

# **Interdisciplinary, Multi-modal and Partial Reality Experimental System with Instrumented Vehicles and Environment (IMPRESIVE) for Testing Connected and Autonomous Vehicle Applications**

*Position Paper by*

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## **1. Problem Statement and Motivation**

While highway transportation systems provide many indispensable functions to our society, several alarming statistics on road accidents, traffic congestion, fuel consumption and emissions have raised serious concerns over the sustainability of today's highway transportation systems. To address these challenges in next generation transportation systems, several approaches and programs have recently been proposed and launched by various governmental, industrial and academic organizations worldwide. Key among those approaches is the Intelligent Transportation Systems concept, and its latest evolution known as the Connected Vehicle (CV) initiative or more broadly Connected Highway and Vehicle Systems (CHIVES), which envisions a truly Cyber Transportation System (CTS) with wireless communications among vehicles, infrastructure elements and travelers, as well as recent advances in Autonomous Vehicles (AVs) and self-driving cars.

CHIVES and AVs are expected to bring about transformative improvements in the highway transportation system's safety efficiency, and sustainability, and reduce long-term costs. However, like any emerging and future designs, technologies, infrastructures, and applications, CHIVES and AV applications must be validated and evaluated before they can be implemented and deployed. The need for conducting extensive testing of CHIVES and AV applications is especially prominent because: 1) human drivers or travelers will always constitute a major component of the system and as such, human lives are at stake; and 2) the development and deployment of applications will be evolutionary or incremental and accordingly, in the foreseeable future, vehicles will have a varying degrees of connectivity (with respect to V2X communications) and automation (with respect to general autonomous driving capability).

While simulation-based studies are a flexible and economical way to evaluate emerging and future designs, technologies, infrastructures and applications of CHIVES and AVs, they lack fidelity and realism. On the other hand, using multiple vehicles instrumented with yet-to-be-proven technologies on the road will not only be costly in terms of time and money, but also risky and inflexible. In either case, the human element also needs to be accounted for. It is therefore critical to have a versatile tool or platform for hybrid simulation and experimentation involving both Hardware-in-The-Loop (HaTL) and Human-in-the-Loop (HuTL) testing.

In particular, in order to enable research related to road safety, traffic congestion and sustainability in CHIVES and AVs, as well as the interactions between human-drivers and automation, such a testing platform should be capable of *i*) using a high fidelity and realistic driving environment with e.g., vehicles on real roads (as opposed to closed test tracks) as inputs, *ii*) supporting large scale and high density experiments, in terms of the number of vehicles and

the size of the geographical area involved; *iii*) simulating not-yet-available technologies (such as advanced V2X communications and networking protocols and applications), and/or rare events (e.g., an extreme event); and *iv*) providing a safe, HaTL and HuTL environment for studying road-safety related CHIVES designs, technologies and applications and human-automation interactions.

To the best of our knowledge, there currently exists no instrument having the four main capabilities listed above in any governmental, industrial and academic organizations. For example, the US DOT's latest *Naturalistic Driving* experiment conducted under the auspices of the Second Strategic Highway Research Program (SHRP2) initiative [1], which represents the state-of-the-art effort in conducting experiments, can offer the capabilities in *i*) and *ii*) but not in *iii*) or *iv*). This is because the experiment is using today's vehicles and technologies, and *cannot* be used to evaluate emerging or unproven CHIVES and AV technologies, which may expose the drivers to risky or dangerous situations. This is also true of some of the latest USDOT's CV test-beds, such as the Safety Pilot experiment currently taking place in Ann Arbor, Michigan [2], and test-beds in New York, California, Virginia, and Florida [3]. While those tests are designed to evaluate the feasibility of wireless V2V and V2I communications, and for evaluating basic CHIVES applications, they are costly and, because they once again cannot expose drivers to undue risks, are limited to testing proven technologies that can be implemented today. In other words, they cannot be used to *safely* and *economically* test *new*, *emerging* and *unproven* designs and technologies. Finally, to date, we have not yet seen large-scale field tests of AVs and their interactions with regular traffic.

## **2. Proposed Solution Approach**

To satisfy the aforementioned functional requirements, this paper is proposing an integrated 7-in-1 platform called IMPRESSIVE (stands for *Interdisciplinary, Multi-modal and Partial Reality Experimental System with Instrumented Vehicles and Environment*) for the validation, evaluation and optimization of CHIVES and AV applications. IMPRESSIVE integrates the following seven main elements into one first-of-its-kind research, development, testing and evaluation (RDT&E) platform:

- (1) A commercial traffic simulator (TS) with virtual yet fairly realistic traffic models and roads/signals to provide background traffic and driving environments;
- (2) One or more high-fidelity driving simulators (DS) for human-in-the-loop (HuTL) studies, each of which is "shadowed" by a TS-generated vehicle (or TSV). In other words, the movement of the TSV, hereafter referred as a Proxy-DS vehicle (Proxy-DSV), is controlled by the human driver of the DS;
- (3) A network (communications) simulator (NS) to study wireless transmissions of various Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) or in general V2X messages generated by a given CHIVES applications. NS obtains information on e.g. the vehicle mobility and communication infrastructure from the TS and outputs V2X messages to the TS and DS among others;
- (4) Vehicle dynamics models (VDM) for simulating more realistic movement of the TSVs (as well as the DS in case it doesn't already have a comparable VDM), and for interacting with hardware-in-the-loop (HaTL) equipment;
- (5) Hardware-in-the-loop (HaTL) apparatus such as a dSPACE MicroAutoBox II running the CHIVES/AV application logic (hereafter referred to as the CHIVES/AV box) and on-

board equipment or units (OBE/OBUs) for DSRC/cellular communications, which are connected to the DSs and TSVs for HaTL simulations;

- (6) Instrumented vehicles (IVs) with GPS, sensors and other OBEs/OBUs for communications, and optionally equipped with the CHIVES application. Such an IV will also be “shadowed” by a TSV in the TS, hereafter referred to as Proxy-IV (Proxy-IV); and
- (7) Instrumented environment (IE), which includes roads, traffic signs/signals and roadside equipment or units (RSE/RSUs). The IE will be modeled using the TS and NS to create a virtual driving environment for the Proxy-DSV and TSVs.

### ***3. Advantages of the Proposed Solution Approach***

IMPRESSIVE will provide significant new capabilities that are not available from any products on the market or in any academic, industrial or government-based R&D laboratory. More specifically, in addition to supporting hybrid simulation and experimentation, MR.CHIVES, as a platform for conducting testing, has the following desirable features:

- Low-cost yet Powerful/Flexible: IMPRESSIVE can answer many “what-if” questions without requiring a large number of costly IVs or reconfigurable IEs. Thanks to the integrated traffic, driving, and network simulators (TS/DS/TS), IMPRESSIVE can test various scenarios related to infrastructure systems that are still to be developed, and emerging, next-generation designs, technologies and CHIVES and AV applications, as well as rare events (such as accidents or inclement weather).
- Safe yet Realistic: By bringing hardware apparatus and real-world views captured by IVs and IE into the virtual world created by the integrated simulators, IMPRESSIVE provide a safe and yet realistic testing environment to conduct large-scale experiments.
- HaTL and HuTL: In IMPRESSIVE, at least one DS, and possibly additional TSVs and IVs, will be connected with the CHIVES/AV box. In addition, a human driver of the DS is involved.
- CHIVES-ready: Thanks to the integrated NS, all the TSVs including Proxy-DSV and Proxy-IVs are capable of V2X communications, and, as a result, the “cooperative” aspect of CHIVES or AV applications can be tested.
- Capable of CHIVES and AV environmental applications: IMPRESSIVE will integrate the TS with microscopic emissions models to allow for evaluating CHIVES and AV applications aimed at improving environmental sustainability.

### **REFERENCES**

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