DATA ACQUISITION SYSTEM FOR STUDIES OF DRIVER PERFORMANCE IN REAL TRAFFIC

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This paper describes a real-time data acquisition system installed in a full-sized North American automobile for the study of driver performance in real traffic and under various conditions of driver stress. The basic parameters recorded are distance traveled and three primary control movements: steering wheel, accelerator, and brake. Provision is also made for vehicle yaw measurement, driver's pulse rate, and perceived illumination level in night-driving tasks. Other parameters may be recorded as dictated by project requirements. Test conditions and principal findings of the various projects carried out at the National Research Council of Canada during the past 3 years are discussed. In these projects, the frequency and magnitude of steering wheel movements have formed the basis for assessment of driver performance and task difficulty. The application of power spectral analysis techniques appears most promising, and it is in this context that the advantages of a system for highly flexible, real-time data acquisition are most apparent.

•DURING the last 11 years, several researchers (3, 4, 5) have used instrumented vehicles to assess a driver's performance in traffic. Some work has also been done (6, 7, 8) on the stimuli that cause particular patterns of control movements. A consensus based on their results indicates that the relative skill of a driver can be assessed by an analytical study of the frequency and correlation of the three primary control movements: steering wheel, accelerator, and brake. Of these three, it appears that the frequency and magnitude of steering wheel movement may have the greatest significance.

In normal circumstances, the changing heading rate of a vehicle stimulates steering wheel movements. Lateral movement in more difficult circumstances in which constraints are imposed on the driver by external factors such as lane width and traffic density may also influence steering wheel movement. Wind speed and pavement surface characteristics will affect assessment of a driver's performance based on control movements. All external stimuli may be considered as independent random variables, and the separation of their individual contribution to the overall pattern of control movements is extremely difficult.

By using the same route for a given experiment in normal traffic situations, starting each test run at the same time of day, and acquiring sufficient data from each subject to form a statistically significant sample size, one can minimize the effect of these random variables.

This paper describes a real-time data acquisition system installed in a full-sized North American automobile for the study of driver performance in traffic. Application of this system in specific tests conducted by the National Research Council of Canada and findings from these tests are also reviewed. Following is a discussion of the test vehicle and the instrumentation used.

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TEST VEHICLE

The test vehicle is a standard North American four-door hardtop with a 429-in.^{3} (7-liter), V-8 engine, three-speed automatic transmission, numerous power options, and air conditioning. The air conditioning was mandatory so that cooled air could be provided for the data acquisition system.

The data acquisition system is housed entirely within the car trunk. The 110-Vac, 60-Hz electrical power requirements for the system are provided by an engine-driven 28-V alternator, a 24-Vdc battery system in the engine compartment, and two static inverters in the trunk. The maximum power output is 500 V-A.

Power for the signal transducers is obtained from a small rechargeable nickel-cadmium battery pack.

Preliminary investigations, confirmed by Blais (15), showed that the Vdc measured directly at the headlamps varied within wide limits, and consequent variations resulted in seeing distance. In night-driving tasks, headlamp voltage had to be controlled within precise limits. This was achieved by boosting the nominal voltage to 18 Vdc, which was then regulated to 12.8 Vdc (±0.10 percent). This did not affect any other part of the basic 12-V electrical system of the vehicle.

The trunk also houses a two-way, 35-W mobile radio transceiver for voice and data communications.

A low-pressure, pneumatic booster system with rear suspension has been added to prevent rear-end sag due to the increased weight in the trunk.

Principal dimensions of the vehicle are (1 in. = 0.03 m)

Item	Dimension (in.)
Overall length	222
Overall width	78
Overall height	57
Wheelbase	123
Track, front	63
Track, rear	64

The gross weight of the vehicle with zero fuel and no occupants is 4,950 lbm (2246 kg), and the weight distribution is 53 percent in the front and 47 percent in the rear.

Figure 1 shows the vehicle.

DATA ACQUISITION SYSTEM

The principal component of the data acquisition system is a third-generation, 16-bit minicomputer consisting of a central processor and a core memory that has a total capacity of 16-K bytes. The following external peripheral devices are interfaced with the central processor:

1. A 16-channel analogue-to-digital (A-D) converter with either random or sequential channel selection under program control. Each channel may be used with any one of five program-controlled gain settings. When there is a gain of unity, the maximum input voltage before conversion is ±10 V. The resolution after conversion corresponds to an output voltage change of approximately ±5 mV.
2. A 7-track reel-to-reel magnetic tape unit for bulk data storage and subsequent recovery. The recording density is 556 bpi, and the maximum tape capacity is 600 ft (183 m). When allowances for writing interrecord gaps and end-of-file gaps are made, the maximum effective data transfer rate from core to tape is approximately 350 eight-bit data bytes/second. At this maximum rate, the duration of a single test run before it is necessary to mount a new tape reel is approximately 45 min.

Figure 1. Test vehicle.

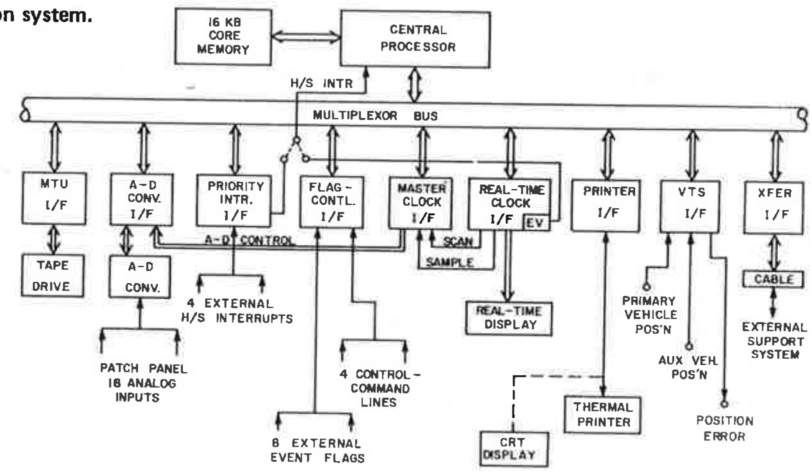


Figure 2. Data acquisition system.

Figure 3. Installation of system in vehicle trunk.

3. An 80-column thermal printer (300-baud rate). This provides direct access to and control of all data acquisition functions by commands entered from the keyboard by the operator. It also serves as an output device for logging system messages, and under certain circumstances, may be used for on-line printing of preselected data parameters during a test run.

The printer may be replaced by an optional cathode ray tube (CRT) display device (2,400-baud rate), which has the same input/output (I/O) functions as the printer but does not provide a hard copy. The CRT device may also be used to provide a graphical display of one or more data parameters, but as such it can only be used as a stand-alone device not under control of the real-time basic operating system.

There are five additional system components or interfaces, but, for the purposes of this paper, they may be considered peripherals because they function as I/O devices. These components are

1. A timing control system, which uses a 6-MHz crystal oscillator as a reference. The output is fed through a divider network and has two functions. It acts as a programmable master clock, which is used to control the time intervals at which data are read from the A-D converter. It also provides the reference for a programmable digital clock, which may be set to real time by an operator entry from the printer keyboard and read under program or operator control with a resolution of 1 ms. Real time may also be read and recorded simultaneously with data to verify data continuity during recovery from tape and to record occurrence time of specific events.
2. A high-speed interrupt device, which accepts up to four interrupts from external stimuli. These interrupts are acknowledged and serviced on a priority basis and take precedence over all normal system I/O interrupts, which are queued on the multiplexor bus.
3. A flag-control device, which has two functions. The flag section accepts up to eight interrupts from external stimuli, which are used simply as on and off indicators (event markers). The control section can control up to four external devices, which are not directly interfaced with the central processor. For example, a control line may be used to switch a chart recorder on and off at specified time intervals.
4. A vehicle-tracking device by which the relative position of the test vehicle and an auxiliary vehicle may be determined at any time. It also acts as a distance-traveled accumulator for the test vehicle.
5. A slave-transfer (I/O) device, which is not part of the data acquisition system proper. It is used with the laboratory support system for loading programs into the vehicle computer and for data transfer from the computer (or magnetic tape unit) to the support system devices for further processing.

Figure 2 shows a functional block diagram of the complete system.

The complete data acquisition system except the printer is rack mounted in a steel frame, which normally lies flat in the trunk (Fig. 3). The lower front edge of the frame is hinged, which allows the complete system to be swung up 90 deg for access to and servicing of the components.

The thermal printer (or CRT device) is installed in the rear-seat space of the vehicle on a board resting on the center portion of the bench seat.

SYSTEM CONTROL AND OPERATION

The data acquisition and control software interfaces with a basic operating system. These two programs together form a real-time system that occupies approximately 12,000 bytes of core memory and that gives the operator complete control of all data acquisition functions by commands entered from the printer keyboard.

The structure and operating principles of the data acquisition and operating system software packages are described by Sewell and Perratt (1).

Note that an equal-capacity, two-buffer system is used that permits incoming data to be stored in one buffer while, at the same time, the contents of the alternate buffer are being written on tape.

VEHICLE INSTRUMENTATION

Vehicle Tracking

The vehicle-tracking system (VTS) was designed primarily for use in night-driving tasks in which the driver of the test vehicle is subjected to headlamp glare from an approaching vehicle. In analysis of the data, one must be able to determine the relative position and velocity of the two vehicles at any given time.

In brief, the VTS accepts wheel revolution counts (equivalent to distance traveled) generated by the test and glare vehicles and, in combination with software, computes the positional error, which is then displayed to the driver of the glare vehicle. The display is a meter needle moving over a graduated scale; the displacement of the needle from the center-zero position indicates to the driver of the glare vehicle whether acceleration or deceleration is necessary to maintain position with the test vehicle.

Wheel revolution counts are generated by the test vehicle in the following manner. A system consisting of a two-lobe shutter and two photocell circuits is built into the left rear wheel hub. The shutter is coupled directly to the rear axle hub assembly, and, as it rotates, it sequentially interrupts the transmission of light between the emitter and receptor of each photocell circuit. Two symmetrical square-wave pulse trains are thus generated with a 90-deg phase shift and with 4 cycles per wheel revolution.

The pulse trains are fed to a sorting and decoding logic circuit designed to discriminate between forward and reverse vehicle motion. The end result is the generation of a single train in which there are eight pulses (counts) per wheel revolution.

Wheel revolution counts are generated by the glare vehicle similarly, except that the shutter is driven from the speedometer drive shaft. The sorting and decoding logic is less sophisticated, and the final train contains only four pulses per wheel revolution. Equating glare vehicle counts with those of the test vehicle is carried out by the data acquisition program.

The pulse train generated by the test vehicle is fed to a 16-bit, up-down counter that is software extended to 28 bits for forward motion only. In normal use, this counter is simply read on command to determine the total distance traveled in terms of the total accumulated wheel counts.

The pulse train generated by the glare vehicle is fed to a 12-bit counter whose contents are modulated and transmitted to the test vehicle every 100 ms by a mobile radio transceiver similar to that installed in the test vehicle. The received signal is fed to a demodulator that converts it back to binary form. The serial binary information is operated on by both hardware and software and is compared with the information in the test vehicle counter. The final result of the comparison represents the positional error of the glare vehicle, which appears as a 6-bit (sign plus 5 bits of magnitude) serial sequence preceded and followed by 1 synchronizing bit. This sequence is modulated and transmitted back to the glare vehicle. The position error signal is then demodulated and used to update a position error storage register, the contents of which are fed to a digital-to-analogue converter. The voltage output from the converter is then used to provide an analogue error signal on the visual display meter of the glare vehicle. The complete system, designed by Perratt, is described in detail and includes all logic circuits and software notes (2).

Digital Inputs

All serial digital inputs occur as step functions that are recorded as a change of state of a control flag. The flag states are set (high) or reset (low). Six serial digital inputs are currently available.

Turn Signals

Operation of the turn signal lever causes either the left- or right-turn flag to be set. A capacitive-discharge circuit ensures that the flag remains set as long as the signal light is flashing. A lockout feature is provided, which ensures that both flags remain reset when the emergency warning flashers are used.

Driver-Controlled Event Marker

The standard turn signal lever has been replaced by a specially designed lever having the same weight and center-of-gravity position. A spring-return microswitch is built into the lever, and the operating button projects from the stalk. The button is operated by light finger pressure and causes the flag to be set whenever it is pushed in.

The button may be used to signal an event of special significance while a test run is in progress. Alternatively, with suitable software, it may be used for data acquisition program control when, for psychological reasons, the presence of an operator in the vehicle is to be avoided.

Operator-Controlled Event Marker

This is a simple on-off switch and has the same functions as the driver-controlled event marker. It may also be used to convey a visual or audible signal to the driver.

High-Beam Indicator

The flag is set whenever the headlamps are switched to high beam and is not reset until low beam is returned to. The time on high beam is determined from the difference between the set and reset times.

Brake Applications

The flag is set whenever the brake pedal travel equals or exceeds 0.50 in. (1.27 cm) from the brakes-off position.

In this context, consideration has been given to measurement of hydraulic pressure directly at the brake cylinders as an analogue signal; however, this creates a number of currently unresolved problems in maintaining integrity of the braking system.

Analogue Inputs

For achieving maximum resolution, all analogue inputs generated by the signal transducers are preconditioned so that the voltage presented to the digitizer of the A-D converter has a maximum range of ±10 V after application of the program-specified gain factors.

Following are the analogue inputs currently available.

Steering Wheel Position

A 10-turn potentiometer is driven from a split pulley clamped to the lower end of the steering column, which is immediately forward of the firewall. The maximum steering wheel rotation is $4\frac{1}{4}$ turns lock-to-lock, and the angular resolution is approximately ±0.25 deg.

Accelerator Pedal Position

A single-turn potentiometer is driven from the throttle shaft linkage to the carburetor. The relationship between output voltage and pedal position is not absolutely linear, but the errors are not sufficiently significant.

The maximum pedal travel is 2.5 in. (6.35 cm), and the positional resolution is approximately ±0.001 in. (±0.025 mm).

Illumination Level

A photovoltaic cell with a cosine receptor is mounted immediately in front of the rear-view mirror at the top center of the windshield. The maximum output voltage is adjusted to suit the maximum opposing glare conditions to be expected. Typically, standard Society of Automotive Engineers (quad) headlamps on high beam result in a perceived illumination level of 1.0 ft-c (10.764 lx).

Yaw Measurement

Two servoaccelerometers are mounted on the vehicle. One is on the front bumper, and one on the rear, and their sensitive axes are perpendicular to the longitudinal centerline of the vehicle in the horizontal plane.

By appropriate combination of the two outputs, the resultant signal represents acceleration in yaw. Vertical and horizontal accelerations, either separately or combined, are almost eliminated by the low cross-axis sensitivity. Lateral- and roll-motion sensitivity are minimized by suitably matching the individual accelerometer sensitivities before the outputs are summed.

Driver's Pulse Rate

Three silver/silver chloride electrodes are attached to the driver's body with a non-irritant electrolyte gel, which completes the circuit between the skin and the electrodes.

The electrodes are placed as follows: (a) on the sternum approximately 2 in. (5.08 cm) below the larynx, (b) immediately over the heart, and (c) over the fifth intercostal space on the right side.

After signal conditioning and amplification are done, the voltage is supplied to a triggering circuit so that a rectangular pulse is generated at approximately 75 percent of the maximum systolic peak voltage.

The wave train thus generated may be used either to determine (a) the average pulse rate over a specified time period or (b) the actual time interval between each systolic peak. In the experiments carried out to date, the latter method has been used because it detects instantaneous changes resulting from transient stress conditions.

SUPPORT SYSTEM

A comprehensive support system is provided in the laboratory so that programs may be loaded into the on-board vehicle computer and recorded data may be extracted from core memory or tape.

The principal component of the support system is an advanced version of the computer installed in the vehicle, with 24-K bytes of core memory.

The following peripheral devices are interfaced with this computer:

1. A standard teletype (110 baud rate);
2. A high-speed card reader (400 cards/min);
3. A 132-column, high-speed line printer (300 lines/min);

4. A high-speed, paper tape reader-punch (read at 400 characters/s, punch at 75 characters/s); and
5. A 9-track, 25-in./s, 800-bpi read/write tape drive and controller for editing and rerecording raw data.

Support system facilities are interfaced with the vehicle computer by using the slave-transfer interface of the latter and a master-transfer interface, which is part of the support system facilities.

The complete support system facilities are also interfaced by a dataset adapter and modem (2,400 baud rate) with the central computational facilities (IBM 360/67 time-sharing system) of the National Research Council of Canada (NRCC).

The laboratory-based support system thus becomes a complete programmable remote-job entry terminal. By this, raw data may be preprocessed for transmission by the datalink to the central computer and may be stored there for further processing and analysis.

RESEARCH STUDIES AT NRCC

Research work carried out at NRCC for assessing driver performance can be classified under four main headings:

1. Experiments on a multilane, limited-access divided highway with a vehicle moving at a nominally constant speed (free-situation driving task);
2. Experiments on a route in which both the number of lanes (divided or otherwise) and the posted speed limit vary (controlled-situation driving task);
3. Night-driving tasks in which the driver of the test vehicle is subjected to headlamp glare from approaching vehicles; and
4. Experiments to determine the effects of alcohol and drugs on driver performance.

The real-time data acquisition system described is a recent development and has been used operationally only in alcohol and drug experiments. All previous work was carried out by using a non-real-time system of considerably less complexity. In addition to the lack of a continuous real-time reference, high-speed interrupt, and external device control features, it did not possess the double-buffer system, which permits simultaneous data storage in the core and data transfer to tape.

Because of the lack of the double-buffer system, the core space available for data storage was restricted to that remaining after the basic control programs had been loaded. When this core space was filled, further data acquisition was suspended until the data in core had been transferred to tape. This gave the researcher two options: (a) acquiring data at relatively infrequent intervals from 30 min to 2 hours or (b) acquiring data at a high rate for as short a time as 1 min.

If the first option were exercised, the number, sign, and magnitude of steering wheel and accelerator pedal movements were determined as control reversals by the data acquisition software by using a logic method developed by Sewell (9). In exercising the second option, control positional information was stored directly in core.

Free-Situation Driving Task

The route chosen was a 35-mile (56-km) section of limited-access divided highway with six lanes on 5 miles (8 km) and four lanes on 30 miles (48 km). The posted speed limit throughout is 60 mph (96 km/h).

Sixteen volunteers were used (11 men and 5 women). Their ages ranged from 25 to 53, and they had from 9 to 30 years of driving experience. All subjects except one had accident-free records.

During the 11 months of the project, a total of about 6,000 miles (9600 km) were driven. For the first 2 months, an observer was carried in the vehicle, whose function was to make subjective estimates of traffic density at selected points along the route. For the remainder of the test period, the driver was the sole occupant.

Data were acquired at intervals of 7.5 s. Each 7.5-s time slice contained the following noncumulative information: wheel counts (distance traveled), number of steering reversals, number of accelerator pedal reversals, and number of brake applications.

For the first 2 months, steering wheel reversals were recorded at only one level of magnitude (2 deg). Preliminary analysis showed that this was insufficient and the number of levels was increased: from two (2 and 10 deg) to seven (from 1 to 30 deg). Accelerator pedal reversals were recorded at one level only [0.10 in. (2.5 mm)], and the number was not increased because of core space restrictions.

By a plot of steering reversal rate against magnitude for three vehicle speed ranges, Figure 4 shows the reasons for increasing the number of steering reversal levels. In Figure 5, essentially the same information is shown, but steering reversal rate is plotted against vehicle speed for seven levels of magnitude.

If the experimenter had selected steering reversal magnitudes from 8 to 12 deg as a criterion for assessment of driver performance, analysis would probably not have indicated any significant differences between subjects, nor would the effect of changes in vehicle speed have been apparent.

Except for one female subject who had driven professionally in sports car and formula A races, no significant correlations were established between steering and accelerator reversal rates. However, for her, correlation patterns were more consistent and were significant at the 5 percent level in 75 percent of the runs made.

The relationship between steering reversal rate and magnitude suggests that the performance of an individual driver may be associated with a unique pattern. Certainly, the more experienced (and less aggressive) drivers exhibited greater consistency in their control movement patterns.

The route was divided into nine sections according to observed average traffic densities. These observations, although highly subjective, were sufficiently informative to indicate that the frequency of steering reversals associated with vehicle tracking (5 deg of magnitude or less) depends on traffic density. Figure 6 shows the percentage of mean variation in steering reversal rate for each section. The highest traffic densities were observed in sections D to F and correspond to the six-lane section in which there are five interchanges.

The data were also analyzed to determine the effect of wind speed on steering reversal rates. Two reversal magnitudes were selected: 2 and 10 deg, the tracking and maneuver reversals respectively. The wind speed ranged from 0 to 20 mph (0 to 32 km/h) and was divided into subranges of 5 mph (8 km/h) each. The actual steering reversal rates obtained were normalized by dividing by the vehicle speed so that effects of changes in vehicle speed could be minimized.

The ratios of tracking and maneuver steering reversal rates to vehicle speed were plotted against wind speed, as shown in Figure 7. Both tracking and maneuver reversal ratios are linear functions of wind speed, and the proportion of tracking to maneuver reversals decreases exponentially with increasing wind speed.

Four experimental test runs were made with four male subjects to determine pulse interval. Each subject was instructed to use the event marker to signal the decision-making point in what he considered to be a difficult overtaking situation. Although the data obtained were insufficient for statistical purposes, some interesting general trends were apparent.

Each subject's pulse rate was first determined in an inactive, at-rest state. The average rate was 68 beats/min. Sitting in the stationary vehicle before starting a run increased the rate to 78, and moving on the highway at 60 mph (96 km/h) increased the average pulse rate further to 84 beats/min in a completely normal situation.

However, when the decision point had been reached in a difficult situation, the systolic interval initially increased from an average, normal situation value of 0.71 s to as much as 1 s and remained at that level for 3 or 4 beats. This was immediately followed by a sharp decrease in the systolic interval to 0.5 s or less, which corresponds to a pulse rate of 120 to 150 beats/min. The high pulse rate was maintained until normal driving conditions had been reestablished. Results of the free-situation driving

Figure 4. Steering reversal rate versus magnitude as function of vehicle speed.

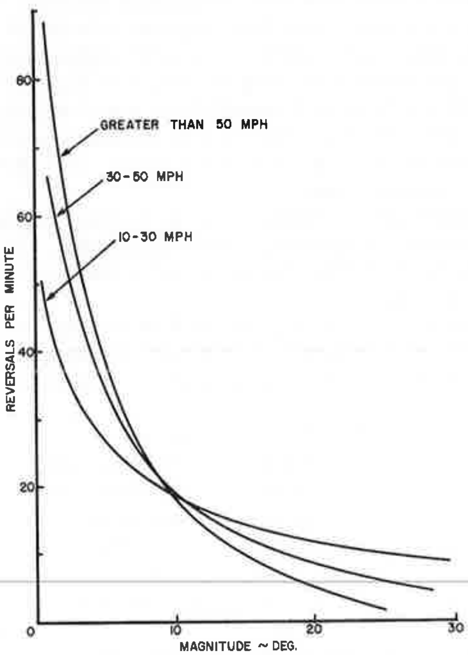


Figure 5. Steering reversal rate versus vehicle speed as function of magnitude.

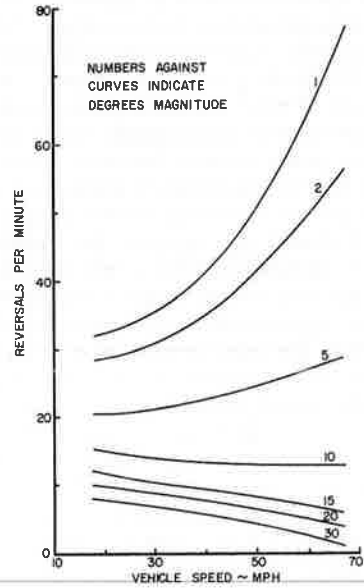


Figure 6. Percentage of mean variation in steering reversal rate by highway section.

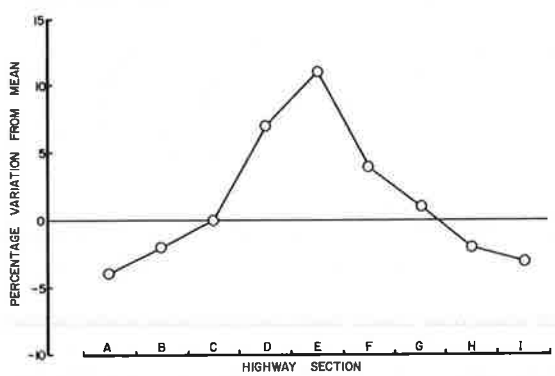
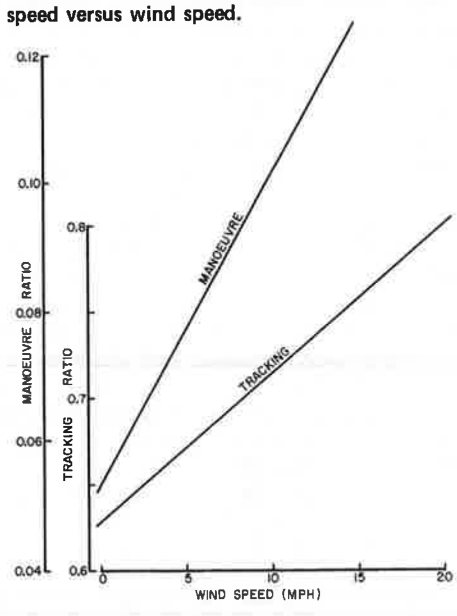


Figure 7. Ratios of steering reversal to vehicle speed versus wind speed.



task experiments will be published by Sewell (14).

Controlled-Situation Driving Task

The route chosen was 18.9 miles (30.2 km) long and was divided as given in Table 1.

Twelve volunteer subjects were divided into two groups according to age and experience. Each group had four men and two women; all had accident-free records.

Each subject was asked to drive over the route nine times and make three runs at each of three specified times of day. In all runs, an observer who was to keep a precise count of the number of approaching vehicles and to record the type of passing maneuver made by the subject was carried in the rear seat.

Data were recorded in the same manner as in the free-situation driving tasks, except that the number of steering reversal levels was increased to eight, and the number of accelerator pedal reversal levels was increased to five.

In general, each subject appeared to have a unique pattern of control movements that remained fairly constant throughout. The relationships between steering reversal rate and vehicle speed and between steering reversal rate and traffic density in the free-situation driving tasks were confirmed.

Statistical differences between the two groups (whose average driving experience was 7.3 years and 26.2 years respectively) were expected to be less than that reported by Greenshields and Platt (4), whose driving experience comparison groups were 10 weeks and 20 years. Although this expectation was found to be true, there were no significant differences in the means of each measure examined. This may reflect a greater similarity in driving ability as distinct from experience.

The less experienced group made significantly more fine-steering reversals (1 deg), which would suggest more accurate tracking performance. This would appear to be a somewhat paradoxical situation because tracking performance may be directly related to driving skill; however, tracking performance should be considered as follows (7):

> Steering is a loosely constrained tracking task requiring that errors be kept within acceptable limits rather than continuously minimized. The ability to assess an acceptable tolerance on steering errors is one of the skills of driving. Excessively accurate steering reduces the driver's capacity for handling other facets of the driving task.

The less experienced group made fewer accelerator reversals and more brake applications. This suggests that the driver with less experience is more inclined to use the brakes as a means of controlling vehicle speed. Results of these experiments have been reported by Smiley (10).

Night-Driving Tasks

Night-driving experiments were conducted on a section of highway not yet opened to the public. The objective was to obtain data for steering wheel position and related illumination levels for typical two-lane passing situations in which the driver of the test vehicle was subjected to glare from approaching vehicles.

Analysis of data in previous work and studies by McLean and Hoffman (6, 7, 11) have indicated that power spectral analysis methods applied to data for steering wheel position would prove most informative.

The successful application of power spectral analysis methods to discrete raw data requires that data samples be obtained at a frequency not less than five times the maximum expected frequency of occurrence. So that this requirement could be satisfied, data were acquired at a rate of approximately 17 samples/s. Core space restrictions limited the duration of a single run to approximately 1 min.

Table 1. Section description of route for controlled-situation driving tasks.

Type of Road	Number of Lanes	Divided	Length (miles)	Traffic Density	Speed Limit (mph)
Suburban	2	No	3.5	Low	30
Limited-access	4	Yes	5.2	Medium-to-high	60
Suburban	4	No	6.8	Medium	30
Suburban	4	Yes	3.4	High	40

Note: 1 mile = 1.6 km.

Table 2. Headlamp conditions.

Condition	Test Vehicle	Glare Vehicle
A	Low beam	None
B	High beam	None
C	Low beam	Low beam
D	Low beam	High beam

Figure 8. Normalized power spectra of steering wheel movement with no opposing glare.

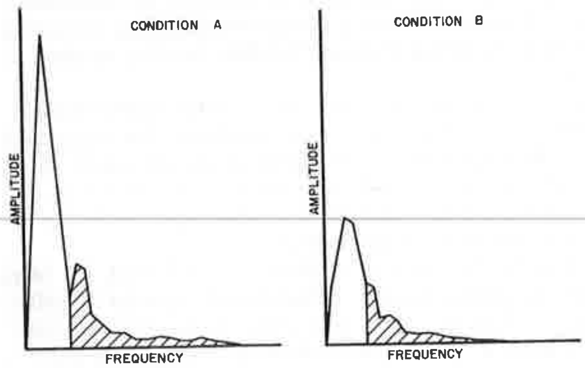
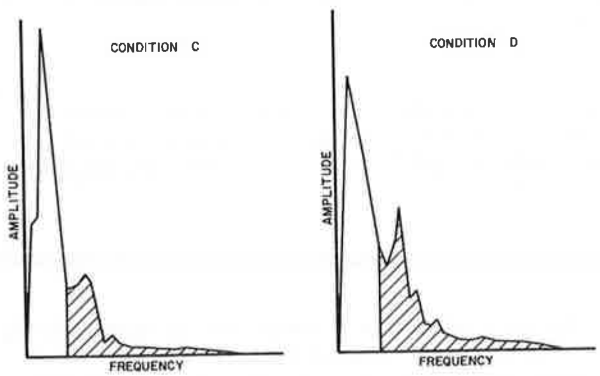


Figure 9. Normalized power spectra of steering wheel movement with opposing glare.



Six subjects were used: Three were between 26 and 30, and three were over 50. The older age group was chosen on the assumption that the eyes of those over 40 are more affected by glare.

All test runs were made at vehicle speeds of 60 mph (96 km/h) under the headlamp conditions given in Table 2.

For conditions C and D, two glare vehicles followed each other so that the driver of the test vehicle would be subjected to glare from the second vehicle 10 to 15 s after the first had passed. The first vehicle or glare vehicle was equipped with a headlamp voltage control system identical to that in the test vehicle. All vehicles were fitted with standard SAE (quad) headlamps. All subjects completed 12 runs for each no-glare condition and 18 runs for each glare condition.

The power spectral analysis of the density function of steering wheel movement frequency was calculated for each run by using the methods given by Bendat and Piersol (12).

For the no-glare conditions, the spectra were calculated for four consecutive 15-s periods and then averaged. For the glare conditions, the spectra were calculated for the 15-s period before each meeting point and 2 s after the second meeting.

According to McLean and Hoffman, the proportion of the area of the spectrum above 0.4 Hz increases with increasing task difficulty. Figures 8 and 9 show four typical normalized spectra, one for each headlamp condition (high-frequency area is indicated by hatching). For the condition given, the increasing order of task difficulty according to the McLean-Hoffman criterion is B, A, C, and D.

The average number of steering reversals between 2 and 8 deg of magnitude was greater for opposing glare conditions, whereas for steering reversal magnitudes equal to or greater than 15 deg, the average number was greater for no-glare conditions.

Any effects of glare on steering wheel movements as a function of the age of the subject were not apparent. The work involved in this project is discussed in detail by Smiley (13).

Effects of Alcohol and Drugs

These experiments were conducted on an easterly extension of the same highway (not open to the public) used for the night-driving tasks. The project was sponsored by the Insurance Bureau of Canada and carried out under medical supervision.

Vodka was administered diluted with orange juice, or it was given with either marijuana, an antihistamine (diphenhydramine), or a sedative (diazepam). Orange juice alone or with sugar capsules or marijuana cigarettes from which the active chemical ingredient (THC) had been extracted were administered as placebos.

Alcohol was administered in sufficient quantity to raise the blood alcohol level to 0.06 percent (the legal limit in Canada is 0.08 percent), and the drugs were given in proportion to body weight.

Eight volunteer subjects were used (6 men and 2 women), aged 19 to 27. All had not less than 2 years of driving experience, and all had used both alcohol and marijuana previously.

This was the first series of experiments in which the complete real-time data acquisition system was used. Steering wheel position and interval wheel counts were recorded at intervals of 50 ms. Total accumulated wheel counts and real time were recorded synchronously with these parameters at intervals of 3 s.

A special feature was introduced to determine the driver's reaction times and ability to cope with a secondary task. A red signal light was switched on at programmed random intervals, and when the driver became aware that the light was on, he or she was to switch it off by depressing a foot-operated switch. Each on-off sequence generated a priority interrupt and the event times were stored in the memory.

The test section was 8.5 miles (13.6 km) long. At the approximate center, a 2,000-ft (610-m) slalom course containing a number of sine-curve bends of varying amplitude was set up by using fluorescent cones to define a path varying in width from 8 to 10 ft (2.4 to 3.0 m). A group of three vehicle-activated traffic signals was set up at the end of the test section.

Each subject was instructed to accelerate to 60 mph (96 km/h) from the start, decelerate to 25 mph (40 km/h) on approaching the slalom, and take the vehicle through the course at that speed. The subject then accelerated to 60 mph (96 km/h) again and, at 300 yd (274 m) from the traffic signals, reduced speed to 30 mph (48 km/h) and stopped at whichever signal showed red. The front wheels were to touch a white line painted across the highway opposite the signal. The stopping error distance was then recorded.

Additional control tasks were introduced in the 60-mph (96-km/h) sections by using approaching vehicles [also traveling at 60 mph (96 km/h)] in the adjacent lane.

After the control runs for familiarization, each subject made one run 1 hour after administration of alcohol alone, the alcohol-drug combination, and the placebo to establish normal patterns. Although a complete report is not yet available, preliminary analyses have indicated the advantages of the real-time system. Power spectra of steering wheel movement show marked differences between all alcohol-drug combinations.

The subjects' approach and traverse through the slalom course varied from recklessness to extreme timidity. Vehicle control in the course was highly erratic, and in some cases, the subject came to a halt in the middle of the course. In some cases, the secondary task reaction times of the impaired drivers were less than when they were unimpaired. This indicates that the subject gave more attention to secondary task detection than to the primary task of controlling the vehicle.

RESEARCH PROJECT DEVELOPMENT

It is difficult, as with much applied research, to make firm predictions about what courses may be pursued in the future. These frequently depend on the results obtained a few months earlier, and it is quite conceivable that much of the data obtained at that time will be discarded. Nevertheless, there are certain fairly obvious statements that can be made about future motor vehicle and driver research projects at NRCC.

Up to the present time, we have been concerned primarily with the measurement of driver control movements, and there do not appear to be any valid reasons for abandoning this basic approach. However, so that information on steering wheel position may be used more effectively, simultaneous recording of heading rate error is essential. There is also room for more and improved measurement of physiological functions.

The advantages of a real-time system with a high data acquisition rate are mainly for applying power spectral analysis techniques, particularly to the establishment of cross correlations. The instrumented vehicle should not, however, be regarded as a tool for the measurement of driver performance simply because one can look at two sets of data and arrive at the immediate conclusion that subject A is a better driver than subject B. Better describes the level of manipulative and cognitive skills that have been used in the task in which the measurements have been taken. There is absolutely no guarantee that a so-called better driver is necessarily a safer driver.

The instrumented vehicle can be used more for assessing differences in behavior in any set of circumstances, determining task difficulty, and probing for investigation of highway conditions that affect driver performance.

CONCLUSIONS

The real-time data acquisition system installed in the test vehicle is highly sophisticated and extremely useful for driver and vehicle research. It is completely open-ended because research is limited only by the time needed to develop such specialized data acquisition subsystems as may be required.

Because of the weight, size, and power requirements, use of the system is, however, obviously limited to full-sized North American vehicles. As a result of this limitation, we are currently engaged in the development of a miniaturized, highly flexible, and relatively simple real-time data logging system in which parallel binary data will be serialized and recorded on a dual-track analogue tape recorder. This system will operate from the standard 12-V electrical system of any vehicle, have a very low power requirement, and be small enough to be installed in subcompact vehicles.

The development of this system and improvements in transducer and other sensor circuitry are expected to increase the data acquisition rate to a maximum of 1,000 data samples/s.

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