

a sophisticated diagnostic inspection such as Auto Check are available.

3. The consumer is in a much better position to communicate with the repair facility if he or she has specific repair instructions to give the repair facility (i.e., prescription forms).

4. The consumer will be more likely to have the more costly and more sophisticated systems such as the engine repaired if he or she has the specific repair instructions to give the repair facility.

5. The consumer will change his or her habits and have car repairs done at different repair facilities if specific repair instructions are at hand.

6. The repair facilities that perform the best, most cost-effective repairs get the most business, suggesting that a good reputation (and performance to match) is critical to business success.

In summary, the results of the 3 years of operation of the Alabama motor vehicle diagnostic inspection demonstration program indicate that the cost of unnecessary repairs can be reduced, if effective communication techniques are used to transfer the results of the diagnostic inspection to the repair industry and if the repair industry is made aware of the financial effects of questionable repair practices.

## Portable Interactive Data Acquisition and Analysis System for Driver Behavior Research

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This report describes a portable interactive data acquisition and analysis system designed for roadway experiments studying driver behavior. The system is microcomputer-controlled and features multichannel sampling capability, on-line operator control of experimental parameters, and on-line data reduction capability. Several novel transducers are incorporated.

The Road Safety Unit of Transport Canada has a general requirement to perform measurements of driver behavior under actual driving conditions (1). The Defence and Civil Institute of Environmental Medicine (DCIEM), Ontario, was asked to provide a car-portable system to provide these measurements.

The general requirements for the instrumentation system were

1. True portability (it was to fit most North American cars, mid-size and larger; installation time of less than 24 h was desired);
2. Low power consumption;
3. Modular design;

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4. On-line data analysis capability; and
5. On-line control over experimental procedures.

There can be as many types of instrumentation systems as there are road experiments. Performance of portable systems can be limited in many ways including sampling rate, data storage, degree of experimental control, power requirements, bulk, and cost.

Generally, a system's bulk, power requirements, and cost are directly related to its capability in terms of sampling rate, data storage, and experimental control. The more sophisticated experimental vehicles are typically equipped with fixed instrumentation and sensors. These are usually expensive, heavy, cumbersome vehicles, bearing more resemblance to portable laboratories than to the family automobile they are intended to simulate.

At the other extreme, the truly lightweight, low-power, inexpensive portable data recording systems are usually inflexible, often monitor few transducers, have slow sampling rates and limited data storage, and offer little control over the experimental parameters.

The LSI-11 system described herein resulted from trade-offs between the conflicting requirements of portability and capability.

## SYSTEM OVERVIEW

The performance of the system is outlined in Table 1. The system also has the capability of transforming basic measures or combining them on-line or both, to form complicated derivative measures.

A functional block diagram appears in Figure 1. The central component is a Digital Equipment Corporation (DEC) LSI-11 microcomputer, a compact machine that consumes relatively little power. When interfaced with appropriate peripheral devices and operated with commercially available software, it behaves like a conventional minicomputer. In the present configuration there are 24 K (24 576) words of metal oxide semiconductor (MOS) memory, with the option to add another 4-K module.

Random access bulk storage is provided by a floppy disk unit (DEC RX01). The storage medium is a preformatted flexible diskette, or floppy disk, which can

store 256-K eight-bit bytes of information. These disks are used for storing data collected during the course of an experiment and providing permanent records of programs.

The other peripherals that provide communication between the operator and the computer include a keyboard terminal with a single line gas-discharge display, a thermal printer for providing limited hard copies of numerical data, and two digital clocks. One clock reads the time of day in hours, minutes, and seconds, while the other provides a millisecond readout. The two clocks can be used to time events under program control. A hardware bootstrap facilitates system initialization when the computer is turned on.

The LSI-11 communicates with the measurement transducers by means of a data acquisition module that samples up to 24 differential analog channels and performs a 12-bit analog-to-digital conversion for each. Under program control, the computer can provide two channels of analog output, using two 12-bit, digital-to-analog converters. In addition, there is provision to accept either discrete inputs from digital transducers or to generate discrete signals for controlling external devices (e.g., light signals).

Speed is measured by a microwave radar Doppler speed sensor (2), and a measure of distance is derived by summation. Coarse and fine readouts of steering wheel position are obtained by measuring the rotation of two potentiometers. Accelerator position is obtained by measuring the displacement of the linkage at the carburetor with a linear displacement transducer. Acceleration along three axes is measured by three sensitive, low-frequency, force-balance accelerometers, mounted orthogonally. Brake pedal force is determined using a force transducer available from GSE Incorporated, Livonia, Michigan. A sophisticated optoelectronic lane tracker, specially designed by the Human Factors Research Corporation of Goleta, California, measures the lateral distance of the vehicle from the roadway center line. A device to measure the distance to either a leading or trailing vehicle is currently under development.

The system is powered by a high-current (105 A) alternator that replaces the vehicle's original alternator. A reserve battery is included. A nominal 12 V

Table 1. Measurement parameters for a portable interactive data acquisition and analysis system.

Parameters	Range	Accuracy <sup>a</sup>	Sampling Rate (Hz) <sup>b</sup>
Time (relative)	Practically unlimited	0.001 s	100
Speed	0-53 m-s <sup>-1</sup>	3%	10
Distance <sup>c</sup>	Practically unlimited		
Acceleration			
X	0 to ±25 m-s <sup>-2</sup>	0.5%	20
Y	0 to ±25 m-s <sup>-2</sup>	0.5%	20
Z	0 to ±25 m-s <sup>-2</sup>	0.5%	50
Steering wheel position	±0.35 rad (fine)	0.5%	50
	±2π rad (coarse)	0.5%	50
Accelerator	0 to full	<1%	50
Brake pedal force	0 to 1300 N	1%	50
Lateral position	±2 m	0.5%	50
Discrete driver responses			Interrupt
Analog responses		1%	10

Note: 1 m = 3.28 ft, π rad = 180°, 1 m-s<sup>-1</sup> = 2.25 mph, 1 m-s<sup>-2</sup> = 0.1 G, and 1 N = 0.224 lbf.

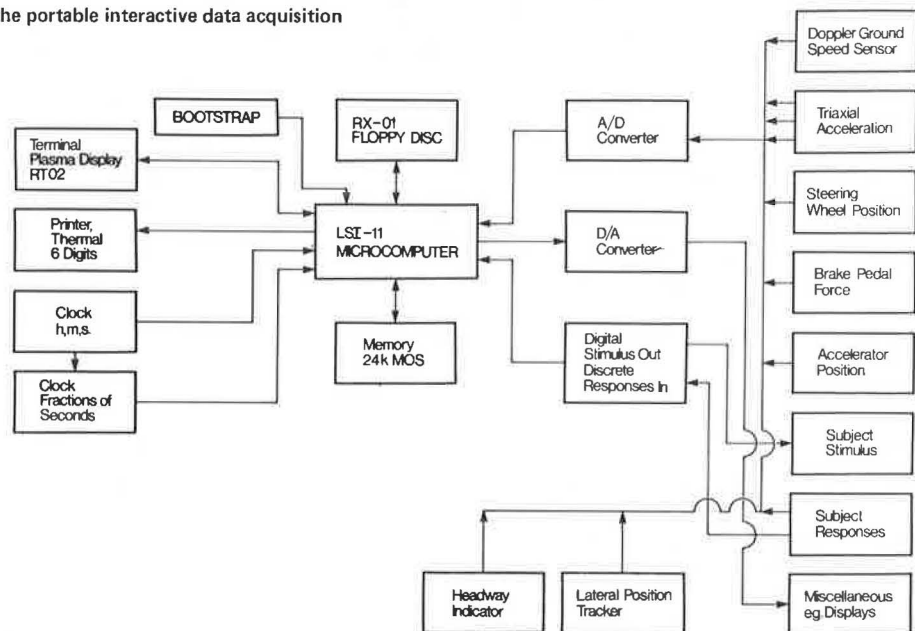
<sup>a</sup>Accuracy given in percent of full scale, except time.

<sup>b</sup>Typical.

<sup>c</sup>Distance is integrated from speed.

<sup>d</sup>Nonlinear measurement, accuracy determined by calibration table.

Figure 1. Functional block diagram of the portable interactive data acquisition and analysis system.



is supplied to a 12-V/12-V converter, 12-V/5-V converter, and a 115-V/60-Hz inverter to provide well-regulated power. Maximum power consumption in the present configuration is less than 800 W.

The total weight of the system, 140 kg (310 lb), is evenly distributed throughout the vehicle. No single component weighs more than 25 kg (55 lb). The system components are typically located in the vehicle as shown in Figure 2.

### MICROCOMPUTER SYSTEM

The use of a microcomputer and associated peripherals for on-road data processing and control represents the most novel aspect of the instrumentation system.

#### LSI-11 Microcomputer

The microcomputer consists essentially of one 25-cm  $\times$  22-cm (10-in  $\times$  8.5-in) "quad-width" board that houses the microprocessor chip set, consisting of a control chip, data chip, two microinstruction chips, and an extended arithmetic-floating point arithmetic chip. The latter is an option, which was purchased to facilitate arithmetical computations.

The microprocessor includes a hardware memory stack for handling structured data, subroutines, and interrupts (3). In addition, there are six general-purpose and two special-purpose registers for data storage or for use as pointers or accumulators.

The microprocessor board also contains 4K words of MOS memory. Another 20K of MOS memory is located on five 12.7-cm  $\times$  22-cm (5-in  $\times$  8.5-in) "double-width" modules, which follow immediately after the microprocessor board on the LSI-11 bus. MOS memory has the advantages of compactness, low power consumption, and fast access times, but requires a periodic refresh operation to maintain the charge in the memory elements.

After power is turned on, the hardware bootstrap first performs a series of tests of the processor and memory, and then loads the machine with a monitor program. The monitor program, which is part of the RT-11 software system, permits programming in Assembler, Fortran, or Basic and contains a large number of utility programs and a library of subroutines. The LSI-11 software is identical to that of the series of PDP-11 minicomputers, so programs written for the LSI-11 can be transferred to other DEC-11 machines.

Peripherals are interfaced to the microcomputer using plug-in parallel line interface units and serial line units. The priority assigned to a peripheral device decreases with electrical distance along the bus. The processor, memory, and interface modules are housed in two backplanes that provide mechanical support, power, and signal connections. These backplanes are located in an instrument case (see Figure 3), along with the data acquisition equipment, clocks, printer, a  $\pm 15$ -V supply, and a fan. This case is 53 cm  $\times$  30 cm  $\times$  66 cm (21 in  $\times$  12 in  $\times$  26 in) and is normally located on the back seat of the car behind the driver, on top of a similar case housing the floppy disk unit.

#### Data and Program Storage

Bulk storage for the system is provided by the RX01 dual floppy disk unit. Its interface is located immediately after the MOS memory on the LSI-11 bus, making it the highest priority peripheral.

The floppy disk unit is a compact magnetic storage device requiring less power than other disk or magnetic tape drives. With an average access time of 500 ms,

Figure 2. Mounting locations for system components.

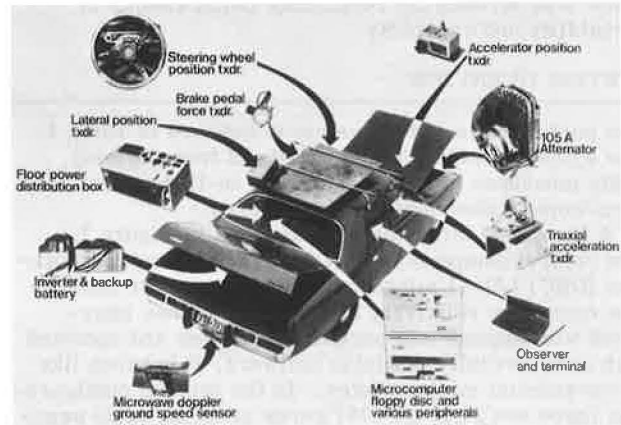
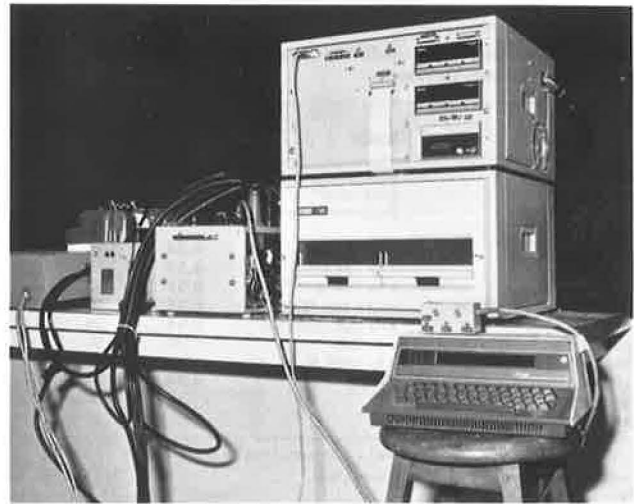


Figure 3. Major system components benchted (left to right: terminal power supply, reserve battery, inverter, power distribution module, microcomputer and floppy disk unit, terminal and power control box).



it is considerably slower than other disks but faster than tape.

During bench operation, the floppy disk is used to store system programs, user programs, and data files. During on-road operation, the operating program is normally resident in the MOS memory, and both diskettes are available for data storage. Depending on the nature of the experiment, specifically on the frequency of data samples, considerable data processing can be performed before storage.

The mounting of the floppy disk unit is illustrated in Figure 3. It may be necessary to use more than two floppy disks for data storage during the course of an experiment. Therefore, indicators tell which diskette is currently being accessed, permitting the operator to change the other without halting the experiment.

#### Data Acquisition Panel

Data from either digital or analog transducers can be acquired. Most transducers provide analog outputs and are interfaced to a data acquisition module (analog MP 6912 with expander). This module requires only one parallel line interface unit on the LSI-11 bus, so all analog transducers appear physically as one device to the computer.

The data acquisition module presents the computer with 12 bits of discrete data for each sample input. Thus the data are quantized both in time and amplitude. Twelve-bit quantization corresponds to a resolution of one part in 4096, or approximately 0.024 percent.

Up to 24 differential input channels can be multiplexed by the data acquisition module. Differential inputs are essential since many transducers produce small full-scale voltages and are connected by long cables in the noisy environment of the car.

Under command of the computer, the data acquisition module selects one of the transducer channels either sequentially or randomly, using a channel address supplied by the computer. The transducer signal is then sampled in an operation that is virtually instantaneous compared to the slow variation of the transducer signals. The sampled datum is held and a 12-bit successive approximation analog-to-digital conversion is performed. The maximum throughput for 12-bit conversions is 30 000/s.

The data acquisition module is located on the rear panel of the microcomputer instrument case. Some transducers require amplification or filtering or both, and the circuits that perform these functions are located in the same area.

Although no digital transducers are employed at the present time, they can be added, requiring the use of one bus interface slot each. Two 12-bit digital-to-analog converters, occupying one bus slot each, provide analog outputs to drive external devices. They are also useful in a feedback arrangement to test the operation of the data acquisition module.

### Operator Interface

During experiments on the road, extensive communication between the computer and operator is not normally required. The experimenter needs the ability to command and interrogate the system. A display of certain essential information is also needed.

Two-way communication is provided by a terminal (DEC RT02), which includes a keyboard and a one-line wraparound display. For compactness, the terminal's power supply has been separated from the remainder of the circuits. The power supply is in the trunk, while a small keyboard on a platform is located in front of the operator.

Since the experimenter may wish to retain numerical information after the terminal display has changed, a small thermal printer is included that provides six columns of numerical output. The printer can be turned on or off from the panel in order to conserve power.

The time of day in hours, minutes, and seconds is displayed by a crystal-controlled digital clock located on the computer panel (see Figure 3). The computer can access this information as well as that from a digital stop clock. Although the stop clock has microsecond resolution, only the millisecond outputs are used for our purposes. The clocks are synchronized and together provide a millisecond event timing facility. The clocks are set from the front panel, and their displays can be turned off to conserve power.

For bench operation, the RT02 terminal is usually replaced by a teletype with paper printout. The microprocessor, memory, floppy disk unit, and teletype then constitute a stand-alone computer system, useful as a general laboratory tool.

## MEASUREMENT TRANSDUCERS

### Lateral Position

For driver behavior studies, one of the most important but most difficult measurements to make is that of

lateral position on the roadway. The Human Factors Research Incorporated lane tracker is the most sophisticated and novel transducer to be incorporated in the system to date. The lane tracker can measure lateral displacement from either a solid or dashed lane marking, or—in the absence of painted lines—from the boundary between the surface and shoulder provided there is sufficient contrast between the two surfaces.

The primary signal output is an analog voltage proportional to displacement from the lane marking. Secondary outputs include an analog video sweep signal, proportional to the light imaged at consecutive sampling points in the focal plane, and a sweep synchronization pulse train.

The lane tracker consists essentially of a Reticon LC600 line scan camera, camera AGC and computational circuitry, a power supply, and mounting hardware.

The focal plane of the line scan camera contains a 256-diode linear array. The diodes are sequentially interrogated, resulting in a 256-pulse video signal. The amplitude of each pulse is proportional to the light intensity incident on the diode, corresponding to light from a section of the field of view. Typically, the lateral extent of roadway scanned is 3 m (10 ft). The resolution, defined by the lateral dimension of a diode, is about 1.2 cm (0.5 in).

The lane tracker counts the number of diodes interrogated from the start of a scan until a signal from one of the diodes exceeds a preset data threshold. By adjusting scan rate, the AGC circuitry permits operation at optimum sensitivity over a range of seven F-stops. Signal-conditioning circuits permit continuous tracking of striped delineations and rejection of high frequency noise associated with transient road surface characteristics. The lane tracker draws about 1.25 A at 12 V.

In a typical mounting position (see Figure 2), the lane tracker is aimed at the road surface behind the left rear wheel. A venturi, mounted on the side of the transducer, maintains a reduced pressure inside the case to inhibit fogging of the optics.

### Speed

True ground-speed information is obtained using an RCA Doppler ground-speed sensor (2). The range of operation is up to approximately 53 m/s (120 mph). Its published accuracy is 1 percent over the range from 9 to 30 m/s (20 to 70 mph).

The unit transmits a 30-mW, 10.53 GHz signal that is diffusely reflected by the road surface. The back-scattered component is received and mixed with the transmitted signal to separate the Doppler difference frequency. The Doppler frequency is proportional to ground speed and is in the low audio region.

Two outputs are provided, a 6-V square wave with frequency equal to the Doppler frequency, and a train of constant width 6-V pulses of the same frequency but with varying duty cycle, which can be integrated to obtain an analog output. The device includes a calibration and checking circuit. For our purposes, the analog output is amplified and low pass filtered to obtain a full-scale output of 5 V.

The dimensions of the unit are 20 cm × 13 cm × 1.6 cm (8 in × 5 in × 0.6 in). In Figure 2 it is shown mounted beneath the rear bumper at a 45° angle to the road.

### Acceleration

Measurement of vehicle acceleration is provided by three orthogonally mounted, low frequency, force



balance accelerometers (Columbia SA 107). Their range is  $\pm 24.5$  m/s ( $2.5 g$ ) with full-scale linearity of 0.2 percent. Their output is  $\pm 5.0$  V full scale for  $\pm 15$ -V dc excitation. The signal is filtered and applied directly to the data acquisition module. The accelerometer package, including a spirit level, is approximately 13 cm  $\times$  13 cm  $\times$  8 cm (5 in  $\times$  5 in  $\times$  3 in), and is mounted on the hump in the floor of the vehicle beside the driver.

#### Brake Pedal Force

Brake pedal force is measured using a pedal force transducer (GSE Incorporated, Model 300), designed specifically for the job. A maximum force of 1300 N (300 lb) can be measured with an accuracy of 2 percent of full scale. This is a bridge-type transducer that has a full-scale output of 22.5 mV. Consequently, the signal is amplified by a factor of 220 before being applied to the data acquisition module. Mounting this transducer is easy; it simply clamps on the pedal as shown in Figure 2.

#### Accelerator Position

Measurement of accelerator position is accomplished using a linear displacement transducer (Celesco Model PT101) attached to the carburetor linkage. This attachment is simple and unobtrusive. The computer compensates for nonlinear effects due to the nature of the linkage using a calibration table.

Displacements of up to 15 cm (6 in) can be measured with the transducer, with a resolution of 0.003 cm (0.001 in). The dimensions of the transducer are 13 cm  $\times$  7 cm  $\times$  6 cm (5 in  $\times$  3 in  $\times$  2 in).

#### Steering Wheel Position

The only transducer that has been manufactured in-house is the steering wheel position transducer. To get a high resolution measurement of steering wheel reversals about the center position, a potentiometer is used which completes one revolution for every 0.7 rad ( $40^\circ$ ) of steering wheel travel. A geared pulley and non-slip drive belt are used with this potentiometer. Coarse measurement of position over the full range of steering wheel movement is provided by a ten-turn potentiometer, with which a standard pulley and O ring are used.

Both potentiometers are miniature precision types and have a linearity better than 0.5 percent and a resolution better than 0.01 percent. They are mounted on the steering wheel housing as shown in Figure 2.

#### Future Transducers

Eventually, it should be possible, using radar, to monitor the distance between the test vehicle and a leading or trailing vehicle. Other transducers may be added to monitor physiological parameters, including heart and respiratory rates, and head and eye position.

#### POWER DISTRIBUTION

Power distribution is summarized in Figure 4. The entire system is powered by the car using a high current alternator (105 A) and an extra battery. The reserve battery allows up to 15 min of operation of the computer system without the alternator. Therefore, in the event that the engine stops, the experimenter has ample time to save all data.

A 12-V to 12-V dc converter rated at 8 A and a 12-V to 5-V dc converter at 30 A provide regulated direct current to supply the computer, digital devices, and some transducers. A 500-W inverter provides 115-V/60-Hz power to devices normally operated from the line, such as the floppy disk unit and terminal. Most analog transducers require  $\pm 15$  V direct current, which is provided by a small modular encapsulated power supply operating from the inverter.

The system features well controlled grounds. All grounds are referenced to a single point that may be chosen anywhere on the car chassis as convenience dictates.

Control circuits allow either the alternator or reserve battery or both to be switched in. In any case, power is initially applied to the converters and the inverter loaded only by the clocks and fans. These devices are considered essential to the basic operation of the system. Another switch applies power to the processor, its peripherals, and the transducers. All power is monitored by a switched meter on the power control unit, and by signal lights on the computer control panel.

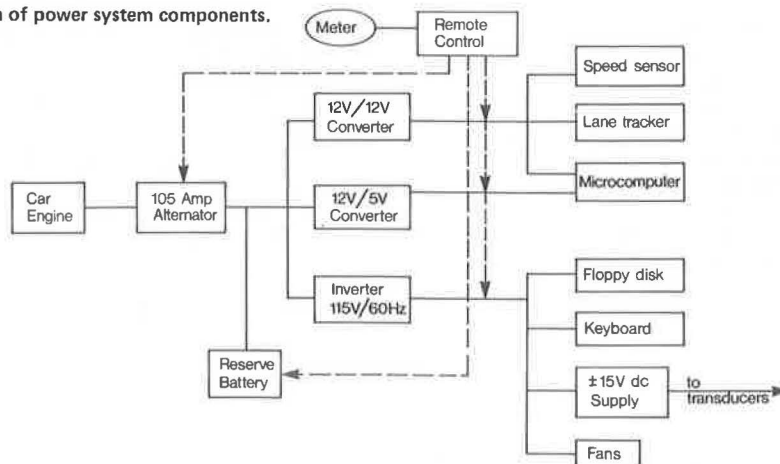
#### SOFTWARE

Software for the system may be conveniently classified in three categories:

1. General purpose,
2. Diagnostic, and
3. Operational.

General purpose software was purchased as a package (DEC RT-11) with the microcomputer. It includes

Figure 4. Block diagram of power system components.



utility programs for microcomputer operation and permits programming in Assembler, Fortran, or Basic. A library of subroutines is provided. With a good knowledge of RT-11 and either Fortran or Assembler, it is possible to write routines to acquire data from the transducers and store the data on diskettes. Using this approach, a program has been written to sample up to nine transducers every 100 ms and to store their outputs and a possible marker. This program has been used for transducer testing and early experiments.

Diagnostic software for checking the microcomputer was also purchased (DEC RXDP-11) in a convenient floppy-disk-based package, useful for exercising and checking the microcomputer, including memory, instructions, and interfaces. The diagnostic programs can be run in either stand-alone, chained, or interactive mode. Since the package is modular, other diagnostic programs can be added.

To run experiments in which many transducers are sampled and calculations are performed on-line, a dedicated system program is being developed. This system program will give the experimenter control over such parameters as sampling rate, channel to be selected, start-stop, and functions to be evaluated. The program will be modular so that it will be possible to add routines or modify existing routines without disturbing its overall framework. To save memory space it will not be necessary to load routines that are not required for an experiment. With this program, it is estimated that up to 15 channels can be sampled at 10-ms intervals.

#### CONCLUSION

This system has been operating on the road since the spring of 1977. Its success has been made possible by

recent advances in microcomputer and data acquisition technology and continued progress in these fields will probably lead to higher sampling rates and relatively lower costs. In the meantime, it provides a unique opportunity to study behavior in actual driving situations in a quantitative manner.

#### ACKNOWLEDGMENT

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# Michigan's Driver Education Evaluation Project: Classroom Testing and In-Car Development

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During 1977, the Michigan Department of Education evaluated statewide driver education programs. Rather than use the traditional approach of accidents and violations, the department investigated students' cognitive skills by means of objective-referenced tests. Previously, minimal performance objectives for both classroom and in-car portions of driver education had been developed. These objectives are considered basic for every Michigan program. After finalizing the objectives, appropriate test items were developed with the major focus on the classroom objectives. Following the pilot testing of the classroom items, 60 objectives were selected for statewide administration. Objective-referenced tests enabled not only the education department but also individual teachers to know the strengths and weaknesses of students and classroom environments. Each classroom objective was measured by five items; to attain an objective, a student would have to answer at least four items correctly. Statewide, the a priori criterion was that 80 percent of the students would attain each objective. Results

based on approximately 100 000 students showed that only 13 objectives met the criterion level. These results indicate that there is a need for improvement in instruction of driver education. As skills became more advanced, attainment decreased. In the summer of 1977, an in-car measure was developed and raters were trained. The in-car test was administered to 30 students to determine its reliability. Forty students were used to validate the measure against the Michigan State University's Driver Performance Measure. Results for both studies were positive. Time, however, did not permit pilot testing this measure on a stratified sample of students.

Since the mid-1930s, Michigan has offered driver education to its youth. By 1954, approximately one-half of the state's school districts offered such instruction.