IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Dynamic Vehicle to Infrastructure TCIP Communications Laboratory Proof of Concept

Final Report for
Transit IDEA Project 89

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October 2019

TRANSPORTATION RESEARCH BOARD
The National Academies of
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- The NCHRP IDEA Program, which focuses on advances in the design, construction, and maintenance of highway systems, is funded by American Association of State Highway and Transportation Officials (AASHTO) as part of the National Cooperative Highway Research Program (NCHRP).
- The Rail Safety IDEA Program currently focuses on innovative approaches for improving railroad safety or performance. The program is currently funded by the Federal Railroad Administration (FRA). The program was previously jointly funded by the Federal Motor Carrier Safety Administration (FMCSA) and the FRA.
- The Transit IDEA Program, which supports development and testing of innovative concepts and methods for advancing transit practice, is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP).

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Washington, DC 20001

Dynamic Vehicle to Infrastructure

TCIP Communications

Laboratory Proof of Concept

IDEA Program Stage 1 Final Report

For the period *April/2018* through *October/2019*

Transit IDEA 89

Prepared for the IDEA Program

Transportation Research Board

National Research Council

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October 31, 2019

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1 IDEA PRODUCT:

Transit agencies in the US use four primary communications mechanisms to dispatch, monitor and manage the operations of their mobile assets: private radio systems, Wi-Fi communications, cellular communications, and track circuits and signaling. Most data communications in the transit industry today are still based on vendor proprietary communications protocols and messaging. This limits agency choices when procuring new systems and often leads to agencies experiencing vendor lock-in where an incumbent vendor has significant control over the agency's ability to procure new systems. Transit Communications Interface Profiles (TCIP) has been used to standardize communications in several agencies and in each case TCIP-based communications have been successful in meeting project requirements.

This project, Dynamic Vehicle to Infrastructure (DV2I) will bring together the capabilities of two long-running industry and government initiatives to bring benefits to the transportation industry: Dedicated Short-Range Communications (DSRC) and TCIP. Upon completion, this project will integrate TCIP messaging over DSRC and cellular communications with the ability to switch between the two communication mechanisms.

DSRC is a standard for short range data communications between vehicles (V2V) and between vehicles and the roadside infrastructure (V2I). DSRC has been under development by the United States Department of Transportation (USDOT) since the1990s. In 1999 the FCC allocated 75MHz of spectrum for DSRC in the 5.9GHz band. The allocation was adjusted in 2004 and 2006 and was 'refreshed' in 2016. Numerous field tests have been conducted with DSRC, but most have involved passenger cars.

TCIP is an American Public Transportation Association (APTA) standard that defines standard, tailorable mechanisms for exchanging information among transit components and business systems in the areas of Onboard Systems, Control Center {Vehicle/Center Communications}, Fare Collection, Scheduling, Transit Signal Priority, Geographical Information, Common Public Transport, Passenger Information, Demand Response Service {Paratransit}, Light Rail Operations, and Incident Management. An early version of the TCIP standard was developed by the National Transportation Communications for ITS Protocol (NTCIP) Consortium of the Association of State Highway Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and the National Electrical Manufacturers Association (NEMA). At the request of the Federal Transit Administration (FTA), APTA assumed the responsibility for the continued development of the standard and issued the first official version of TCIP (Version3.0) in 2006. TCIP has undergone a number of updates over the past several years with the current version being 5.1.0.

A number of prior research efforts have been conducted using DSRC and TCIP with several TCIP installations used in production throughout the US and Canada including Washington DC, New York, Montreal, and Petersburg.

2 CONCEPT AND INNOVATION:

Prior to this program, DSRC has undergone very little testing and development in the transit space. DV2I is innovative because it combines two standards that have been developed independently within the ITS program. It implements dynamic switching between DSRC and cellular to obtain the advantages of both. It combines high bandwidth, no marginal usage cost of DSRC with near continuous coverage cellular communications. With DSRC, DV2I provides continued communication with no overloads from public usage, such as those that occur on cellular networks during incidents such as natural disasters or large-scale emergencies. DV2I also provides consistent message payloads across both media with TCIP. aE has extended the communications media to enable to switching to WiFi as well.

During the course of this investigation, aE will perform the first demonstration of TCIP communications over DSRC, the first use of DSRC with transit operating data, and a demonstration of real-time Dynamic V2I media switching in aE's prototype system lab.

The successful integration of DSRC, WiFi, and cellular communications to transmit TCIP data will open the door to a number of benefits to transit agencies in future production projects including:

- Availability of en-route high-capacity communications with transit vehicles with a cost-effective means to update schedules and GIS information.
- Reduction of cellular costs and dependency by rerouting cellular traffic over DSRC where it is available.
- Improvement of tracking and monitoring system performance in agencies with private radio systems by sending large messages over DSRC rather than over private radio systems.
- Reduction of cellular dependence during major incidents by allowing intermittent communications with en route vehicles, even if cellular communications are unavailable.
- Availability of cost effective high-capacity communications.

- Improvement of tracking and monitoring system performance.
- Transit keeping pace with other future road vehicles that will be delivered with DSRC as standard equipment.

3 INVESTIGATION: Stage I - Laboratory Integration and Laboratory Testing

3.1 Laboratory Development

aE completed a variety of activities during the process of developing a laboratory environment for testing DV2I. aE finalized the list of equipment for the laboratory from the initial list given in the project proposal. Next, aE purchased, and upon receipt, performed incoming inspection on all equipment, including the onboard and roadside DSRC radios, computer equipment, racks and cabling, and the VPN server. aE then finalized the lab test configuration details and assembled components into laboratory test configuration and devised the mechanism to enable/disable DSRC connection to simulate the effects of vehicles entering and departing the range of DSRC roadside devices. All laboratory computers were configured and back-office communications were setup. Cellular modems were then configured and cellular service was initiated. Figure 1 shows the test lab with the DSRC radios on top of the half rack.

aE also obtained the experimental Federal Communications Commission (FCC) license required to broadcast within the DSRC spectrum. The initial license was effective through April 1, 2019. aE has recently renewed this license through to April 1, 2022 as part of the commitment to continued enhancement of DV2I features and to developing DV2I into a saleable product.

FIGURE 1: Laboratory Test Equipment and Lab

3.2 Software Development

aE has developed a significant amount of software for DV2I with a 105-page requirements document that describes the operation of the system. In the requirements document the system name is "TCIP over DSRC" or ToD. The requirements document describes the DV2I {ToD} system and specifies all the predefined messages, definitions of handoffs between mechanisms, and the architecture of the system. In accordance with the requirements document aE generated eighty-six test cases. Of those, three fall into the "Environment" category, two are in "Acceptance", and eighty-one are "Functional" test cases. Of those, twenty are "positive" message validation and ten are "negative" message validation. Among the remaining test cases, thirty-seven are "positive" tests and nineteen are "negative" tests.

aE created three new applications for DV2I: BaseStation, Onboard Gateway, and Fixed Gateway. These applications were developed using the existing aEServices platform. aE then developed an endpoint simulator to test the communications between the BaseStation, Onboard Gateway, and the Fixed Gateway. Software testing began with simple functions and included significant debugging efforts that required detailed analysis of the transmission of messages to/from the onboard system to the base station, the fixed gateway, and the back office through the DSRC radios. aE then integrated the existing TCIP-based transit management products with DSRC communications using its library that implements the entire TCIP message suite, transit applications for dispatching, vehicle tracking, and passenger information. Figure 2 shows the system configuration.

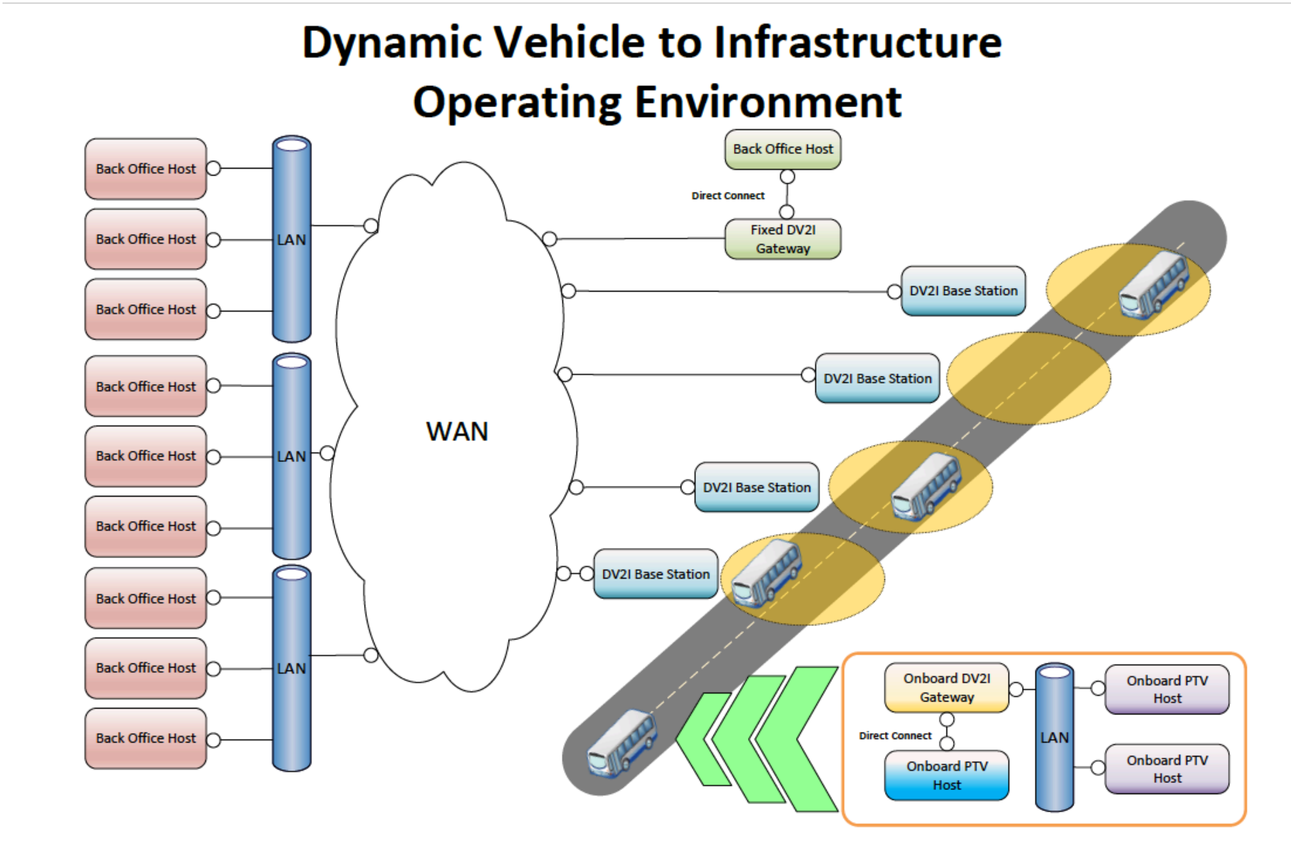

FIGURE 2: System Configuration

3.3 Laboratory Test and Integration

aE developed a laboratory test plan, test scenarios, and test cases for performing functional and performance testing of the DV2I system in the DV2I laboratory. The test cases validate that the system operates according to the DV2I requirements. Using a defect tracking software system and a defined defect process to ensure the quality of the software developed, aE is currently correcting defects that have been uncovered to ensure the system is ready for future field testing.

Early in the integration process, the DSRC radios from UNEX worked well for transmitting simple messages. Shortly after this initial integration mode, aE had moved to a new location. The DV2I lab was disassembled, moved, and reinstalled in the new office several weeks later. At this point, testers found that the connection that had worked previously, no longer worked. Approximately three weeks of testing and troubleshooting, it was determined that the UNEX DSRC radios no longer operated as described in the documentation provided by UNEX. After several weeks of local debugging, the system integrator contacted UNEX, the DSCR radio vendor, to continue the debugging effort and the problem was determined to be a vendor change to the DSRC firmware. The new firmware required changes to the DV2I software which were made to complete the first phase of testing. During this time, aE procured a second onboard and base radio pair from an alternate vendor in the event that the firmware and software changes did not work. This also gives aE a second source of hardware for use with future customers while ensuring compatibility. In order to maintain the schedule, aE interviewed candidates to increase the testing staff and considered the option of rescheduling other projects. After discussions with the NAS program manager, aE applied for and received a no cost extension for the project.

Functional end-to-end testing began in late March 2019 and has continued through the end of August 2019. In the DV2I system, an end-to-end test send a message from the back-office host through the Fixed Gateway, the Base Station, the Onboard Gateway, to the onboard host (see FIGURE 2). For end-to-end testing, a ToDCFSOM (ToD Fixed Central Application to Fixed Gateway Send Outbound Message) message to the onboard host is sent. Upon receipt by the Onboard Host, a ToDFCMAK (ToD Fixed Gateway to Central Application Message Acknowledgement) message is sent to the central application host. Formal testing for three different communication media are detailed in FIGURE 3 below. End-to-end testing was completely successful for both DSRC and WiFi. Initially in end-to-end testing where a drop of cellular communications was simulated, there were instances where the office sim, which simulates the back-office host, was not always receiving the message acknowledgement message (ToDFCMAK) for each outbound message (ToDCFSOM) it sends. However, the fixed gateway is receiving the acknowledgement message for every outbound message. The cause of the message drop was investigated.

Network issues were also a source of difficulty. The Onboard Gateway was not able to maintain a VPN connection while the Onboard Gateway was connected to other networks such as DSRC radio, the onboard network (Ethernet), and WiFi. It was discovered that the observed behavior was caused by standard Windows operating system behavior. This was part of the Windows cyber security features. It prevented the assignment of default gateways to each of the network adaptors. aE brought in outside consultant for assistance with network to determine how to have DV2I communicate through a chosen media without compromising network security. This involved changes to network diagram and IP address schema. The configuration was implemented in a test machine and function verified. Software code was developed code to allow control of the selection of the network adaptor to be used for outbound traffic. Code was also developed for .Net memory management of buffers used for communications with .Net sockets. In regard to the WiFi network, changes to network diagram and IP address schema led to a problem with the onboard gateway. It was not able to communicate with the devices inside the enterprise network (DataServer, Officesim, etc.). A minor change in the network topology fixed the communication issue. Once these issues were resolved, functional testing could continue. The results of functional testing are tabulated in FIGURE 3 below.

The final functional test involving cell going in and out of coverage failed to produce the expected results. Starting in a disabled state, enabling the cell modem after sending 1 message over the cell network resulted in a failure of communication between the Onboard Gateway and the Fixed Gateway and a replication of messages within the Onboard Gateway itself. In this test, ten messages were sent by the Onboard Sim, none of which were received nor acknowledged by the Office Sim.

Test Case Number	Description	Result	Date
TC-98	Valid ToDCFSOM: End to End - WiFi Only	Passed	8/6/19 11:14 AM
TC-99	Valid ToDCFSOM: End to End - Cell Only	Passed	8/28/19 1:32 PM
TC-100	Valid ToDCFSOM: End to End - Secondary Handling (DSRC to Cell)	Passed	10/8/19 1:44 PM
TC-101	Valid ToDCFSOM: End to End - Secondary Handling (Cell to DSRC)	Passed	8/6/19 11:45 AM
TC-102	Valid ToDCFSOM: End to end - Secondary Handling (WiFi to DSRC)	Passed	8/6/19 12:52 PM
TC-103	Valid ToDCFSOM: End to end - Secondary Handling (WiFi to Cell)	Passed	10/8/19 2:41 PM
TC-116	Valid ToDCFSOM: End to end - Going Into Coverage (WiFi Only)	Passed	8/6/19 1:42 PM
TC-117	Valid ToDCFSOM: End to end - Going Into Coverage (Cell Only)	Passed	10/11/19 10:47 AM
TC-118	Valid ToDCFSOM: End to end - Going Into Coverage (DSRC Only)	Passed	8/7/19 2:41 PM

Test Case Number	Description	Result	Date
TC-119	Valid ToDCFSOM: End to end - Secondary Handling (Cell to WiFi)	Passed	8/6/19 12:36 PM
TC-120	Valid ToDCFSOM: End to end - Secondary Handling (DSRC to WiFi)	Passed	8/8/19 10:05 AM
TC-104	Valid ToDVOSIM: End to end - DSRC Only	Passed	8/15/19 11:50 AM
TC-105	Valid ToDVOSIM: End to end - WiFi Only	Passed	8/13/19 4:10 PM
TC-113	Valid ToDVOSIM: End to end - Going Into Coverage (WiFi Only)	Passed	8/15/19 12:12 PM
TC-106	Valid ToDVOSIM: End to end - Cell Only	Passed	8/27/19 12:26 PM
TC-108	Valid ToDVOSIM: End to end - Secondary Handling (DSRC to Cell)	Passed	8/27/19 1:11 PM
TC-115	Valid ToDVOSIM: End to end - Going Into Coverage (Cell Only)	Failed	10/25/19 3:47 PM
TC-109	Valid ToDVOSIM: End to end - Secondary Handling (WiFi to DSRC)	Passed	8/19/19 12:07 PM

Test Case Number	Description	Result	Date
TC-111	Valid ToDVOSIM: End to end - Secondary Handling (Cell to DSRC)	Passed	8/19/19 12:47 PM
TC-112	Valid ToDVOSIM: End to end - Secondary Handling (Cell to WiFi)	Passed	8/19/19 4:03 PM
TC-114	Valid ToDVOSIM: End to end - Going Into Coverage (DSRC Only)	Passed	8/20/19 3:29 PM
TC-110	Valid ToDVOSIM: End to end - Secondary Handling (WiFi to Cell)	Passed	8/27/19 2:15 PM
TC-121	Stress Test - Inbound - DSRC	Passed	10/28/19 10:33 AM
TC-122	Stress Test - Inbound - WiFi	Passed	10/28/19 10:33 AM
TC-123	Stress Test - Inbound - Cell	Passed	10/28/19 10:33 AM
TC-124	Stress Test - Inbound - Multi-Medium	Passed	10/28/19 10:33 AM
TC-125	Stress Test - Outbound - DSRC	Passed	10/28/19 10:34 AM

Test Case Number	Description	Result	Date
TC-126	Stress Test - Outbound - WiFi	Passed	10/28/19 10:34 AM
TC-127	Stress Test - Outbound - Cell	Passed	10/28/19 10:34 AM
TC-128	Stress Test - Outbound - Multi-Medium	Passed	10/28/19 10:34 AM
TC-129	Stress Test - Bidirectional - DSRC	Passed	10/28/19 10:34 AM
TC-130	Stress Test - Bidirectional - WiFi	Passed	10/28/19 10:34 AM
TC-131	Stress Test - Bidirectional - Cell	Passed	10/28/19 10:34 AM
TC-132	Stress Test - Bidirectional - Multi-Medium	Passed	10/28/19 10:34 AM
TC-133	Soak Test - 24 Hours - Bidirectional - All Mediums	Passed	10/28/19 10:34 AM

FIGURE 3: DV2I Functional Tests

3.4 Project Progress and Spending

FIGURE 4 shows the project status with list of tasks. Obtaining the No-Cost Extension for four months has allowed aE time to complete laboratory testing of the DV2I system. As indicated in Figure 5, labor spending is somewhat ahead for this project due to the additional debugging and testing required by difficulties detailed in section 3.3. aE performed a financial analysis when the No-Cost Extension was granted and determined that there were sufficient internal funds to cover the cost overages for completing the data collection and the final report**.**

Reports	Tasks to be completed	Status	Due Dates
1st quarterly report	Procure Required Equipment Setup Laboratory Test Equipment	Completed	6/30/18
2nd quarterly report	Software Development Obtain FCC License	Completed	9/30/18
Stage 1 report	Stage 1 report	Completed	4/30/19
3rd quarterly report	Data Collection	Completed	7/31/19
Draft Final Report	Draft Final Report	Completed	8/31/19
Final Report	Final Report	Completed	10/31/19

FIGURE 4: DV2I Project Status

Category	Expense Total
aE planned contribution - labor	$99,725.00
NAS planned contribution - labor	$88,662.00
Actual aE spending to date - labor	$192,539.58
Labor % Spent	102%

FIGURE 5: Project Spending

3.5 STAGE II: Laboratory Data Collection and Final Report

aE has been operating the system in the laboratory and collecting data on its performance and behavior. The testing to date has included preliminary soak tests to determine the efficacy of configuration adjustments and software fixes. At completion, the system has been running over a period of approximately two months. Performance testing began with stress testing. During the dry runs for stress testing of the message handling capabilities of DV2I, it became apparent that there was performance degradation at send rates below the initially predicted range of 25 to 200 messages per second. It was determined through a series of tests on each communication method that the successful message send rates ranged between 0.25 and 8.0 messages per second. This testing determined that there was substantial drop-off of sent messages reaching their destination as well as message acknowledgments returning to the sender at send rates of 4 messages per second for Cell and Wi-Fi, and 1 message per second for DSRC. As such, testing the system at the rates previously planned would not only have been unsuccessful, but inconsequential for finding the limits of the message handling capabilities of DV2I in its current state. Instead, formal stress testing was conducted at various send rates between 1.0 and 4.0 messages per second for Cell and Wi-Fi, and between 0.25 and 1.0 messages per second for DSRC. Combinations of these were used for stress tests involving multi-medium sending. It should be noted that acknowledgement rates in the results table consisting of values above 100% are a result of multi-modal acknowledgement redundancy utilized by DSRC and Wi-Fi mediums under certain circumstances. Furthermore, receival rates over 100% are a result of a bug occasionally causing message duplication within the Onboard Gateway. It was also discovered that the system reached its message sending capacity in approximately ten minutes or less. So rather than stress testing the system for each message rate for four hours, it was determined that running each stress test for fifteen minutes was sufficient to determine whether the system had reached its maximum message rate.

Stress testing consisted of running the system at a set number of messages per second with messages split across all media types and for each media type individually in fifteen-minute blocks (FIGURE 6). Wireshark was used at the beginning of each stress test to ensure that the messages reached their intended destination along the intended path. The system limit was said to have been reached if the CPU of one of the devices in the message path reaches 100% or the number of messages per second received at the intended destination is lower than the number set for the test.

Following stress testing, a soak test was run for twenty-four hours across all media. The soak test was run at message rates of two messages per second for WiFi and Cell and 0.5 messages per second for DSRC, which is half of the system's message rate for each communication media as determined during dry run testing. Hardware and software configurations for all devices in the system under test were recorded and kept as part of the record for the tests. Results for the soak test are listed in FIGURE 6 below.

Type	Description	Message Rate (Messages/Second)	Messages Sent	Messages Received	Acknowledgements Received	Receival Rate (%)	Acknowledgement Rate (%)
Stress	Inbound - DSRC	0.25	225	216	431	96%	192%
Stress	Inbound - DSRC	0.50	450	380	759	84%	169%
Stress	Inbound - DSRC	0.75	675	654	1286	97%	191%
Stress	Inbound - DSRC	1.00	900	891	1647	99%	183%
Stress	Inbound - WiFi	1.00	900	901	902	100%	100%
Stress	Inbound - WiFi	2.00	1800	1790	1790	99%	99%
Stress	Inbound - WiFi	3.00	2700	2635	2591	98%	96%
Stress	Inbound - WiFi	4.00	3600	3430	3338	95%	93%
Stress	Inbound - Cell	1.00	900	900	900	100%	100%
Stress	Inbound - Cell	2.00	1800	1802	1802	100%	100%
Stress	Inbound - Cell	3.00	2700	2758	2650	102%	98%
Stress	Inbound - Cell	4.00	3600	3749	3363	104%	93%
Stress	Inbound - All Mediums	0.25 (DSRC) 1.00 (Cell and WiFi)	2025	1984	2219	98%	110%
Stress	Inbound - All Mediums	0.5 (DSRC) 2.00 (Cell and WiFi)	4050	3861	3934	95%	97%
Stress	Inbound - All Mediums	0.75 (DSRC) 3.00 (Cell and WiFi)	6075	5966	5389	98%	89%
Stress	Inbound - All Mediums	1.00 (DSRC) 4.00 (Cell and WiFi)	8100	7882	6383	97%	79%
Stress	Outbound - DSRC	0.25	225	224	436	100%	194%
Stress	Outbound - DSRC	0.50	450	349	438	78%	97%
Stress	Outbound - DSRC	0.75	675	297	307	44%	45%
Stress	Outbound - DSRC	1.00	900	331	359	37%	40%
Stress	Outbound - WiFi	1.00	900	1116	1809	124%	201%
Stress	Outbound - WiFi	2.00	1800	1799	3085	100%	171%
Stress	Outbound - WiFi	3.00	2700	2698	2905	100%	108%
Stress	Outbound - WiFi	4.00	3600	3580	3311	99%	92%
Stress	Outbound - Cell	1.00	900	928	1993	103%	221%
Stress	Outbound - Cell	2.00	1800	1800	3429	100%	191%
Stress	Outbound - Cell	3.00	2700	2695	3576	100%	132%
Stress	Outbound - Cell	4.00	3600	3573	3670	99%	102%
Stress	Outbound - All Mediums	0.25 (DSRC) 1.00 (Cell and WiFi)	2025	2027	3153	100%	156%
Stress	Outbound - All Mediums	0.5 (DSRC) 2.00 (Cell and WiFi)	4050	4121	3249	102%	80%
Stress	Outbound - All Mediums	0.75 (DSRC) 3.00 (Cell and WiFi)	6075	5422	3495	89%	58%
Stress	Outbound - All Mediums	1.00 (DSRC) 4.00 (Cell and WiFi)	8100	6709	3494	83%	43%
Stress	Bidirectional - DSRC	0.25	450	451	884	100%	196%
Stress	Bidirectional - DSRC	0.50	900	594	703	66%	78%
Stress	Bidirectional - DSRC	0.75	1350	784	836	58%	62%
Stress	Bidirectional - DSRC	1.00	1800	968	1025	54%	57%
Stress	Bidirectional - WiFi	1.00	1800	1785	2568	99%	143%
Stress	Bidirectional - WiFi	2.00	3600	3544	4820	98%	134%
Stress	Bidirectional - WiFi	3.00	5400	5161	5347	96%	99%
Stress	Bidirectional - WiFi	4.00	7200	6922	6572	96%	91%
Stress	Bidirectional - Cell	1.00	1800	1814	2847	101%	158%
Stress	Bidirectional - Cell	2.00	3600	3637	4652	101%	129%
Stress	Bidirectional - Cell	3.00	5400	5461	5650	101%	105%
Stress	Bidirectional - Cell	4.00	7200	7588	6957	105%	97%
Stress	Bidirectional - All Mediums	0.25 (DSRC) 1.00 (Cell and WiFi)	4050	4039	5249	100%	130%
Stress	Bidirectional - All Mediums	0.5 (DSRC) 2.00 (Cell and WiFi)	8100	7902	7048	98%	87%
Stress	Bidirectional - All Mediums	0.75 (DSRC) 3.00 (Cell and WiFi)	12150	11097	8698	91%	72%
Stress	Bidirectional - All Mediums	1.00 (DSRC) 4.00 (Cell and WiFi)	16200	13986	8984	86%	55%
Soak	Bidirectional - All Mediums 24 Hours	0.50 (DSRC) 2.00 (Cell and WiFi)	777600	746995	688584	96%	89%

FIGURE 6: Stress Tests

4 PLANS FOR IMPLEMENTATION

After reviewing the results of stress and soak testing, it was determined that while the system is functional, the system is not running at a desirable message rate. As such, it is believed that additional system optimization would be required, followed by additional testing in a laboratory setting. Once the system is optimized, local field tests can be run in the vicinity of the aE office. One of the existing DSRC radio inside the office would continue to be configured as a fixed base station alongside a cell modem and WiFi. The DSRC radio configured as a mobile radio would be installed in a vehicle along with a cell modem, and WiFi. A comprehensive test suite would then be run for the local field test. The test suite would include all of the tests that were run in the laboratory tests. Any issues found would be corrected and further tests would be developed before the next phase begins.

Once the local field tests are successfully completed, aE could partner with a transit agency for a pilot installation and test of the system. aE has a business developer part-time to seek out these potential partners for the pilot program. This portion of the project would demonstrate the viability of using DSRC to convey standardized TCIP information between control centers and en-route vehicles. DSRC would be installed at multiple stations and on the transit agencies' back-office system. Vehicles passing or stopping at the stations communicate with the office systems via DSRC roadside units installed at those locations. Since DSRC would not be available along the vehicle's entire route, cellular communications would be used to 'fill in' communications at other locations. This system could provide transit agencies with a vendor independent solution for low cost data transmission.

As developed, DV2I implements a message system that can wrap non-TCIP messages so that they can be sent through the DV2I system. This permits the DV2I system to be integrated with existing systems owned by transit agencies.

5 CONCLUSIONS

With the completion of function, stress and soak testing, aE has determined that there are some technical items that need to be addressed for the DV2I system to become a viable commercial product. The first is to optimize the message transmission rates across all media. The DSRC message rate is particularly slow through the system. It may be that the radios used have a firmware problem similar to the issue encountered earlier in this study. Additionally, there are some enhancements that have been proposed by the aE test team during the course of this study. During formal stress testing, there were repeated manual inputs of destination addresses and communication methods, as well as other message details repeatedly used during testing in the sender form. To alleviate this, the team indicated the need for a premade message list that could be selected to autofill message details. This would be especially helpful in further testing of the system, as it would minimize manual input, reduce the time needed to setup each test, reduce the potential for input errors, and aid in the repeatability of the tests. Another helpful feature would be additional columns on the sender list which show the medium(s) which that sender is using. This would help differentiate senders which use the same send rate and message quantity, but different mediums.

Overall, the DV2I system functions as intended, but at a lower than expected throughput. With additional investigation and field testing, the system has the potential for becoming a viable commercial product.