table 1, "must have" features, identified by the authors, are summarized as follows:

- Vehicle dynamics with advanced control technologies
- Interactions within and between autonomous and manned vehicles
- Driving performance with e-services
- Quantifying benefits of CVIS and others
- Online traffic control
- Advanced control algorithms
- Modeling reliability of technology gadgets and communications
- Automated calibration/validation with real sensor data
- Interface/integration between traffic and communication simulators
- Driving behavior model with information
- Route guidance algorithm
- Measuring sustainability indicators, and quantifying sustainability

Given that none of existing microscopic traffic simulation modeling tools could adequately model these requirements, the application programming interface (API) should be added on top of the base traffic simulation modeling tool to realize these 'must have' functional requirements.

Three Possible Approaches and their Pros and Cons

This section describes three possible approaches that a research institute (or possibly a community as experienced by the NGSIM development) can take to develop the next generation of microscopic traffic simulation tools for the cooperative vehicle infrastructure systems, incorporating the "must have" functional requirements.

1. Incorporate existing plug-ins (i.e., APIs) with open source simulation tool(s)
   There are several open source microscopic simulation models such as MITSIM. This approach will use an open source simulation program in which provides flexibility in making any changes deemed necessary in the selected open source microscopic simulation tool, or even building a new simulation tool from the scratch. A potential downside is the validity of the open source microscopic simulation tool or a new simulation modeling tool (to be developed) – people are often less skeptical when a well established commercial software was used in the analyses and/or evaluations. An advantage is that everything is transparent such that there are no more worries on the black box simulation imposed by the commercial simulation model developer.
2. VISSIM + Add-on type plug-in layers
   Given that VISSIM has been widely adopted by many localities in the US as well as many research institutes, consulting firms and universities around the world, this approach is worth considering. Existing plug-ins already developed for other tools can be gradually ported to VISSIM, whenever a need arises. A disadvantage is that this approach presents a dependency on PTV's VISSIM.
3. Develop APIs (i.e., Plug-ins) that are simulation model independent
   This approach provides flexibility for the community (or researchers) to use any kinds of commercially as well as freely available microscopic simulation models, while obviously requires additional work ensuring the plug-ins properly work with selected models. Another advantage is that this approach can take advantage of winning simulation modeling tools. Given that PARAMICS, VISSIM and AIMSUM were not popular or even not available about 15 years ago, it is likely that new generation of microscopic (or sub-microscopic) simulation tools emerge. This approach could develop a framework that implements a plug-in written in a pseudo-code (or even a macro script language) into the new generation as well as existing microscopic simulation modeling tools. This of course assumes that each microscopic simulation model provides similar API functions to be accessed by the pseudo codes or macro scripts. In addition, it is expected that microscopic traffic simulation model developers (e.g., PTV, QuadStone, TTS, etc.) continue to enhance the support for APIs. Thus, when adequate needs arise for incorporating cooperative vehicle infrastructure systems or IntelliDrive, the developers will enhance their tools to easily integrate the CVIS and IntelliDrive environment. As such, this approach can take advantages of enhanced APIs from the traffic simulation model developers as well.

These three potential approaches are evaluated on the basis of programming, maintenance, dependency with selected simulator, reliability, flexibility, computation efficiency, licensing possibility, and integration with future simulations criteria. The evaluation is performed on the basis of relative difficulties and/or challenges. For example, programming efforts would be easiest with existing the VISSIM model (as it provides a solid foundation to build up new APIs), relatively easy to use open source simulation tools, and not easy to develop independent API plug-ins to be used by any simulation tools. Although the scores are subjective, it is believed that they would be generally accepted by research community. Table 2 summarizes the evaluation results using these criteria.

It is clear that each approach has pros and cons. The 3rd approach developing simulation model independent plug-ins scores the highest.

Table 2. Evaluation of the Five Approaches

Criterion	Migrate to Open Source Simulation	Develop Plug-ins with VISSIM	Develop Simulation Independent Plug-ins
Programming efforts	Medium (++)	Low (+++)	High (+)
Maintenance efforts	Low (+++)	Medium (++)	High (+)
Dependency with selected simulator	Low (+++)	High (+)	Low (+++)
Reliability	Low (+)	High (+++)	High (+++)
Flexibility	High (+++)	Low (+)	High (+++)
Computation efficiency	Medium (++)	High (+++)	High (+++)
Licensing possibility	Low (+)	High (+++)	High (+++)
Integration with future simulations	Medium (++)	Low (+)	High (+++)
Total Score (# of '+' signs)	17	17	20

Recommendations

Based on the findings from literature and discussions and evaluations made in this paper, the following recommendations are made:

Short-Term Enhancements

These short-term enhancements can be made with any of the approaches presented earlier.

- Simulation model calibration and validation: It is generally understood that the calibration and validation is one of the most important elements in the simulation based evaluation. The next generation traffic simulation tool should include a module automatically implementing such calibration/validation. A quick enhancement can be made by adopting the microscopic simulation model calibration and validation handbook developed by Park and Won (2006). Additional information can be found at http://faculty.virginia.edu/brianpark/SimCalVal/.

- Cooperative lane changing and forced merging behavior models: NGSIM developed a combined merging model that explicitly accounts for cooperation and competition between target lane drivers, and integrates normal, cooperative, and forced lane changing (source: http://www.ngsim.fhwa.dot.gov/).
- Post processing programs: In this context, a post processor is a standalone program implementing an algorithm (e.g., emission estimation) using the traffic simulation output. An example is the VERSIT+ post processor, which uses individual vehicular speed and acceleration output from microscopic traffic simulation for emission and fuel consumption estimations. An advantage is that it does not need to be integrated into microscopic simulation model. It is recommended that a standard vehicle trajectory data format be developed to ensure easy data sharing among various post processing programs.

Selection of Next Generation Traffic Simulation Modeling Tool

As noted, developing simulation model independent plug-ins is recommended. In addition, a next generation simulation modeling tool should be able to, but not be limited to,

- Interface with existing microscopic traffic simulation models including PARAMICS, AIMSUN, VISSIM, etc. as well as open source models
- Work as modules such that end users can easily select and combine them based on their needs
- Incorporate modeling needs for cooperative vehicle infrastructure systems simulations, including human factor, communications network, automotive, emission, etc.
- Interface with various HIL simulators, submicrosimulators, driving simulators, etc. In the TNO context this includes interfacing with VeHIL, PreScan, driving simulators, MARS, and other tools– for example, a cooperative adaptive cruise control mechanism tested within VeHIL and driving simulator can be used in the development of a plug-in module for the next generation traffic simulator
- Take advantage of modules (e.g., NGSIM core algorithms) developed by others

Consideration of Communications Network Modeling Tool

One possible reason to integrate the microscopic traffic and communications network simulators is when an adaptive communications control is being considered. For example, there is a slippery spot on the roadway and a vehicle identified its location wanted to communicate such information to the upstream vehicles. Without the adaptive control, the information will be sent to backward (toward upstream) with a predetermined signal length (i.e., a fixed maximum communications distance). It could cause an information loss when no vehicles are within the communications range, while the adaptive communications could initiate longer communications distance or convey message through the vehicles traveling on the other direction – as it knows no upstream vehicles within the range. Furthermore, adaptive communications could consider interferences among the messages sent by adjacent vehicles to ensure best performance.

In the short term, it is not worth integrating a communications network simulation and a microscopic traffic simulation model. This is because of the discrepancies between two models – one being continuous event based simulation and the other being discrete time-scan based simulation. This not only requires pause of one simulator to update the other simulator but also needs interpolation of communication time among vehicles or vehicle to infrastructure. Instead, a post processing mechanism is recommended. The outputs from the microscopic simulation model under a default communications logic can be fed into the communications network simulation model to evaluate the performance of the given communications specifications or even to optimize best specifications (e.g., communication protocols, locations of infrastructure hubs, vehicle-to-vehicle communication ranges, etc.). If needed, multiple iterations between two simulation models can achieve convergence.

In the long term, the integration does make sense as the cost of computation time will be negligible. Furthermore, there exists an IEEE standard for modeling and simulation (M&S) high level architecture (HLA) consisting of rules, a runtime infrastructure and interface descriptions, and an object model template (IEEE, 2000). One can even envision that the entire traffic and communications network can be monitored real time at a traffic/communications center (like the current air traffic management center does).

Opportunities

These opportunities can be incorporated with any of the approaches presented earlier.

- Simulation model based safety assessment – the Federal Highway Administration as well as University of Virginia developed statistical crash prediction models based on individual vehicular speed and time headway information
- Network coding – level of detail as well as automatically updating changes in traffic signal timing plan, lane assignments, ramp metering plan, etc.
- Direct optimization – Optimization of ramp metering, traffic signal control, or estimation of origin-destination tables, etc. are mostly done by macroscopic simulation tools. Microscopic simulation models can be directly used to improve the quality of the solution, assuming the model is adequately calibrated
- Cooperative systems – a mass of vehicular information that could be useful for better simulation model development (e.g., core functionality development – archived driving behavior data along with data on the adjacent vehicles and roadway information can be directly used in the calibration of driving models)
- Behavior data collection – Seamless integration among many data sources to simulation modeling tools – for example, travelers (e.g., pedestrians, bicyclists, drivers) who opted-in sharing their traveling behavior can automatically transmit their driving information wirelessly to a secure server for further processing, in return, they can receive suggestions for shortening travel times, emissions, even coupons, etc.

ACKNOWLEDGEMENT

This paper was written when the first author was working at the Netherlands Organization for Applied Scientific Research TNO as a Visiting Researcher.

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