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Abstract
The development of SAE J1939 was prompted by the Heavy Truck industry because of a need for a in-vehicle real time network operating capability (referred to as a "SAE Class C Network"). SAE J1939 has now been adopted for use in tractors and other off road equipment. This paper will outline SAE J1939 network development tools that are available to support hardware and software engineers. An example SAE J1939 network application done by Oklahoma State University will show how some of these tools could be used on tractors.

Introduction
The SAE J1939 specification was developed by the Heavy Truck and Off Road Vehicle industries for use as a Class C network. SAE J1939 is based on the Controller Area Network (CAN) protocol. SAE J1939 defines layers 1, 2, 3 and 7 of the ISO OSI 7 layer network model. CAN protocol by itself specifies only part of the network requirements (i.e. data link layer implementation). A brief summary of the CAN protocol specification is given below:

- Bus Scheme: Carrier Sense Multiple Access/with Collision Detection (CSMA/CD)
- Message Format: 0 to 8 bytes of data.
- Messages Types: Data, Remote Frames (request data).
- Receiving nodes accept messages by content not by addressing.
- Transfer rate: 1 to 1000 kilo-bits per second (kbps).
- Bit Coding: Non Return to Zero (NRZ) with bit stuffing.

The SAE J1939 specification further defines the network protocol by adding to the CAN definition the following requirements:

- Physical Layer:
Twisted shielded pair cable, differential voltage driven, 250kbps.

- Data Link:
Protocol Data Unit (PDU) definitions.

- Application Layer:
Messages and data parameters.

In addition to the capability of real time control, the advantages of a Class C network like SAE J1939 include: enhanced modes of operation, more serviceable electronic subsystems, simpler vehicle system configuration, and easier monitoring/management of the vehicle system. For example, SAE J1939 permits 10ms control message transfer times that are needed for applications such as the Intelligent Sprayer System designed by Oklahoma State University. The sprayer's subsystems have a Qagnostics interface via the network to support servicing. The vehicle was easily configured to interface with the sprayer system. Finally, the sprayer system was interfaced with the tractor's management computer for data collection and monitoring.

Intelligent Sprayer System
Figure 1 shows the Oklahoma State University Intelligent Sprayer System (ISS). The ISS is a computerized tractor mounted crop sprayer that is designed to automatically identify weeds in a fallow wheat field and to apply herbicide to the weed only. The ISS is designed to minimize the

amount of herbicide applied in the field thus reducing process cost. The tractor mounted ISS consists of a specially modified standard commercial crop spraying rig with a chemical storage tank, a pump, a boom extending several meters out to the sides of the tractor, and multiple spray nozzles attached to the boom. The special modifications to the spraying rig done by Oklahoma State University include: a) individually controlled solenoid operated nozzles, b) intelligent optical sensors for identifying specific vegetation (i.e., weeds), c) a CAN based J1939 network to interface the sensors to the solenoid actuators, and d) an interface (or gateway) to the tractor's electronic controller system.

At each spray nozzle there is an optical sensor with a microcontroller. The microcontroller implements a neural network algorithm which decides if a weed is present under the optical sensor. If a weed is found, then a message will be sent to the proper nozzle solenoid to spray the weed. Another important component of the ISS is the network link to the tractor's radar speed monitor. In order for the ISS to know how long to leave the sprayer turned on, it must be able to acquire the vehicle's true ground speed. The vehicle's true speed is measured by the tractor's ground radar electronic controller system and then communicated in real time to the spray nozzles.

The network nodes that comprise the ISS components communicate with both standard and proprietary J1939 messages. The nozzle nodes on the J1939 network will receive commands for turning the sprayer off and on. The nozzles will also transmit status information to the tractor's management computer system in order to collect data on the location of the identified weeds. These command and status messages are proprietary messages. The nozzle nodes also periodically receive a standard J1939 message reporting the vehicle's true ground speed as calculated from the tractor's on-board management computer.

The gateway node exchanges information between the ISS and the tractor. The tractor (John Deere Model 7800) uses a CCD (Chrysler Collision Detection) network to communicate with its on-board electronic controller systems and its on-board management computer. The SAE J1939 network on the ISS is not compatible with the tractor's CCD network. The ENAT hardware (described below) was used as the gateway node to translate messages back and forth between the ISS and the tractor.

The following sections describe network development tools that were used in the development of the ISS. The tools are classified in two categories: Evaluation Systems, and Emulation/Analysis Systems.

Evaluation Systems

The evaluation systems are used to learn about the network interface. Initial hardware and software development is also possible with these systems. An example of one such system is the Evaluation and Network Analysis Tool (ENAT). The ENAT utilizes Intel's 82527 chip (currently the only commercially available network controller device that fully supports SAE J1939) and a Motorola 68HC11 microcontroller. The ENAT system provides three software interface methods for communication on a J1939 network. First, by using the provided software that resides on a host personal computer to send and receive messages on the network (PC hosted mode). Second, the user can write application specific software that can be programmed into the onboard EPROM (embedded mode). Third, the user can use the EPROM based monitor program to download an application specific program into the onboard nonvolatile RAM (download mode).

Oklahoma State University has developed a complete in-vehicle network incorporating multiple ENAT boards attached to a tractor based sprayer (ISS). The network handles communication for the sprayer sub-system supporting the color sensing optical sensors used to detect color differences between desired crops and weeds so that only the weeds receive herbicide. The weed data is combined with location information that is provided by the global positioning system so that future crop and weed developments can be tracked for annual analysis. The network architecture of this application of the ENAT ***evaluation systems*** is shown in Figure 1.

In Figure 2 an example of J1939 Message Capabilities is shown with message

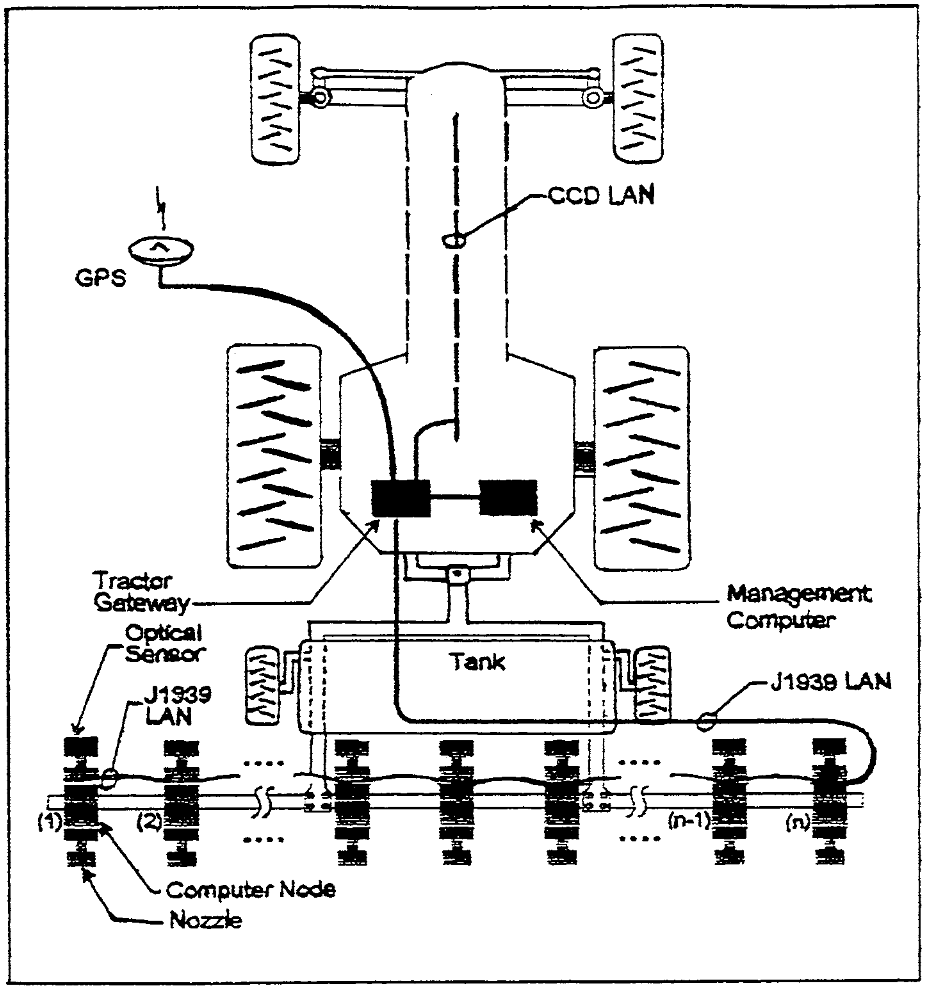

Figure # 1. Illustration of Intelligent Sprayer

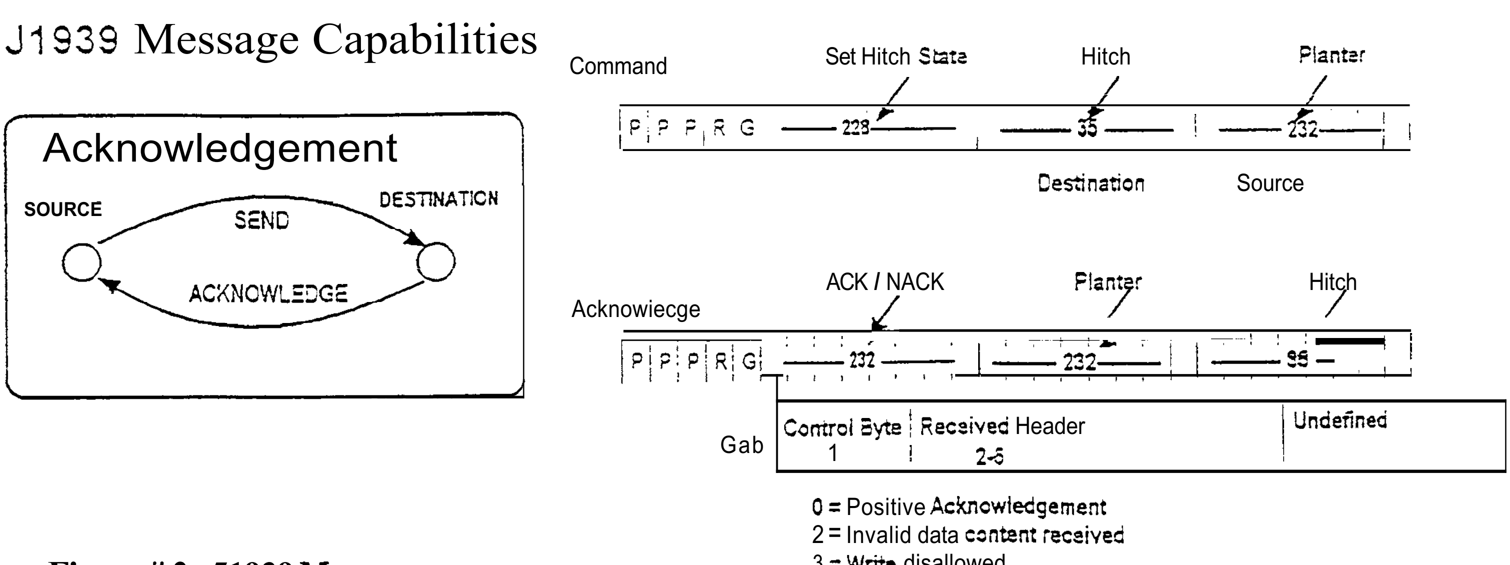

Figure # 2. 51939 Message

traffic between a planter and the hitch of a tractor. The programming of these messages was done with an ENAT *evaluation system.*

An ENAT *evaluation system* could also be used in conjunction with a separate simple, small, and very low cost "satellite board" which can act as an additional network node. The satellite board consists of only a CPU, EPROM, and CAN device. The tractor with its three implements as shown in Figure 3 might have one or many nodes, simulated with a small inexpensive satellite board. Evaluation systems, by design, are a compromise between price and performance. Users might upgrade the evaluation systems by adding software monitors and higher speed host PC interfaces in order to accomplish tasks like protocol analysis. This upgraded evaluation system is called an "Emulation and Analysis" tool. If the user requires the upgraded capabilities, it is usually more cost effective to acquire a tool specifically designed for tasks like high speed emulation or protocol analysis.

The ISS project required a tool for real time network emulation for laboratory development work. A protocol analyzer tool was also needed for recording network traffic in the field ("flight recording") and playing it back in the laboratory for performance analysis. The following section describes these tools and how they were used.

Emulation and Analysis Systems

There are several products available specifically for SAE J1939 emulation and analysis applications. A summary of some of these products and features are shown below in Table 1. The CAN Application Controller Version 2.0 (AC2) is an intelligent CAN interface board that is inserted into a personal computer. An example of how the AC2 *emulation/analysis system* may be used is in the processing and buffering of the incoming data packets from the ISS network. The reason for the use of the AC2 for emulation and analysis vs. an ENAT is that the AC2 card offers an important benefit of high speed, real time data acquisition requirements needed to support the SAE J1939 network on the ISS. Note that most *evaluation systems* like the ENAT card work very well as a network node, they do not support the high speed interface required for the 250Kbps SAE J1939 network data collection and emulation.

System	**Features**	**Cost**
AC2	user programming possible	low
Emulator-Analyzer	hardware triggers, advanced functions	high
CANalyzer	graphical interface	medium

Table 1 - Evaluation and Analysis Systems

The "Emulator-Analyzer" system allows for the emulation of the behavior of different devices on the J1939 network. This capability is invaluable in the early design and development stages of a project. It consists of a plug in board for a personal computer and software. The emulator functions supported are message orientated monitoring, editing and transmission of messages, recording of message traffic, on-line bus load measurements, and measurement of message delay. The analysis functions allow recording of bus traffic at the bit level. It is possible to capture all bus states, in particular, the observation of individual error frames and the disturbed messages normally suppressed by the CAN chips. Several trigger sources are available on the CAN Emulator-Analyzer board with the data recorded directly to the hard disk in the form of a sequential bit stream. Recorded or edited bit *streams* can be sent to the CAN bus again controlled by various triggers or conditions. An analysis of the recorded data is performed off-line by the analyzer statistics software. The analyzer functions operate at 1 Mega bits per second (1 Mbps). It is possible to create several different file types from a user defined ASCII input file, as in Figure 4.

The "CANalyzer" provides a user friendly real time J1939 network interface for emulation and analysis. It is a software package used in conjunction with either the CAN AC2 card or a CAN PCMCIA interface card. It has the capabilities to monitor, analyze, and generate data communication on the bus line. The built in basic functions include: tracing the bus data communication, displaying data segments of specific messages, sending predefined

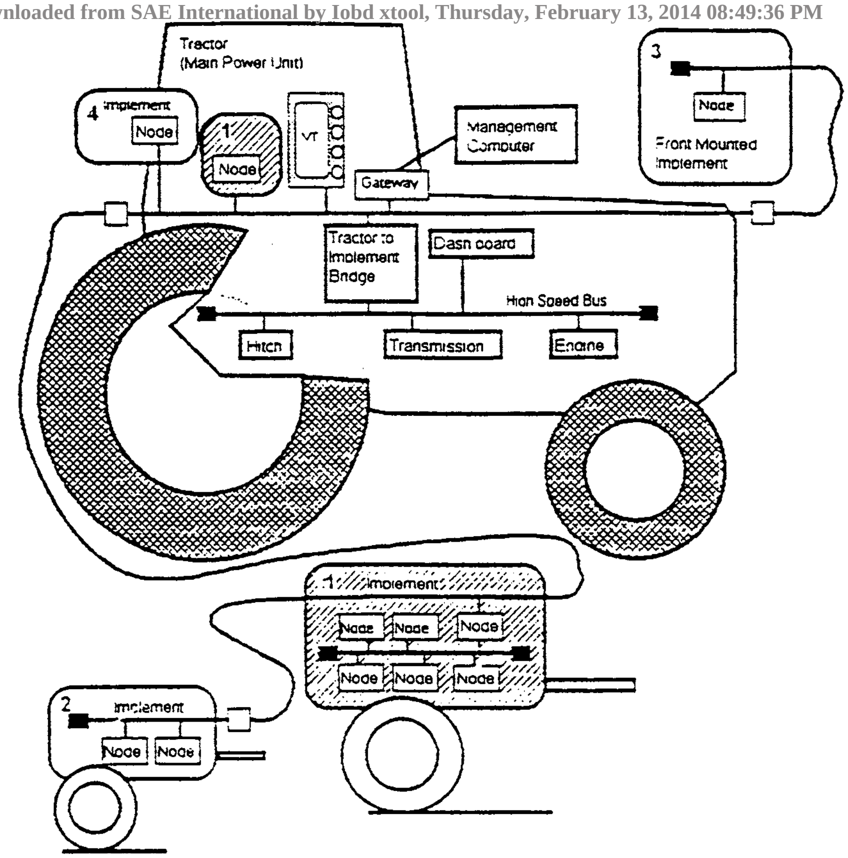

Figure # 3. Tractor with Multiple Implements

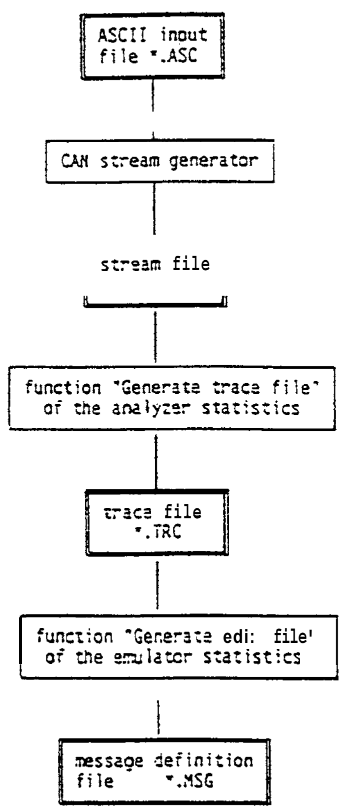

Figure # 4. Creating different types from an ASCII input

messages, providing statistics regarding the bus load and disturbance, recording messages for replay or for off-line evaluation, and to generate error flags on the bus line. Application examples are: Emulation of a bus module, Gateway between two busses including a filter function, Program controlled logging of critical phases, and User specific on-line evaluation with comprehensible text messages.

Development projects like the ISS use the CANalyzer installed in a notebook PC located in the tractor cab to collect SAE J1939 network traffic. This captured message traffic is then analyzed off line to check for correct message content. The CANalyzer is also useful as a "flight recorder" tool to look for communication errors.

Summary and Conclusion

SAE J1939 is a comprehensive document that fully describes a Class C data bus for mobile equipment. With the merging of the SAE Off-Road Vehicle industry group and the SAE Heavy Truck groups, there has been an acceleration in the pace of adoption of this new standard network. The Oklahoma State University ISS project demonstrates how the SAE J1939 network has been incorporated into an off road vehicle. The ISS project utilized standard network tools to facilitate the development of the sprayer system and vehicle interface. The ISS project shows how important it was to have both a standard to support tractor and implement communications (SAE J1939) ***and*** to have standard tools available for network development and testing.

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