Tech Brief: J1939 Network Testing

The goal of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce the large truck fatality rate by 41 percent from 1996 to 2008. This reduction translates into a rate of 1.65 fatalities in truck crashes per 100 million miles of truck travel.

The Office of Bus and Truck Standards and Operations, which produced this Tech Brief, develops and promotes national motor carrier safety program goals, priorities, and initiatives. It provides technical expertise and advice in the development and deployment of motor carrier safety programs, including the development of regulations. The Office determines national motor carrier safety operational program requirements, standards, and procedures for vehicle and roadside operations, driver and carrier operations, and physical qualifications of truck and bus drivers.

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J1939 Network Testing

Project Funding

Under the provisions of Section 5117 of the Transportation Equity Act for the 21st Century of 1998 (TEA-21), Congress authorized the U.S. Department of Transportation (USDOT) to:

> "… conduct research on the deployment of a system of advanced sensors and signal processors in trucks and tractor trailers to determine axle and wheel alignment, monitor collision alarm, check tire pressure and tire balance conditions, measure and detect load distribution in the vehicle, and adjust automatic braking systems."

As a result of a comprehensive technology scan, as well as numerous interviews with key industry stakeholders such as truck manufacturers, fleet operators, suppliers, and regulators, a variety of research areas were identified including the design, functionality, and performance of the Society of Automotive Engineers (SAE) J1939 network for commercial vehicle applications.

Background

The SAE J1939 is a worldwide serial data bus communication standard for truck, bus, off-road, construction, and marine vehicle applications. The J1939 communication standard is a control and information data bus that supports critical safety-related systems and subsystems on heavy-duty tractors, trucks, converter dollies, and trailers. Safety-critical systems currently in production that utilize (or have the potential to utilize) the J1939 network include engines, transmissions, drive slip control (subset of antilock brake systems), collision avoidance, and lane guidance systems. Since the J1939 network represents an advanced high-speed network, the number of subsystems utilizing this network, both safety-critical (as related to fundamental vehicle systems and controls in the context of this study) and non-critical systems, will likely continue to increase on future commercial vehicles.

One of the most important potential applications of the J1939 data bus will be the next generation of brake systems, known generically as electronically controlled brake systems (ECBS). ECBS will employ the J1939 data bus to control the tractor and trailer brakes. The greatest safety improvements, gained through reductions in stopping distance and improved vehicle control, will be on combination vehicles that employ ECBS on both the tractor and the trailer. Currently, the tractor modulates the trailer's brake system through pneumatic control (compressed air). However, some U.S. fleets run double and triple trailers. These double and triple trailer applications are prone to greater problems (i.e., brake and vehicle control issues and/or brake wear problems) because of a brake imbalance between the tractor and the trailer(s). The brake control and wear problems can almost be eliminated by ECBS. In addition, roll stability control systems and electronic stability control systems (ESC) that are currently available can improve the stability of tractor-trailer combinations, using different levels of brake application at individual wheels. These electronic ESC systems depend on reliable high-speed signal communication that the J1939 network provides.

Motor carrier industry stakeholders, such as the brake system suppliers, tractor and trailer original equipment manufacturers (OEMs), and the Federal government, have been working together to facilitate ECBS products for the heavy-duty trucking industry. The challenge the industry faces, however, is in minimizing the potential risks associated with the coexistence of both critical and non-critical systems on the same data bus. Therefore, the J1939 network must be carefully tested to ensure that the "coexistence" does not undermine or compromise major vehicle systems such as brake controls. A second challenge is to ensure the long-term signal communications integrity of a system whose hardware components are subjected to the challenges of the physical environment (e.g., moisture, oil, dirt, road salt). The capacity of the network to accommodate additional devices that increase the network loading is also a concern.

For this study, a laboratory simulation of a commercial motor vehicle (CMV) J1939 network was tested and evaluated under a variety of conditions designed to "stress" the network. Testing and evaluation consisted of applying test loads designed to create high network load levels while simulating safety-critical actions, failed components in the network, and a weakened physical network. The performance of the data bus, defined by the integrity, accuracy, and speed of communications signals, was monitored during various physical fault conditions, network loadings, and injected noise levels. The tests also determined the effect of the physical condition of the network, such as cable type and length, on the performance of the network.

The results of this study can be used to contribute significantly to improving the safety- and performance-oriented state-of-the-practice for CMV signal communications. They provide quantitative information concerning the validity of the current design philosophy that combines safety-critical and non-safety-critical data communications devices and paths. They also provide a quantitative measure of the network's capacity to accommodate additional safety-critical networked devices. Additionally, they provide quantitative information to designers and manufacturers of the components, connectors, and systems to improve their physical and operational integrity for better safe performance and economy of operation.

Overview of Project Approach

Work on this project consisted of the following subtasks:

- Collect information on the hardware and software requirements to support J1939-related system functionality from the commercial vehicle user, CMV OEM, equipment suppliers, and component manufacturer communities engaged in equipment and component design and integration

- Conduct a comprehensive literature search and review of documents published by public, quasi-public (e.g., associations, committees, coalitions, institutes, etc.), and private companies that have conducted J1939-related research and development

- Compile a comprehensive test matrix and test plan based on industry, public, and Federal agency input

- Identify specific features and capabilities available and incorporated in commercially available electronic control units (ECUs)

- Construct a hardware-in-the-loop (HIL) J1939 simulator

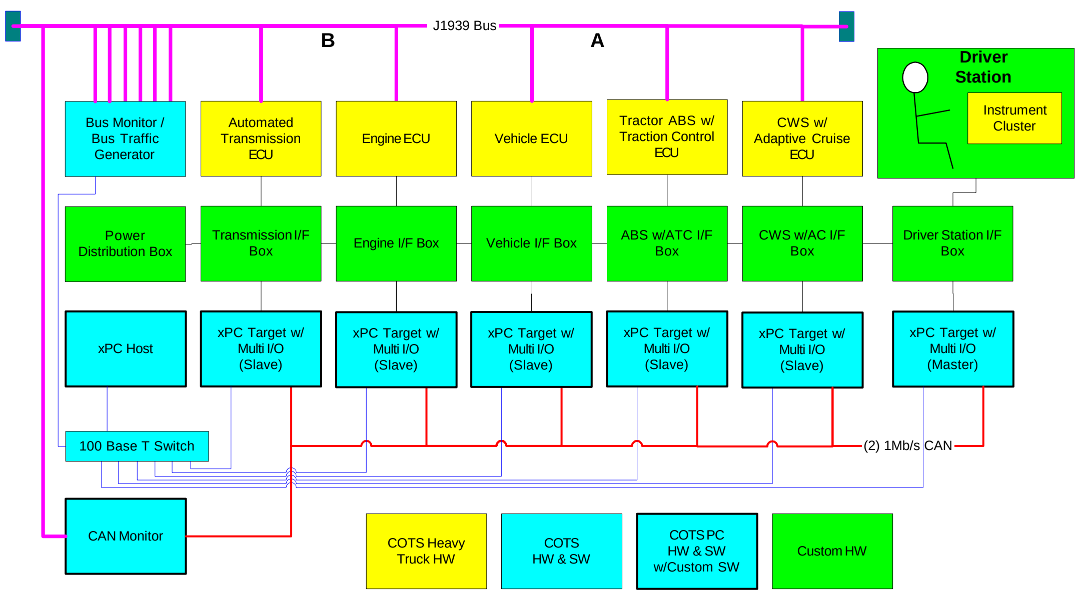
- Validate the simulator

- Perform, record, and report on physical fault testing

- Perform, record, and report on network load testing

- Perform, record, and report on noise tolerance testing

HIL Simulator Test Bed



HIL Test Bed Simulator Block Diagram

Summary of Results

The following are key observations and results from the testing of the J1939 network using the HIL simulator:

Physical Fault Testing

During the physical fault testing, the network reacted to physical failures as discussed in SAE J1939-11, Section 7.4. Deviations in network performance caused by individual ECU variations from J1939 in connector type and wiring were not observed. An anomalous vehicle operational mode was repeatedly observed when the transmission ECU was segmented from the engine ECU (EECU). However, this was an application layer-based implementation anomaly and not J1939 standards-related.

In the physical fault testing, there were three primary classes of bus faults:

1. Signal-to-noise ratio reduction, but communications still possible
2. Segmenting faults that prohibit/inhibit communication across the fault location
3. Network failure faults that cause loss of communications over the entire network

A total of eight network configurations were tested against physical faults. The network configurations were chosen to stress the networks in realistic manner by varying the complexity of the ECU hardware, adding virtual ECUs and failing the network in specific locations. The headway controller (HWC) was viewed as a “complex” network addition. The HWC provided adaptive cruise control functionality and issues high rate Torque/Speed Control #1 (TSC1) messages. The HWC also directly controlled vehicle deceleration and reacceleration without operator intervention. The number of virtual ECUs added to the network was decided upon in consultation with industry. The four additional ECUs resulted in an 80-percent increase over the complex network (with HWC) and a 100-percent increase over the “simple” network (without HWC).

Each test configuration was tested for physical faults one through nine and included a nominal test at the beginning of each new test series to determine proper network functionality before inducing physical faults. The network response to physical faults was as specified in J1939. Faults that resulted in a reduced network signal-to-noise (S/N) ratio allowed the network to function nominally with no operator observable loss of function. When the network was subjected to physical faults where the SAE J1939 Recommended Practice states that network communication should not be possible, the network failed.

Network Load Testing

A total of 60 network loading tests were conducted. Six different network configurations were tested and each series of physical fault and load testing consisted of ten tests. TSC1 messages were injected into the network using an ECU simulator. The network handled bus loads up to 100 percent of its rated capacity without error, and the performance of the network remained nominal. The process of producing bus loadings of up to 100 percent, required the use of six virtual ECUs with each transmitting two high-rate, high-priority messages. This additional emulated traffic represented a 150-percent increase over the maximum observed network load of the nominally operating HIL simulator test bed during complex operating conditions. Physical faults induced during high bus loading produced qualitatively similar results to those observed in the physical fault test series.

Noise Tolerance Testing

A total of 115 noise tests were conducted. Injected Gaussian white noise tolerance appeared consistent with other networks, which have specifications for injected noise tolerance (such as MIL-STD-1553). Ten configuration-fault combinations were tested for noise tolerance. The first several test series involved more tests than the latter, since the level of noise tolerance was not known. Once the noise tolerance level was established in these first series, subsequent series started at these levels and eliminated low noise tests, thus reducing the number of tests in those configurations. The arbitrary function generator was adjusted in 30 mV root mean square steps for most test series. Finer steps than this were considered excessive for these tests, since they are not conducted against any specific standard. The tests were meant to show a general comparison between configurations/faults and other known specifications.

The SAE J1939 Recommended Practice does not specify a tolerance to injected Gaussian white noise. However, the J1939 network exhibits a tolerance that appears consistent with other similar communications networks, which have specifications for injected noise tolerance, such as MIL-SPEC-1553. Both the J1939-11 with shielded twisted pair (STP) test harness and the J1939-15 unshielded twisted pair (UTP) test harnesses performed equally well for injected noise. The noise tolerance for a harness of the maximum specified length of 40 meters was within 0.3 dB of the noise tolerance demonstrated by harnesses with lengths of 14.8 meters (37 percent of maximum specified length) and 25.2 meters (63 percent of maximum specified length).

Summary of Testing

Based on the network testing conducted, the commercial-off-the-shelf (COTS) ECUs used in the network testing that are representative of a typical complex network on a commercial truck implemented J1939 well within the standards. The results from the HIL simulator indicated that the network appears to have the capacity to accommodate 2.5 to 3 times the current network loading (30 percent to 40 percent) used by the majority of commercial heavy vehicles in the United States. However, this testing did not include an extensive survey of COTS ECUs, and an ECU that does not comply with J1939 specifications could have a major impact on the performance and reliability of the network. The ECUs that were used in this test were from large, established manufacturers that have a proven capability to provide ECUs that meet network specifications. Industry members have reported problems with specific ECUs creating bus loadings on the network that greatly exceed those that were observed during this testing.

The COTS ECUs used in this network-testing program demonstrated excellent adherence to J1939 network specifications. They performed very well even when network loading reached 100 percent. Even a relatively well-equipped heavy truck, as represented by the

HIL simulator, uses only up to 42 percent of the J1939 network. Thus, there is significant room for additional networked devices.

While not specifically a planned part of the testing, an issue regarding improper shifting of the transmission, which occurred during a physical failure of the network, was identified and confirmed within the industry. This issue highlighted the CMV OEMs' or ECU vendors' lack of ownership of the network and the corresponding responsibility for integration, condition monitoring, and performance of the network and associated harnessing. The original work accomplished in developing the HIL simulator has attracted industry attention, and may be incorporated into commercial products as a tool for engine and vehicle simulation.

Availability:
The study final report (FMCSA-PSV-07-003) is available from the U.S. Department of Transportation.

Key Words:
Commercial motor vehicles, electronically controlled brake systems, event data recorders, Society of Automotive Engineers, vehicle data recorders

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