Using SAE J-1939 CAN on Mobile Equipment for Complete Machine Control

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This paper will cover several current applications of SAE J-1939 CAN using both registered and proprietary addresses for total machine control. In addition to the expected control schemes, the paper will unveil several unique approaches to long-standing problems and their method resolution. Also included will be several glimpses of future uses of CAN on Mobile Equipment.

The paper will cover both On Highway and Off Highway applications along with some unique monitoring and trouble shooting applications. Applications cover machines requiring thousands of modules per year to one representing less than 100 per year.

How SAE J-1939 started

SAE saw the need for a higher capacity bus communication system for use on trucks, buses, and heavy equipment in the late 1980s and early 1990s. Their discussions resulted in the adoption of the work of Bosch and especially the 2.0b version of CAN.

Heavy Mobile Equipment use of CAN was the providence of just a few large companies until approximately four years ago, Caterpillar had “Cat-CAN” and John Deere had what was referred to as “Ag-CAN” that were very similar to SAE J-1939. These were based on the work by Bosch in the 1980s. The first CAN licensee was Intel in 1987. In 1991 CAN Specification 1.2 became the proposed SAE Truck and Bus standard (J-1939). In 1991 Bosch CAN specification 2.0 was announced and was adopted by the J-1939 committee.[1]

SAE published the first parts of the J-1939 standard in 1994. J-1939-21 Data Link Layer, J-1939-71 Vehicle Application Layer, and J-1939-3 Network Layer were published then.

When HED started their first SAE J-1939 application project in 1997, there was still a lack of microprocessors with the CAN 2.0B control scheme masked on the chip. HED as well as several others can tell “war stories” about the problems in obtaining information and parts that year. While there were several potential customers for the technology, only one “bellied up to the bar” and placed orders to develop product. Those orders changed the direction of HED.

Why J-1939?

The SAE J-1939 standard was selected for the first HED CAN project because we knew that the diesel engine manufacturers were moving toward standardizing on J-1939 for engine to the outside world communications. Investigation of the portions of the SAE J-1939 standard available confirmed that this was the way to go for any heavy mobile equipment. The standards and their rationalization documents listed:

- 250 kB communication rate
- up to 30 nodes
- up to 40 meter bus length
- the provision for registered addresses controlled by SAE
- the provision for proprietary addresses

[1] Technical Presentation of In-Vehicle Networks, Dearborn Group, Farmington Hills, MI- 1997 private presentation.

- a two wire communications electrical scheme that shifted between three voltages
- The communications scheme would probably allow operation of unshielded twisted pair for EMI/RFI susceptibility tolerance to 100 V/M
- 29 bit identifier that include priority and other features.
- the standard was developed with intention of carrying GPS and Video information.

Controlling Distributed Functions

CAN is a natural for use in controlling widely distributed functions because of the ability to place nodes wherever there is a concentration of inputs and/or outputs. Controlling a number of lights or other loads located on all faces of the vehicle through the operation of a switch located in another location is the “bread and butter” of CAN systems. The transmission of information from many nodes to one or more nodes also is the standard fare of CAN.
The addition of the use of J-1939 CAN by the engine manufacturers and the availability of information and control of the engine made possible by integrating the control system with the engine is a strong incentive to use CAN. Adding information from and control of the transmission, PTO, and brakes adds to the appeal of CAN.

Unique advantages of CAN

CAN also has a number of other advantages as a result of the use of microprocessors for the CAN communication. Complex logic can be used to describe the interlocking relationships of sensors, controlled items, and the logic of the control.
Simple interlocks such as being sure that all of the equipment doors on a Fire Engine are closed before placing the transmission in gear can save thousands of dollars. The system can be programmed to allow the removal of specified doors from the check. The driver can override the interlock if he needs to move a truck in an emergency.
Interlocking the drive transmission with the water pump and hydraulic pump prevents destruction of the pump.
Multiple control locations can be placed where needed on the vehicle. The control algorithm can be written to provide priority of specific functions based on the location of the controls. (See below- Fire Engine)
On specific purpose vehicles, the ability to shed electrical loads based on the then current vehicle function is a “Must have” to prevent electrical system failure. The CAN system provides the capability of specifying what loads should be shed in what order for each programmed vehicle condition. (See below- Fire Engine)
Multiple requirements for engine power can be aggregated and the engine commanded via the J-1939 CAN registered backbone. Through the use of the data being sent by the engine, the engine can be also commanded to hold a specified RPM to provide the proper environment for such items as 120 VAC alternators, etc.

Applications

Rough terrain Hydraulic Crane

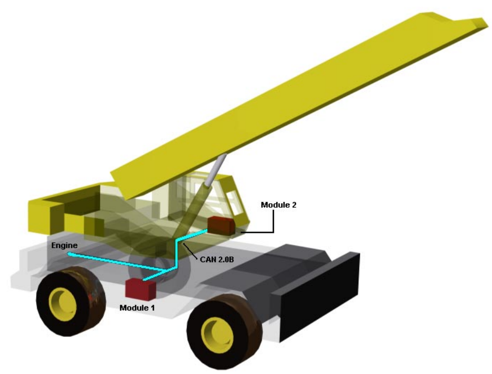


Fig. 1 Rough Terrain Hydraulic Crane

Hydraulic construction cranes have been built the same way for years. A number of hydraulic lines and wires pass through a swivel from the lower frame with the engine and travel drive components to the

operator's/driver's cab located above rotation. The swivel is a necessary high cost item if the designer wants to be able to allow continuous rotation of the upper portion of the crane- something most customers want.
This resulted in 40 to 80 wires passing through the swivel. Each wire represents a cost for the commutator assembly consisting of a wiper set, a track and the necessary space to mount the wiper and track. Each wire represents one more possible error in wiring and failure point in the field.

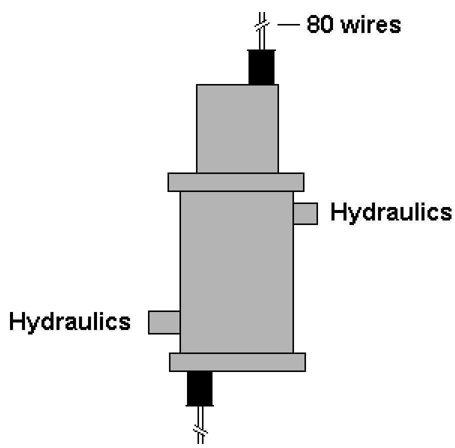


Fig. 2, Conventional Swivel assy.

Today there are cranes being introduced that use two CAN J-1939 wires to replace all but the power supply and ground wires. The installed cost (which is cost of the swivel reduction plus the reduction in wiring troubleshooting less the CAN modules) justifies the addition of electronics.

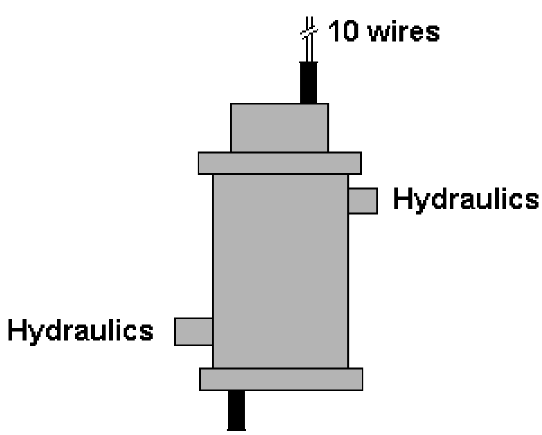


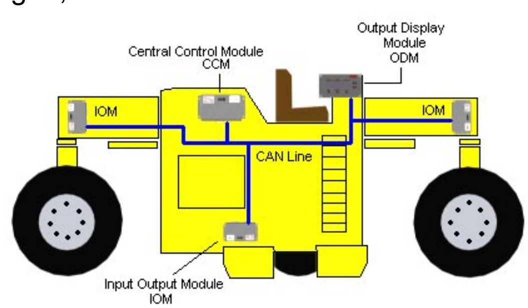
Fig. 3, New CAN Swivel

The CAN system allows the use of an electronic throttle and transmission control in the upper cab with the signals sent down to the main frame by the twisted pair. The fuel level and all of the engine, transmission, and other lower networked systems send their information to the upper cab over the same wires.
As the designers become comfortable with the reliability of CAN, other functions will be integrated in to the CAN network. The lifting function controls and the RCL (Rated Capacity Limiter) are prime candidates for inclusion on the CAN network. Integration will result in "soft limits", function specific control response, and improved safety interlocks.

Soil Stabilizer

The large soil stabilizers used to improve road beds by the addition of asphalt or quicklime and rejuvenate asphalt pavement surfaces would not be able to operate without electronics. Many of the units today have a single controller that controls steering, height (depth of cut), slope, and engine loading. These machines will be converting to distributed CAN systems in the next few years as each model comes up for redesign.

Fig. 4, Soil Stabilizer



Because each of the steering posts (or legs) has valving to raise and lower as well as to turn clockwise and counterclockwise as well as sensors to measure each, distributed control is the logical way to go.

A CAN system also makes addition of accessory systems easy- plug and play.

Special Purpose Tractor

Fig. 5, Special Purpose tractor

This application is typical of the introduction opportunities afforded by CAN J-1939. The manufacturer needed microprocessor control to automate safety interlocks and to reduce wiring on the machine for the 15 outputs and 18 inputs. With the addition of SAE J-1939 to the microprocessor unit, the customer can easily add engine data to the control interlocks to prevent damaging the engine. The multiple CAN ports allows the isolation of the engine's registered code from the proprietary code for the balance of the machine.

Fire Engine

The "Quint" Fire Engine described below, is probably one of the highest integration of SAE J-1939 CAN control in a production vehicle today. (Because of confidentiality agreements, the description is generic ad should not be attributed to a specific manufacturer.)
The *number one reason to convert* a conventionally wired fire engine to a SAE J-1939 Can based fire engine is the number of wires. The typical truck has 300 plus wires going through the floorboards to positions throughout the truck. The additional enhancements are "icing on the cake".
Why is the large number of wires so important? Because every order is different. No two Fire Trucks are the same unless they are ordered on the same order (even then there are likely to be differences).

Fig. 6, "Quint" Fire Engine

The items covered with the previous examples also apply. The engine reporting, monitoring, and control as well as the same for the transmission and the brakes are communicated on a *SAE J-1939 Registered* CAN bus. All of the other functions are on a *"Proprietary" SAE J-1939* type bus.
The Registered bus talks to the Proprietary bus through a CCM (Command and Control Module) that has multiple SAE J-1939 CAN ports. The CCM prevents identification clash from occurring when a registered address duplicates a proprietary address. While the manufacturer may be very careful to not use a registered address when writing the application software, any time after the writing of the application code, someone may register the same address as one of the application codes and cause a conflict. Placing both registered and proprietary addresses on the same bus is like "betting against the house" in Las Vegas. You will lose.
The worst creator of the high wire count on Fire Engines is the *lighting requirements*. By using J-1939 to command all of the lighting, the number of wires running down the chassis rails is greatly reduced. Using CAN also creates four additional advantages.

First is the ease of *troubleshooting*. The use of CAN allows all of the specific purpose power wiring to be place within an arms length from the output device to the controlled device. This reduces troubleshooting by hours and even days. The control modules can detect current flow so that they can report when there is an incorrect load resulting from a deficient, misconnected, or shorted device. Trouble shooting can be from a test program that activates each light in sequence for checking.

Second is the ability of the microprocessor based system to *control the maximum load* presented to the battery/alternator. If the operator turns on too many lights resulting in an overload for the alternator, the system can be programmed to reduce the load in a sequence predetermined by the manufacturer in relation to the current function of the truck. This capability removes a thousand dollar separate load control system from the vehicle. The loads must be limited as a typical vehicle could draw enough power to drain the batteries quickly if everything was turned on at the same time.

Third is the ability of the microprocessor to *control lights* (and other functions) *in relation to the current duties* of the Fire Engine. The system will activate different lights for travel versus being on the scene. For example, the system will not let the aircraft warning strobe be activated until the transmission is in the park mode and the ladder is out of the cradle. This is critical as the strobe is directly in front of the driver and is capable of temporarily blinding him as he goes down the road if it is activated during travel.

The fourth feature is one not even considered in the initial evaluation as to the desirability of using a CAN based system. If the standards change for a specific light pattern, attaching a laptop computer to the Fire Engine and *reprogramming* the timing for all of the required modules from one connection can make the change.

Interlocks are critical on a Fire Engine. One of the least discussed; but, most important is the ability to interlock the compartment doors with the compartment lights. Also to interlock the compartment doors with a warning if one is still open when moving the Fire Engine. Open doors have a high mortality rate and a high collateral damage capability.

Interlocks that insure that the hydraulic pump is not engaged until the truck is in the park mode and disengaged before shifting into a travel gear cut the possibility of damage to the hydraulic pump. Same for the water pump. [NOTE: interlocks are warnings to the operator. In fire service applications, the operator is always given the ability to override the interlocks. [See "Data Logging" below.]

The pump(s) can also be controlled by controlling the engine RPM so that there is adequate flow and pressure. The water pump is also controlled so as to prevent surges in pressure that would create unsafe conditions for the hosemen.

The operating center for the Fire Engine when it is at the scene of a fire is the *Pump Panel.* A number of fire departments require that control be available from either side of the Fire Engine. With CAN, it is easy to allow control from either or both sides as the operator wishes. On "Quints", there is often a control for the Monitor (large stationary nozzle mounted on the ladder end or on the platform) at both Pump Control Panels, the lower aerial control station and at the platform or tip of the ladder. Control can be at any or all of the locations depending on the programmed priority.

The Aerial Ladder also presents a number of control problems and opportunities.

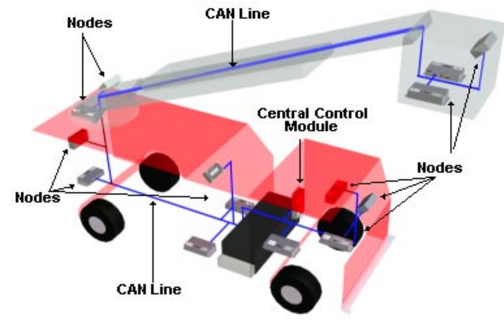


Fig. 7, Ladder with CAN

There are both upper controls (located at the tip or in the platform) and lower controls (located at the point of rotation of the ladder).

There is need to interlock the extension and lift of the outriggers to the permitted ladder positions. On a modern truck, the outriggers are deployed automatically under the supervision of the operator (for safety). The Fire Engine is leveled automatically after deployment of the outriggers. If there is an obstacle in the way, one or more than one outrigger may be "Short Jacked".

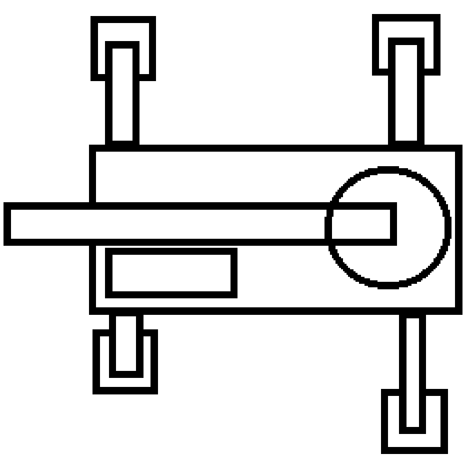


Fig. 8, Short Jacked Ladder Truck

The capacity of the Ladder Truck is severely restricted in the direction of the "Short Jacked" outrigger. Presently outriggers are considered to be "short jacked, in some cases _ short jacked, or fully extended. In the future look for the outrigger extension to be measured automatically and the amount of short jacking to be infinitely adjustable.

The Load Limiter function is based on the measurement of the ladder position versus the load on the ladder versus the outrigger positions to set limits as to where the ladder can be moved by the operator. The integration of the Load Limiting function to the ladder control allows the use of "soft limits". "Soft Limits are achieved when the rate of approach to a predetermined limit is decreased in proportion to how close the ladder is to the limit.

The most violent motion of the ladder is rotation. Using the electronic control to impose "Jerk" limitations can significantly improve the forces placed on the persons at the end of the ladder. "Jerk" is taken from the name of the derivative of acceleration. Thus "Jerk" is the control of the rate of change of acceleration.

The added sensors need for Short Jacking also can provide an additional feature- *Envelope Control* or collision avoidance. Significant damage to the truck can occur when an operator inadvertently lowers the ladder to the position where it crashes with mounted equipment on the truck. Because each truck is different, this feature is generally activated by placing the unit into a "Teach and Learn" mode and running the ladder in a full circle and raising and lowering as needed to describe the "no fly zone".

With the memory capabilities of today's CAN modules, *Data Logging* becomes a natural addition to the system. All or almost all of the sensors are already onboard, all that needs to be done is to set up memory allocations for what the customer, distributor, and/or manufacturer want to be able to recover.

With the capability of the CAN modules used today, it is possible to report both planned and unplanned events.

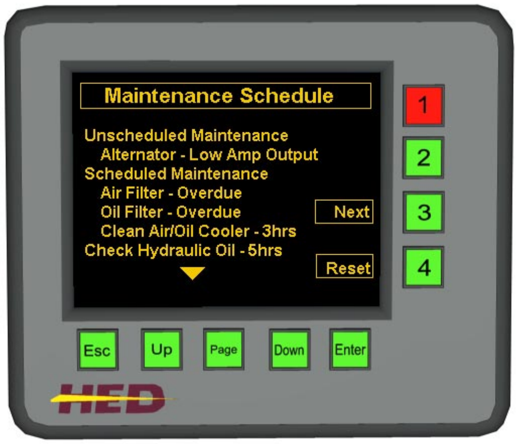


Fig.9, Data Log Report

The addition of additional sensors such as compass, GPS, or others will provide positions in real time as well as a history. This data can be communicated to a central location via any radio such as satellite, cellular, etc. (Recently this has become to be called "Telematics".)

What is in the future?

For the last five years, many people have been waiting for the Mobile Equipment market to embrace electronics. It is now happening. What is listed above are some examples of the start. The big push came with the decision of the engine manufacturers to use SAE J-1939 on the new generation of diesel engines to meet the next generation of environmental regulations. The protocol selected proved to be extremely robust and powerful. It has proven that it is capable of withstand the requirements of the industry including EMI/RFI. The components and designs used in creating the modules have proven to be able to withstand the electrical and physical environments in which they must operate successfully.

The application of electronics and in particular SAE J-1939 CAN will accelerate with each passing year. One very optimistic economic forecaster predicted a doubling of the market every three years during the next decade. I don't believe that it will grow that fast; but, it will grow substantially.

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APPENDIX

The following is taken from another presentation. Because of the hype surrounding electronics and CAN, it is necessary that both are applied for the right reasons. No one should use electronics because “it is the thing to do.”

Electronics will solve many problems for many manufacturers of mobile equipment. With out proper care in applying electronics, electronics will create many more problems than it solves.

The way to use electronics is to:

- Determine what will improve your machine. (This is not a determination of how to apply electronics.)
- Talk to your customers to find out what they want to see improved.
- Meet with several electronic suppliers that have systems experience and get their suggestions.
- Evaluate the suppliers that have the better understanding of your needs.
  - Do they have experience in surviving the environment your equipment works in.
  - Do they have the experienced staff to successfully complete your redesign.
  - Do they present a realistic plan that can be achieved.
  - Can they recover quickly if something goes wrong with the plan.
  - Do they keep up with the changes in the state of the art or do they only offer tired designs.
  - Are they prepared to be more of a partner than a “off the shelf” vendor.
- Commit sufficient resources to succeed. This is not only financial, you need to be prepared to commit your qualified personnel. You and your people know the market and your machines better than even the best supplier.
- Be sure that the design is ready before making all of the public announcements. Nothing can sour your sales people and customers than to receive a machine that does not deliver what was promised. Product improvement of features, productivity, total cost, and durability are still the only goal.