Development of CID-free Hardware-in-the-Loop Simulation Framework

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ABSTRACT

Hardware-in-the-loop simulation (HILS) has gained great attention for its applicability dealing with real-time simulation by factoring in the complexity of hardware signal controllers. In conducting signalized intersection HILS, controller Interface Devices (CIDs) had been necessary components. However, the use of CIDs often makes the simulation framework more redundant by adding an extra hardware component. CIDs also add communication overhead between simulation software and the signal controllers, which may reduce the feasibility of conducting HILS. Besides, modern controllers embedded with advanced control algorithms which are hard to emulate by generic simulation software. To improve exiting HILS framework, the concept of CID-free HILS is proposed. By replacing CIDs with a software module based on National Transportation Communication for Intelligent Transportation System Protocol (NTCIP), HILS becomes more efficient with less hardware redundancy. In view of the interchangeability and interoperability of NTCIP, the proposed CID-free HILS is expected to expand the scope of simulation as well as improve the degree of realism of HILS. The proof-of-concept (POC) test demonstrates that the CID free HILS can be successfully conducted and it can provide comprehensive evaluation for transportation agencies who are planning to enlist advanced adaptive signal control technologies (ASCTs). Moreover, the propose framework show its promising applications in evaluation connective vehicle technologies.

INTRODUCTION

Hardware-in-the-loop simulation (HILS) is a type of real-time simulation technique which is used to test how a test component (e.g., a signal controller) response to realistic or virtual stimuli and whether a physical system model is valid (*1*). This technique has been using in various disciplines, such as automotive systems design and testing(*2*) in automotive engineering, jet engine development (*3*) in aerospace engineering, power delivery system (*4*) in electrical engineering, and control system (*5*) in marine engineering. HILS can enhance the testing quality of the simulation. Not only does HILS factors in the complexity of a component hardware, something that is hard to emulated by software, but HILS also improves the quality of the test by enabling researcher to expand the testing scope, to the realm where testing could be deemed unsafe for test operators (e.g. vehicle brake failure, engine failure during a flight test).

In transportation engineering context, HILS for signalized transportation network is conducted by replacing signal controller emulators in the simulation by corresponding physical hardware (e.g., the actual controller that is ready to deployment in the roadside cabinet). The simplest signalized intersection HILS framework includes a host computer running the simulation software, a controller interface device (CID) device, and a signal controller. Signal controllers are not designed to interface with simulation software directly. Therefore, CIDs are used to convert the signal, making it communicable between simulation program and signal controller. CID HILS for signalization is not without its problems: first the complexity of the simulation framework is increase by adding an extra hardware component in the loop; secondly, extra cost is required to procure CID devices, which inevitably increase the cost of HILS significantly when it comes to large-scale network.

More importantly, CID does not provide universal interfacing capability and may have compatibility issue among different manufactures. Based on current signal controller practices, there are difficulties in different controllers or devices from multiple vendors to communicate directly, because of proprietary protocols (*6*). The National Transportation Communication for ITS Protocol (NTCIP) is developed to provide communication standards which ensure the interoperability and interchangeability among traffic controllers and ITS devices (*7*) under oversight by the American Association of State Highway and Transportation officials , the Institute of Transportation Engineers, and the National Electrical Manufactures Association, The protocol is designed to accommodate a wide variety of information and message with a general polling engine in a multi-manufacture environment with one caveat which is the NTCIP may not be able to maintain the same polling period with the equal number of device per channel: the manufacture fixed message is extended for improved flexibility (*8*). Because of the increased flexibility , interoperability among ITS devices are ensured and more ideally, some interfacing component (e.g., CID (*9*)) used to facilitate the required communication could be removed.

In this paper, we proposed a CID-free framework for HILS with rapid prototyping and realistic testing capabilities with the help of NCTIP protocol. The paper is organized as follows. The relevant research efforts examining HILS as well as NTCIP protocol applications are reviewed. Details for the proposed framework are discussed in the section of CID-free HILS Test Bed section by addressing several findings obtained through a Proof-of-Concept (POC) test. Potential use cases of the CID-free HILS framework are presented in the next section, followed by Conclusion at the end of the paper.

LITERATURE REVIEW

According to Stevanovic et al. (*10*), there are three ways to conduct advanced controller operation analysis: emulator-in-the-loop simulation (EILS), software-in-the-loop simulation (SILS), and hardware-in-the-loop simulation (HILS). EILS is based on an internal module of a typical simulation program. For instance, VISSIM (*11*), a microscopic simulation software developed by PTV, has its internal emulator for signal operations during the simulation. The emulator is based on NEMA standards. During each simulation step, the status of the detectors and the signal head is passed to the emulator which returns the signal head status for the next simulation step. Since the emulator is part of the overall simulation package, its speed is higher and the setup is easy. On top of these, seamless coordination with the traffic simulation model is provided. Despite that microscopic simulation has evolved over the past decades, however, it remains inadequate to deliver the level of sophistication and verity of control operation as physical controllers.

Different from EILS, SILS uses a standalone virtual controller, external to the simulation software, to conduct the simulation. A virtual controller interface is typically developed to display the information (e.g., signal head phase, remaining green time) which is being exchanged. In the MOST Project(*12*), PTV America, in partnership with Econolite Control Product and University of Idaho, has developed a ASC/3 controller software for SILS(*13*). The controller software runs identical code as that of the ASC/3 hardware counterpart. The software can run signal timing, either faster or slower than real time. For ASC/3 SILS, it have been tested in a framework call system-in-the-loop (*14*). However, not all SILSs can simulate the communication feature of a physical controller (e.g. communication capability within a field cabinet or within a centralized traffic signal system (*15*))

HILS is a real-time system where the traffic simulation software sends detector information to a physical controller and retrieve phase during each simulation step(*16*) through CID. The CID assumes the role of interfacing between hardware controller and simulation software via electrical signals. Both SILS and HILS can be considered as real-time system, which is classified based on failure tolerance (i.e. failure to meet the deadline). The timing constraints of real-time system can be divided into hard temporal constraints and soft temporal constraints. HILS is considered as soft temporal constrained real-time system, because an occasional missed deadline should not cause the simulation to fail completely. It may, however, affect some measure of effectiveness.

In EILS, negligible latency is observed in terms of updating of the signal phase and detector status, whereas in HILS hardware latency is more pronounced, which primarily includes: 1) propagation delay, 2) transmission delay, 3) CID signal processing delay, and 4) software processing time (*10*). To meet such task scheduling and sequencing, the HILS must run faster than real-time to allow CID to processing the input and output data. Therefore the potential reduction in communication time could enhance the feasibility of HILS by allocated available time to other tasks (e.g., simulation computation). The added benefits by removing CID could become more significant when the simulation is more computationally demanding. In some extreme cases, it could converting an infeasible HILS to a feasible one.

Bullock et al. (*17*) proposed a HILS framework which was comprised of a CID, a microscopic simulation engine (i.e. CORSIM), and a software interface module providing the linkage between the CID and the microscopic simulation software. Technical issues pertaining to HILS were discussed, including task scheduling, assessment of real-time simulation error, and result comparisons between CORSIM emulator and HILS. The authors pointed out that HILS signal controller simulation is feasible only if a simulation runs faster than real time, which allows the interface software to have certain degree of freedom to run and wait for real-time clock to reach the start of the next simulation step. In addition, they emphasized the importance of synchronization between the simulation and the external controllers. While with the integration of the hardware controller complexity, the study results, as concluded, still yielded statistically different mean value in few measures of effectiveness.

NTCIP is a family of standards intended for use in all types of management systems concerning transportation environment (e.g., traffic signals, transit, emergency management, data archiving). The core features of NTCIP are interoperability and interchangeability. The former is represented by the ability information exchange among different types of devices, whereas the latter is reflected by the ability to use the same communication channel among the same type of devices. The applications for NTCIP can be categorized into 2 groups: center to center (C2C) and center to field (C2F)

Bevor, a sematic-based ITS middleware, was proposed by Chen et al. (*18*) to facilitate emergency vehicle preemption. Bevor circumvented traditional vendor proprietary communication protocol by using NTCIP. Two applications: 1) Condition-aware Vehicle Monitor and 2) Ambulance First Preemptive Road Access, were derived from the prototype system. A miniature ambulance preemption system prototype was designed within a miniature city module constructed by LEGO NXT Brick. The communication between emergency center and the smart car (LEGO smart car) was using Bluetooth; whereas the communication between emergency center and traffic center was executed by a Java socket program using UDP/IP protocol. Test in a miniature city module has demonstrated the ambulance preemption framework successfully actuated vehicle preemption when needed. Additionally, the authors reported that Simple Mail Transfer Protocol(*19*) performed 6 times faster than Simple Network Management Protocol(*20*) for each data transaction.

Ahmed et al. (*21*) conducted a proof-of-concept (POC) study using an external logic processor for NTCIP-compatible traffic controller to verify whether it could successfully terminate and decide the following phase sequence. The test system was comprised of three components: 1) an ASC/3-2100 hardware controller, 2) a CID, and 3) Rabbit 3000 Microprocessor which is designed for embedded controlling. Ethernet communication was used between the controller and the microprocessor, whereas serial connection was used between the microprocessor and the computer. Since all NTCIP dynamic objects with regard to phase status are read-only, an indirect approach by either modifying the passage time to zero or reducing the maximum green is used to trigger terminations of a phase. Detector actuation status, phase status, next phase and changing green duration were compared side-by-side between the records from VISSIM and those collected by the microprocessor from the hardware controller. The outcome showed NTCIP can logically terminate a phase and determine phase sequence besides changing other important parameters of controller.

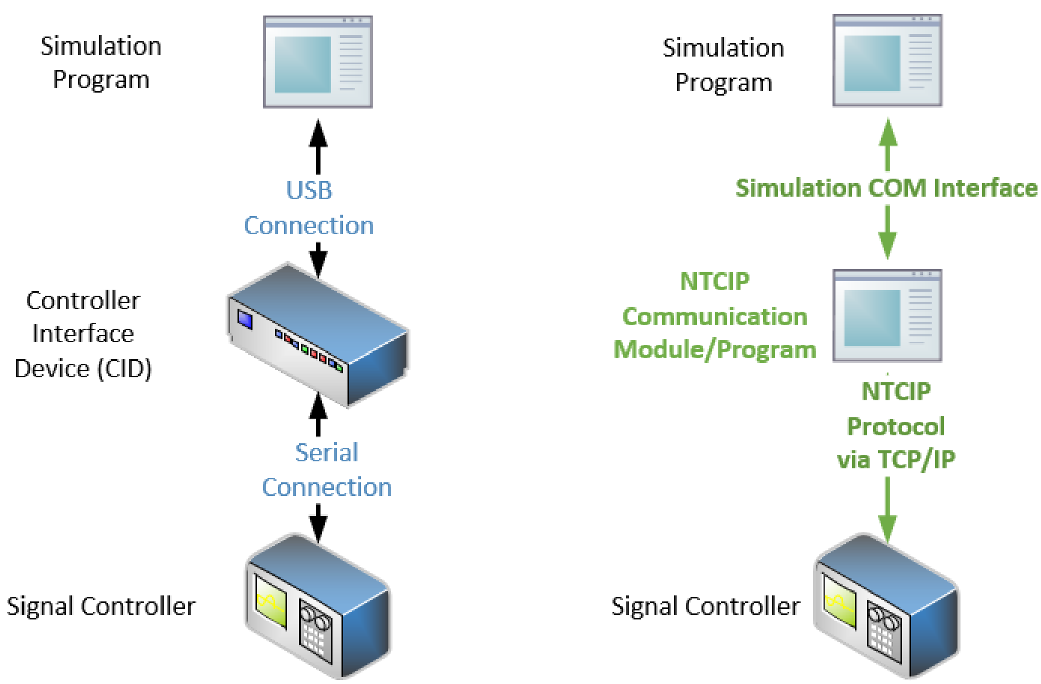
Chaudhary et al. (*22*) developed a custom toolbox, NTCIP Portable Traffic Signal Evaluation System (NTPSES) for monitoring as well as operational troubleshooting at signalized intersection. In addition, a third-party optimization program for signal timing was incorporated into the toolbox. NTPSES was divided into three functional modules: 1) the monitoring module (NTPSES-M), 2) the analysis module (NTPSES-A), and 3) update module (NTPSES-U). NTPSES-M was used to request static and dynamic data from the controller, whereas NTPSES-U was used to send new signal information to a controller by changing the standard objective identifier (OIDs) using NTCIP protocol. The OIDs applicable to various NTCIP device can be identified by the Management Information Base (MIB) (*23*), which are made available from the NEMA FTP site(*24*). Test showed that NPTSES-M successfully retrieved timing information (e.g., maximum number of phase, phase groups, detector groups) from a controller. Then signal timing analysis was conducted by NPTSES-A with the retrieved data. Universal traffic data format (UTDF), promoted by Trafficware, is an open standard data format specification for traffic signal and related data for intersections (*25*), which is used by NPTSES-U for uploading a subset of controller database. SILS with Econolite soft controller, followed by a HILS with CORSIM and eventually field tests were successfully conducted.

In summary, EILS and SILS both appear inadequate when advanced controller operations are used(*10*). Research has reported that EILS shows significant difference than that observed form the HILS and SILS. HILS is an economical and efficient way to safely test ITS signal control algorithm as well as other applications (e.g., connected vehicle, pedestrian assistance signal). As discussed, HILS is only feasible and reliable when simulation runs faster than real time, which allows CID or its software counterpart to process and transmits data to a controller.   With the removal of CID in the HILS environment, not only can we reduce the probability of hardware failure which could halt the overall simulation, but we can also reduce the simulation communication overhead of using CID, which potentially increases the feasibility of HILS. As such, scalability of HILS can also be improved. NCTIP could fundamentally transform the organization of simulation as well as field deployment of ITS devices by circumventing the communication barriers. In this study, we proposed a NTCIP-based CID-free HILS framework to harness the benefits provided by HILS and NCTIP as well as the ease of scaling of state-of-the-art microscopic simulation. More appealingly, the subsuming communication program can be imbedded in a microcomputer (e.g., Raspberry Pi) for seamless field deployment after being fully tested during HILS.

CID-FREE HARDWARE-IN-THE-LOOP SIMULATION

Framework

Figure 1 shows the comparison between traditional CID HILS and proposed CID-free HILS framework. Figure 1(a) shows three major components for conducting HILS, which are simulation program (hosted on a computer), a CID, and a signal controller. CID assumes the communication role between simulation program and controller. Figure 1(b) demonstrates the proposed CID-free HILS framework. Without the CID, the major components for conducting HILS reduces to only two. The communication role provide by CID is now replaced by a NCTIP module which can be run concurrently on the host computer along with the simulation program.



(a) HILS with CID (b) HILS without CID

FIGURE 1 System Architecture Comparison

NTCIP object definitions and identifications used for actuated signal controller could be found in the NTCIP 1202 document (*8*). All of the objective identifiers are hierarchically associated with MIB. Despite the interoperability and interchangeability of NTCIP is aiming to achieve, not all the objects within the NTCIP are editable. Some objects are read only, for instance the instantaneous signal phase status, for safety purpose; some objects which relate to low-level electrical components are not even accessible (*8*). Some vendors may choose to have proprietary objects in their signal controllers which are not included in the NTCIP OID list. Therefore, one should know the scope and accessibility when it comes to unitizing NTCIP. Table 1 presents the adaptive signal controller OID used in the test.

Table 1 NTCIP OID for CID-free HILS

OID	Object Name	NTCIP Accessibility
1.3.6.1.4.1.1206.4.2.1.1.4.1.4	phaseStatusGroupGreens	read-only
1.3.6.1.4.1.1206.4.2.1.1.4.1.3	phaseStatusGroupYellow	read-only
1.3.6.1.4.1.1206.4.2.1.1.4.1.2	phaseStatusGroupRed	read-only
1.3.6.1.4.1.1206.4.2.1.1.5.1.6	phaseControlGroupVehCall	read-write
1.3.6.1.4.1.1206.4.2.1.1.5.1.7	phaseControlGroupPedCall	read-write

Proof-of-concept Test

The proposed framework increases the feasibility of conducting HILS. Additionally the NTCIP communication framework adopted provides rapid prototyping capability, which could drastically reduce the application development time. Namely, the step in which a developer may have to take (e.g., software conversion as per controller specifications) when deploying intended signal applications in the roadside cabinet. The POC test was conducted with a 4-leg intersection simulation network with vehicle actuated signal plan in VISSIM. Owning to the CID-free concept, one now can remove the CID from the traditional HILS framework. FIGURE 2 illustrates the overall architecture for the CID-free HILS using VISSIM (*11*) which provides the network geometry, car following model, and signal module, all of which are essential in running the simulation. The VISSIM COM Interface (*26*) allows VISSIM to export objects, methods, and properties. Additionally, the Interface uses NTCIP via TCP/IP protocol to exchanging information between VISSIM and signal controller.

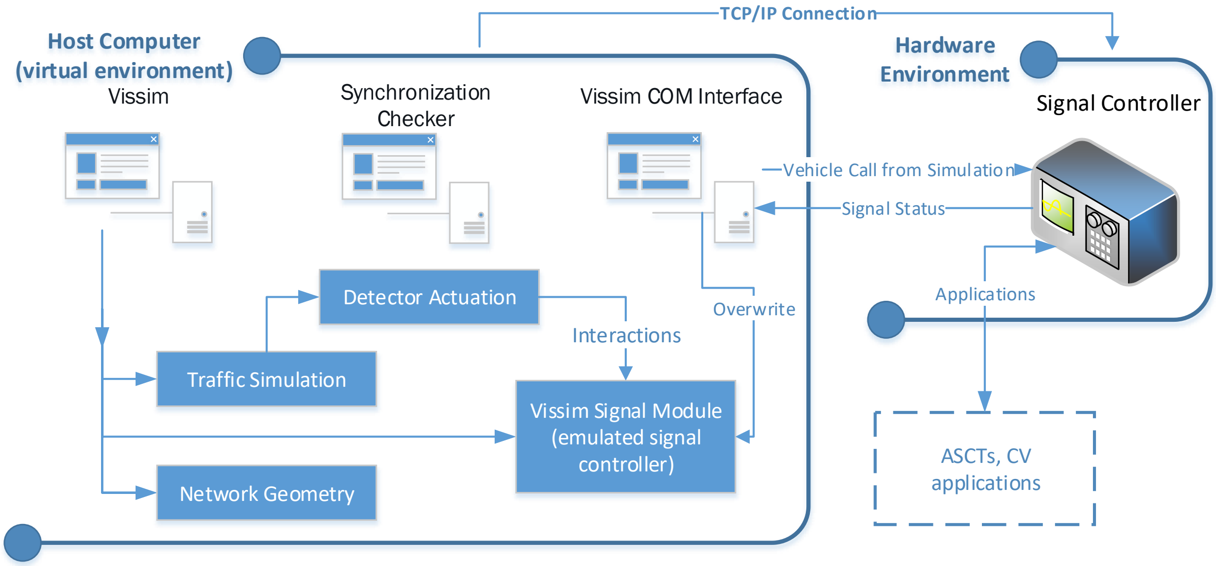
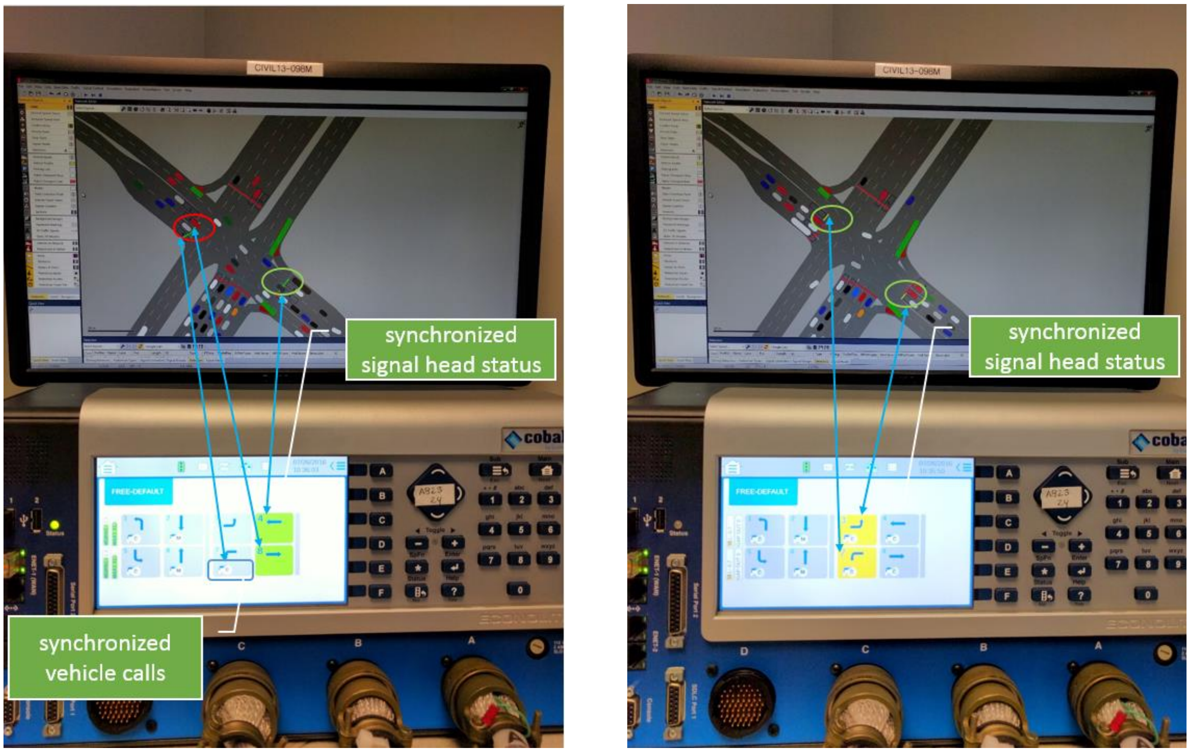


FIGURE 2 CID-free VISSIM signalized intersection simulation architecture

It is helpful to first clarify essential definitions or terminologies in relation to the POC test. 0.5 seconds simulation speed with 5 simulation resolution was used. Simulation speed, which does not affect simulation results, is a time lapse factor indicating simulation steps per real-time second. Simulation speed could be either slower or faster than real time. In HILS, the VISSIM simulation speed needed to be reduced in order to synchronize with the hardware controller. It is important to know that the highest simulation speed also depends on another parameter called simulation resolution, which indicates the number of computations in each simulation second. For instance, simulation resolution of 5 represents that VISSIM computes and updates the vehicle trajectories or pedestrian movements 5 times within 1 second in the simulation. The higher the resolution, the more microscopic aspects of the traffic flow the simulation can provide, but the slower the simulation becomes.

In each simulation cycle, the Interface program collects vehicle calls triggered by vehicle detections in the minor street as well as pedestrian crossing calls, if any. The calls then are encoded by the Interface program according to NTCIP protocol and transmitted to the physical controller via Simple Network Management Protocol (SNMP) (*20*), a TCP/IP-based communication protocol to perform data exchange for remote device in the network. Upon receiving the detector occupancy information as if it would in the field, the controller processes the request based on its internal actuation logic. When the updating for signal controller is completed, the Interface reads the real-time signal phase status (i.e. green, amber, red) and updates the signal phase status in the VISSIM simulation as shown in Figure 3.



(a) Vehicle call synchronization (b) Signal head phase status synchronization

Figure 3 Proof-of-concept (POC) test of CID-free HILS

Since HILS is a real-time system, synchronization mechanism ensuring same operational status between simulation and controller is required for accurate implementation. One-second synchronization interval strikes a good balance for HILS for traffic signal controller: too long of a synchronization interval may suffer from overly generalization, whereas too short of a synchronization interval may impose unnecessary computational burden for the simulation. VISSIM is designed to run as fast as the computational capability of the host computer is available. In ideal case where the communication overhead is zero, which means the communication (e.g., host computer and controller) among all components is immediate, the simulation speed could set to one second with the highest resolution feasible. However, such ideal case merely presents itself. Hence most HILS have to set the simulation speed less than the intended synchronization interval on the hardware by using a synchronization method. In VISSIM, the simulation engine computes the vehicles' movements in approximately 0.5 seconds in case of a simulation interval (i.e., resolution in VISSIM) set to 2. At the end of every computation interval, data exchange between VISSIM and the controller took place to deal with detection and signal head status information. When the signal head status is received and updated in VISSIM, the interface program compares the time used in the current computation interval, if it is less than 1000 milliseconds, the interface program will wait until the system clock reaches 1000 milliseconds before allowing VISSIM conducts next computation. It is necessary to note that the research team has noticed a few cases of synchronization failures. It was also observed that such failures were caused by disruptions network connect, improper (e.g., too high) setting of simulation resolution, host computer internal programmatic conflicts. Measures to address any of the issues could ultimately contribute to the success of conducting CID-free HILS:

- A dedicated local network (e.g., local router) could be used instead of wide area network, in which data traffic is transferred among multiple servers or routers. Significant lagging reduction was observed by switching to local network.
- A dedicated computer with only essential programs for running the simulation program and NTCIP module is desired to reduce potential programmatic conflicts. The less programs running on a host computer, the less competition of computer hardware resource will be.
- Depending on the network geometry and traffic conduction, combined with the applications to be evaluation, fine-tuning the simulation resolution is highly recommended to balance simulation fidelity and HILS feasibility.

In addition, the POC test revealed the potential impact of simulation resolution on vehicle detection in VISSIM. It was discovered that VISSIM COM 6.0 or later versions only recognize a detection instance when a vehicle is on the detector at the moment of simulation update interval. Depending on the combination of network prevailing speed, detector location, and simulation seconds, it could be the case that the vehicle passes through a detector between two consecutive simulation steps. In another word, VISSIM detector is likely to miss a vehicle call when the traveling distance of a vehicle for the simulation interval is greater that the length of the detector. However, this detection issue can be easily resolved by adding an extra detection tracking module within the VISSIM COM Interface program (e.g., adding virtual detector for tracking purpose only, directly tracks the trajectories of approaching vehicles etc.)

POTENTIAL CID-Free HILS APPLICATIONS

This section briefly discusses about potential applications utilizing the proposed CID-free HILS.

Virtual Test bed for Adaptive Signal Control Technologies

According to 2015 Urban Mobility Scorecard, an extra 6.9 billion hours and an extra 3.1 billion gallons of fuel was incurred to urban Americans. Among America's 100 largest metro areas, more cities have experienced increase in traffic congestion from 2013 to 2014(1). Roadways interweaving each other in the urban area are often equipped with traffic control systems whose primary function is minimizing the delay imposed on motorists travelling through signalized intersection. Numerous advanced efforts have been deployed to alleviate the congestion, including Adaptive Signal Control Technologies (ASCTs). Recently, commercial off-the-shelf ASCT solutions, such as SCATS (*27*), SynchroGreen(*28*), InSync(Ref), and Centracs (*29*), have gained increasing attentions in the state-of-the practice.

ASCTs response to the prevailing traffic fluctuations more intelligently by adjusting phase split times, cycle length, and offsets etc. Thus, unlike pre-timed and actuated control systems, it is challenging to evaluate its effectiveness by using either simulation or mathematical approach.

Ideally, the best way to evaluate the effectiveness of ASCTs would be via field deployment and subsequent observation. However, the field test would become very risky and cost-ineffective. Particularly, including numerous advanced features, mistakes caused by ASCT operators during the field evaluation could potentially lead to irreversible conditions such as gridlock and more seriously, traffic incidents. Hence, direct field experimentation with the public motorists is precluded for the trials of various innovative ASCTs for safety, administrative, and infrastructure availability reasons. Furthermore, ASCTs are necessary to enhance the mobility and safety of the signalized roadway. Their implementation should not be hindered because of the availability of experiment data. In that sense, the proposed CID-Free HILS would be suitable for the evaluation of ASCTs. By building a simulation test-bed, the proposed CID-Free HILS is capable of conducting the implementation of ASCTs to collect various performance measures without any risks and substantial costs in the evaluation stage.

Connected Vehicle Applications for Intersection Management

Few field tests of CV technologies have been conducted due to budgetary, administrative, and more importantly safety concerns. Simulations for the evaluations of CV applications in signalized intersection have been reported: e.g., cooperative vehicle intersection control(*30*), intersection control with autonomous vehicle technology (*31*), and optimal intersection movement for cooperative adaptive cruise control (*32*). The majority of those simulations could be improved by testing under the CID-free HILS framework. HILS is a crucial step to advance the research for connected vehicle applications with a greater degree of realism. The potential risk of connecting signal controller in the field without fully knowing its potential integration issues is one of the main deterrent of field tests for many CV technologies. CID-free HILS offers a cost-effective way of detecting potential integration problem, if any.

CONCLUDING REMARKS

In this study, we proposed a CID-free HILS framework using NTCIP protocol via TCP/IP connection. By adopting this framework, it is expected that the feasibility of HILS and the quality of the simulation are elevated. The POC study successfully demonstrated the proposed CID-free HILS framework while potential issues (i.e. communication lagging, high simulation resolution, detector overlook) have been discovered. However, it was also addressed that those issues can be easily resolved by employing the approaches discussed in the previous section.

Furthermore, using the CID-free HILS will enable to advance the development of CV technologies for intersection control with minimal risk and enhanced realism. The future study could focus on employing the advance ASCTs. Since the use of NTCIP and make simulation independent of CID, boarder scope of simulation could be conducted (e.g., signal related mobile application, accessible intersection crossing mobile). In addition, the prototype deployment from realistic HILS to actual field deployment is worthy of study: what additional steps, if any, have to take (e.g., integration with a variety of signal controllers and agency existing signal infrastructures).

Finally, it is worth noting that the proposed CID-free HILS framework is compatible with NTCIP-enabled traffic signal controllers. Thus, several traffic signal controllers in the state-of-the practice would not work properly for the proposed framework. Knowing that the NTCIP is a public open protocol, as long as communications protocols of such non-NTCIP controllers are known, it is certainly available to apply the proposed framework to develop customized CID-free HILS environment.

REFERENCE

1.*What Is Hardware-in-the-Loop Simulation?* MathWorks. http://www.mathworks.com/help/physmod/simscape/ug/what%ADis%ADhardware%ADin%ADthe%ADloop%ADsimulation.html.

2.Hwang, T., J. Roh, K. Park, J. Hwang, K. H. Lee, K. Lee, S. j. Lee, and Y. j. Kim. Development of HILS Systems for Active Brake Control Systems.In *2006 SICE-ICASE International Joint Conference*, 2006. pp. 4404-4408.

3.Montazeri-Gh, M., M. Nasiri, and S. Jafari. Real-time multi-rate HIL simulation platform for evaluation of a jet engine fuel controller. *Simulation Modelling Practice and Theory,* Vol. 19, No. 3, 2011, pp. 996-1006.

4.Al-Hammouri, A. T., L. Nordstr, x00F, M. Chenine, L. Vanfretti, N. Honeth, and R. Leelaruji. Virtualization of synchronized phasor measurement units within real-time simulators for smart grid applications.In *2012 IEEE Power and Energy Society General Meeting*, 2012. pp. 1-7.

5.Johansen, T. A., T. I. Fossen, and B. Vik. Hardware-in-the-loop testing of DP systems.In *Dynamic positioning conference*, Citeseer, 2005.

6.Patel, R. K., and E. J. Seymour. The National Transportation Communication for ITS Protocol (NTCIP) for transportation interoperability.In *Intelligent Transportation System, 1997. ITSC '97., IEEE Conference on*, 1997. pp. 543-548.

7.National Transportation Communications for ITS Protocol-The NTCIP Guide.In, 2009.

8.NTCIP 1202-Objective Definitions for Actuated Traffic Signal Controller (ASC) Units.In, American Association of State Highway and Transportation Officials(AASHTO), Institute of Transportation Engineers (ITE), National Electrical Manufactures Association (NEMA), 1997.

9.Johnson, r., R. Wells;, M. Kyte, D. Bullock, Z. Li, Y. Zhou, J. Richards, J. Fisher, and J. Remus. Controller Interface Device (CID) II.In, National Institute for Advanced Transportation Technology, 2001.

10.Stevanovic, A., A. Abdel-Rahim, M. Zlatkovic, and E. Amin. Microscopic Modeling of Traffic Signal Operations Comparative Evaluation of Hardware-in-the-Loop and Software-in-the-Loop Simulations. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 2128, 2009.

11.*PTV Vissim 8 User Manual*. PTV AG, Karlsruhe, Germany, 2015.

12.Kyte, M. *MOST, A Hands on Approach to Traffic Signal Timing Education.* National Institute for Advanced Transportation Technology. http://www.webpages.uidaho.edu/most/2016.

13.*2070-Lite Fully-Actuated Advanced Traffic Controller Software.* Econolite. https://www.econolite.com/index.php/products/controllers/software/#software2016.

14.Day, C., J. Ernst, T. Brennan Jr, C.-S. Chou, A. Hainen, S. Remias, A. Nichols, B. Griggs, and D. Bullock. Performance measures for adaptive signal control: Case study of system-in-the-loop simulation. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2311, 2012, pp. 1-15.

15.Hardware-in-the-Loop Testbed for Evaluating Connected Vehicle Applications.In, 2016.

16.Bullock, D., and A. Catarella. A real-time simulation environment for evaluating traffic signal systems. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1634, 1998, pp. 130-135.

17.Bullock, D., B. Johnson, R. B. Wells, M. Kyte, and Z. Li. Hardware-in-the-loop simulation. *Transportation Research Part C: Emerging Technologies,* Vol. 12, No. 1, 2004, pp. 73-89.

18.Chen, K. H., C. R. Dow, D. J. Lin, C. W. Yang, and W. C. Chiang. An NTCIP-based Semantic ITS Middleware for Emergency Vehicle Preemption.In *2008 11th International IEEE Conference on Intelligent Transportation Systems*, 2008. pp. 363-368.

19.Klensin, J. *Simple Mail Transfer Protocol*. https://tools.ietf.org/html/rfc5321?u=878041af.

20.Schoenwaelder, J. *Simple Network Management Protocol (SNMP) over IEEE 802 Network*. https://tools.ietf.org/pdf/rfc4789.pdf2016.

21.Ahmed, S. M., A. Abdel-Rahim, and M. Dixon. An external logic processor for NTCIP-based traffic controllers: Proof of concept for data exchange capability.In *2009 12th International IEEE Conference on Intelligent Transportation Systems*, 2009. pp. 1-6.

22.Chaudhary, N. A., H. A. Charara, and S. R. Sunkari. Development of NTCIP-based Portable Traffic Signal Evaluation System.In, Texas A&M Transportation Institute, 2014.

23.NTCIP 1201:2005-Global Object Definitions.In, American Association of State Highway and Transportation Officials(AASHTO), Institute of Transportation Engineers (ITE), National Electrical Manufactures Association (NEMA), 2005.

24.*Library: How to Get MIBs.* American Association of State Highway and Transpotation Officials (AASHTO), Institute of Transportation Engineers (ITE), National Electrical Manufactures Association (NEMA). https://www.ntcip.org/library/MIB/.

25.Gerken, J., and E. BRW. A Practical Approach to Managing Intersection Traffic Data for Large Scale Studies.In *Mid-Continent Transportation Symposium*, 2000.

26.*PTV VISSIM 8 Introduction to the COM API*. PTV Group, Germany.

27.*An Introduction To The New Generation Scats 6*. http://www.scats.com.au/files/an_introduction_to_scats_6.pdf2016.

28.*SynchroGreen Real-time Adaptive Control System.* Trafficware.

29.Centracs Adaptive.In, Econolite.

30.Lee, J., B. Park, K. Malakorn, and J. So. Sustainability assessments of cooperative vehicle intersection control at an urban corridor. *Transportation Research Part C: Emerging Technologies,* Vol. 32, No. 0, 2013, pp. 193-206.

31.Ilgin Guler, S., M. Menendez, and L. Meier. Using connected vehicle technology to improve the efficiency of intersections. *Transportation Research Part C: Emerging Technologies,* Vol. 46, 2014, pp. 121-131.

32.Zohdy, I. H., and H. A. Rakha. Intersection management via vehicle connectivity: The intersection cooperative adaptive cruise control system concept. *Journal of Intelligent Transportation Systems,* Vol. 20, No. 1, 2016, pp. 17-32.