Low-Cost Part Task Driving Simulator Using Microcomputer Technology

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Low-cost desktop personal computers and bus-compatible expansion cards have sufficient capability for the implementation of part task driving simulators. A simulation that provides a roadway scene display, sound effects, and automated orientation and training features is described. A simulator application for long-haul truck driver fatigue is also summarized.

The role of driving simulators for research and training is steadily increasing. Advanced driving simulators including motion bases are available (*1,2*) and future designs have been proposed (*3*). However, the significant cost of these advanced, high-fidelity simulators will limit their use to a few key research facilities. Because of the relatively low cost of ground vehicles and typical instrumentation, the change from full-scale applications to the widespread use of driving simulators will require modest cost considerations. Low- to moderate-cost driving simulators have been used in the past (*4–8*) and have proven successful. Low-cost simulators use microcomputer technology found in desktop personal computers (PCs).

Microcomputer technology, which is developing at a rapid pace, is currently capable of supporting a range of simulator applications. Main processors have powerful computational capability and speed and when combined with math coprocessors provide significant speedup in numerical applications typically required for simulations. A range of bus-compatible expansion cards are also available for the IBM PC-compatible computers that permit complex visual displays and sound effects. Software capability, including development tools and run-time performance, is quite advanced for MS–DOS applications.

The general approach for simulation development on the IBM PC-compatible computers has been described by Allen et al. (*9*). This approach was used in the development of a part task truck-driving simulation to measure the effects of driver fatigue. General simulator design, capability, and a specific application were also summarized.

BACKGROUND

Visual, motion, proprioceptive, and auditory feedback cues are all important to driver performance in real-world driving. Visual and auditory cues are the least costly to provide and well within the capability of current microcomputer technology (*9*). Proprioceptive cues related to control actions are somewhat more expensive to simulate because force-feel systems require electrical, mechanical, hydraulic, or pneumatic systems for simulating control force-feel characteristics. In addition, full-body motion cues are typically quite expensive to provide because they require powerful actuator devices to move the cab environment. There is also some question about the efficacy of motion cues in military simulators (*10*), and high-fidelity simulators in general seem to induce simulator sickness (*11,12*). Thus, a lower-fidelity, fixed-base simulator may have some additional virtues in addition to low cost, particularly in applications requiring extended exposure.

Microcomputer technology can meet all of the driving simulation functional requirements for visual and auditory feedback, as discussed by Allen et al. (*9*). Driver control inputs (i.e., steering, throttle, and brake) are processed by a vehicle dynamics model, which computes vehicle angular and translational motions. On the basis of a set of visual and sound transformations, these vehicle motions are then presented to the driver through visual and auditory displays. Numerical algorithms required for the vehicle dynamics mathematical model and the display transformations can be handled adequately by the microcomputer's main processor and math coprocessor. PC bus-compatible expansion cards for visual displays and sound are available that will process display information and drive displays on the basis of simple main processor commands.

SIMULATOR DESIGN

An overall block diagram for the PC-based part task driving simulator is shown in Figure 1. The simulator uses an 80386 computer that allows sufficient computational speed to permit a reasonable compromise between update rate and complexity. Control actions are accommodated with an analog/digital (A/D) expansion card that accepts inputs from steering, throttle and brake potentiometers, and turn indicator and horn switches. Additional A/D channels will permit future expansion of control inputs. Steering, throttle, and brake signals are processed by the vehicle dynamics model that computes variables for driving the visual roadway display scene. Transformations are applied to three-dimensional (3–D) objects in the roadway scene to create a driver's perspective as displayed on a roadway scene monitor.

A block diagram of the simplified vehicle dynamics mathematical model is shown in Figure 2. Vehicle yaw rate is assumed to be directly proportional to steering wheel angle,

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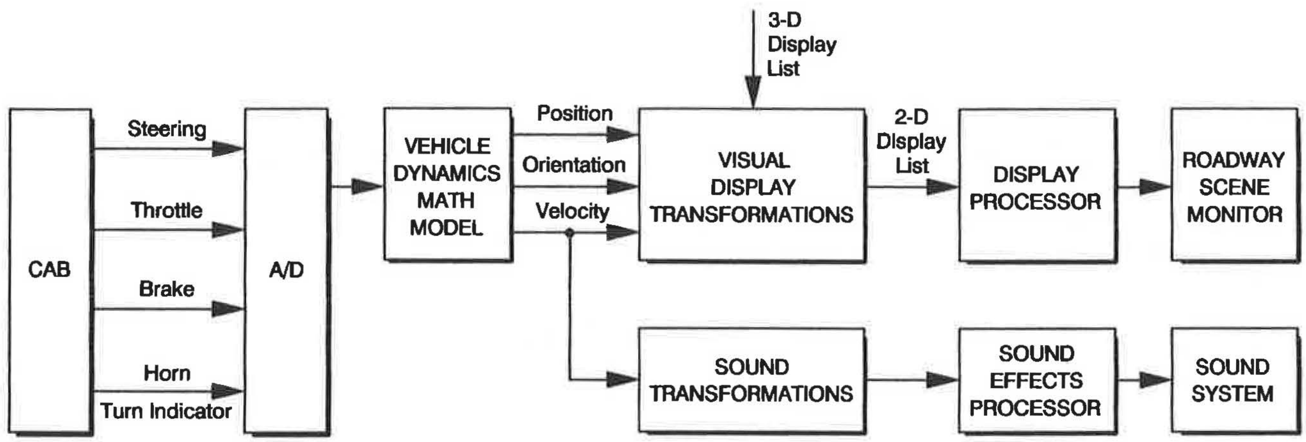

FIGURE 1 Simulator block diagram.

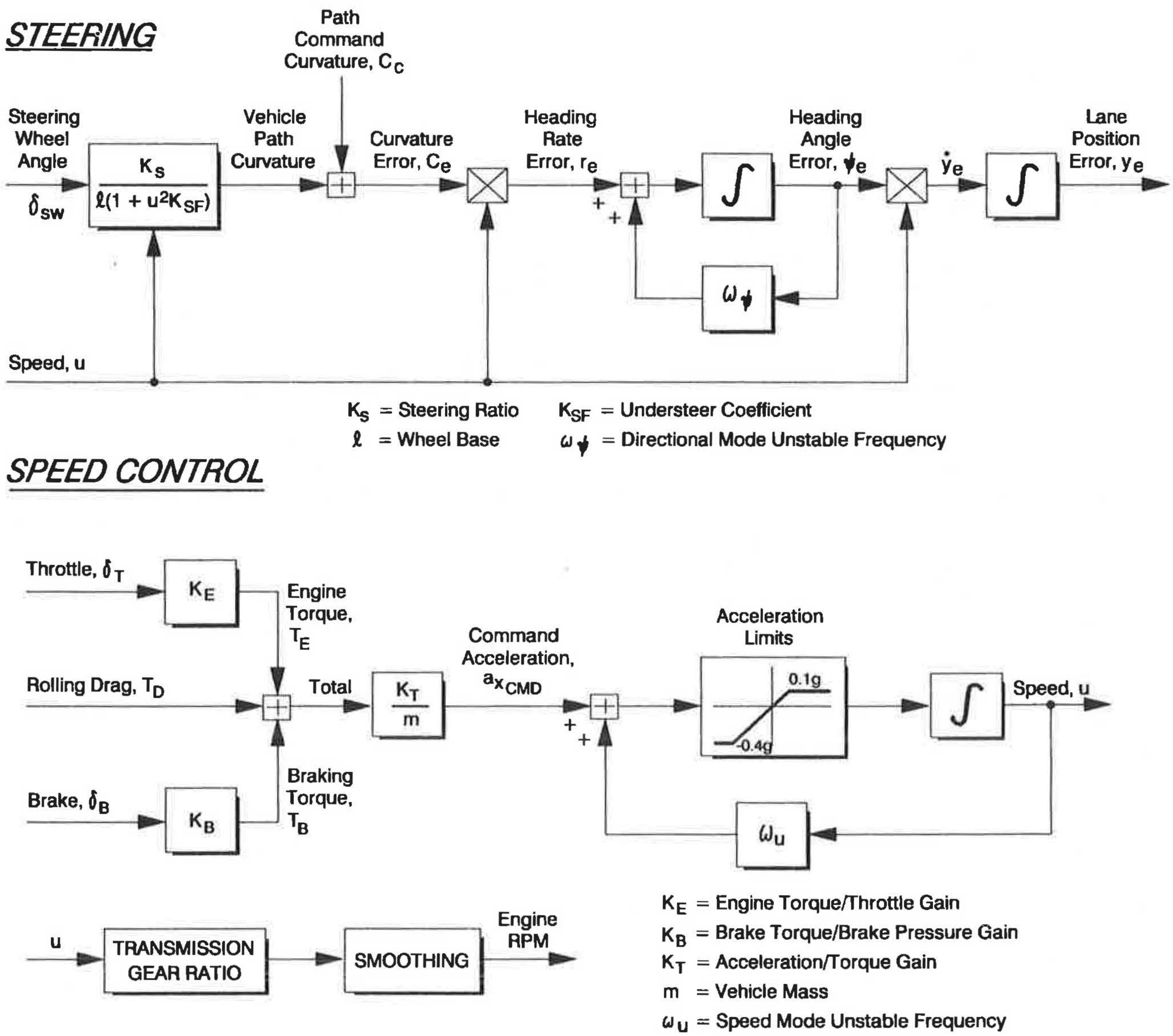

FIGURE 2 Simulation vehicle dynamics mathematical model for truck driving application.

with a scale factor associated with the vehicle Ackerman steer ratio and understeer coefficient. Vehicle yaw rate typically lags behind steering inputs because of directional (yaw) mode dynamics and tire lags. For this application, the combined computer and display system update delay as perceived by the driver was assumed to be equivalent to the delay associated with the vehicle's directional dynamics. A positive feedback is included around the yaw rate integration to simulate the effects of road crown and allow a calibrated instability to be included in the steering dynamics. Instability keeps the steering task active so that meaningful performance can be measured without resorting to arbitrary disturbances. Steering workload task can also be varied in a calibrated manner by setting the level of this instability (*13*).

Longitudinal, or speed control, dynamics assume that engine thrust is proportional to throttle opening within engine limits specified as maximum acceleration and deceleration capability. Gear ratios are simulated for a five-speed automatic transmission. Engine revolutions-per-minute commands are sent to an expansion sound effects card that creates a complex frequency engine sound with periodicity proportional to engine speed. Positive feedback instability is also included in the speed control dynamics to keep the speed task active for performance measurement purposes and to provide an additional source of workload. Vehicle speed drives a speed indicator at the bottom of the roadway display.

Display transformations process 3–D objects in a display list, as shown in Figure 3, to yield a perspective roadway scene. Simplified display transformations used have been described previously (*14*). The 3–D data base is not constrained by a physical map. Instead, the display list is object oriented, and a scenario definition module takes instructions from a scenario file to define objects that appear in the driver's field of view. Objects can be moved independently of one another in the field of view to permit traffic interactions. Objects or events (e.g., signal timing) in the scenario file can be accessed as a function either of time or of distance down the road. The time function is important as it allows control of event timing for decision making situations (e.g., whether or not to stop when a traffic signal changes from green to yellow). Time dependence of events is also necessary for experiments where exposure time is a primary variable.

Typical examples of roadway scenes are shown in Figure 4. Roadway scenes are composed of full-color polygons defined by the display transformations applied to the 3–D data base. Roadway markings, signs, and intersections move toward the driver as a function of speed. The speed of approaching and lead vehicles can be controlled independently of the simulated vehicle's speed. Vehicles, signs, and intersections can be commanded to occur through instructions programmed into a driving scenario file. The roadway display also includes a subsidiary side view mirror response task that is included as a divided-attention or workload task. The appearance of arrow or horn symbols, controlled by the driving scenario file, commands the subject to respond by activating the turn indicator (right or left as appropriate) or horn, respectively. A horizontal indicator at the bottom of the roadway display screen functions as a thermometer bar speedometer that is commanded by vehicle speed as computed in the vehicle dynamics mathematical model.

Performance measures are currently mechanized for steering, speed control, and divided-attention (horn and turn indicator) tasks as follows:

Steering Control

- Standard deviation about the mean for steering activity—the variability of steering wheel rate.
- Standard deviation about the mean for curvature error—the driver's variability in tracking behavior.
- Mean lane position—the average location of the center of the vehicle within the lane.
- Standard deviation about the mean for lane position—the variability of the preceding measure.

Speed Control

- Standard deviation about the mean for throttle activity—the variability of throttle rate.
- Mean vehicle speed—the average speed of the vehicle throughout the measurement period.
- Standard deviation about the mean for vehicle speed—the variability of speed.

Side View Mirror Task

- Mean response time—the average response time to the divided-attention task.

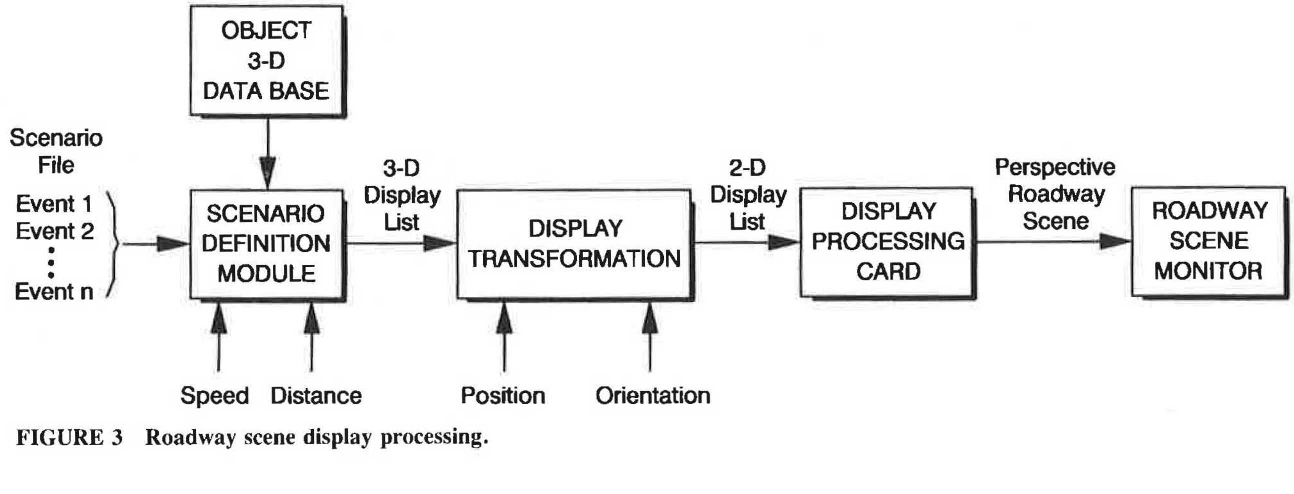

FIGURE 3 Roadway scene display processing.

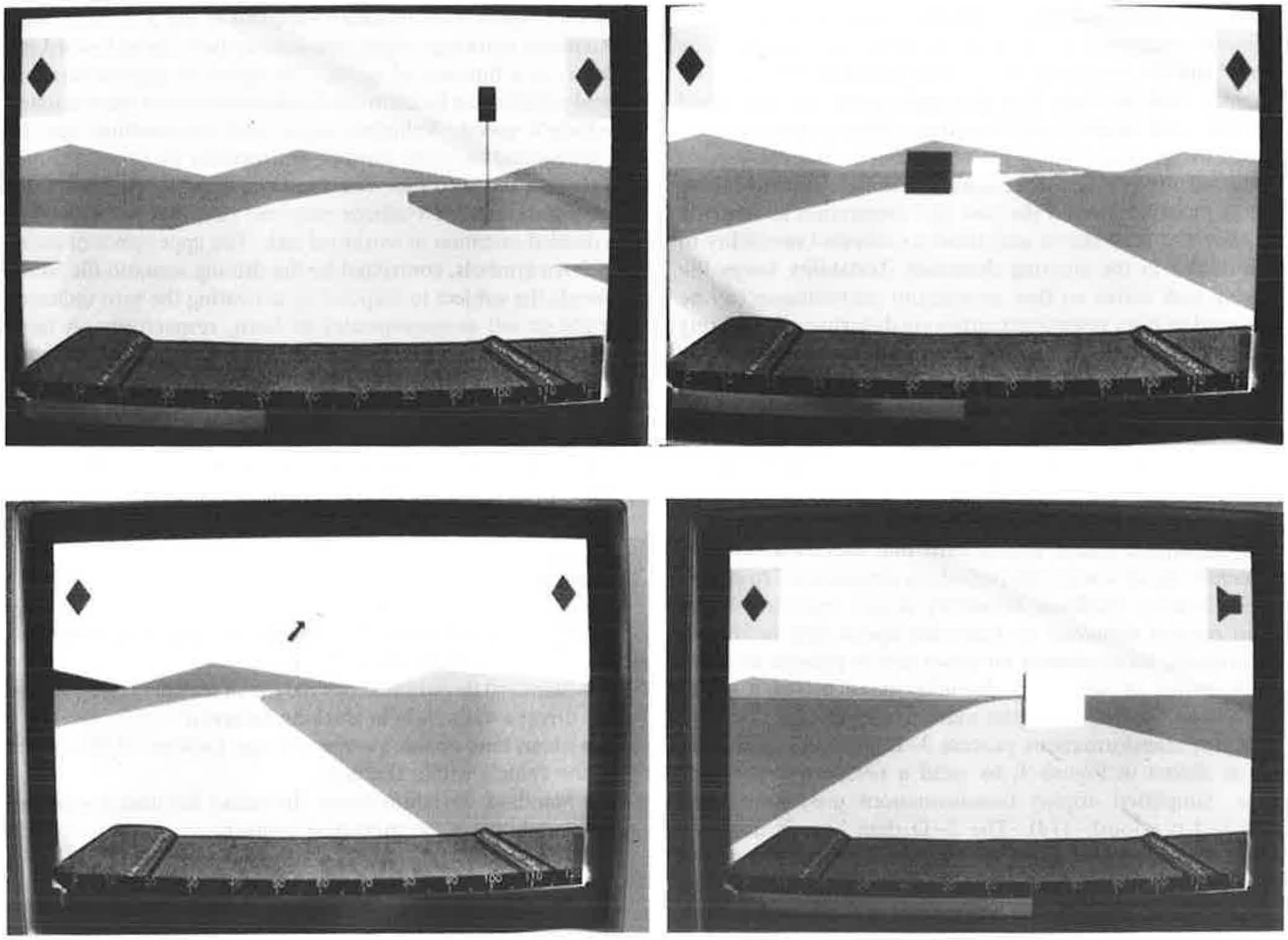

FIGURE 4 Typical roadway display scenes: intersections (*top left*), interactive traffic (*top right*), signing (*bottom left*), and subsidiary task "horn" command (*bottom right*).

- Standard deviation about the mean for response time—the variability of the preceding measure.

Steering and throttle activity measures are related to traditional reversal measures (e.g., *15*) that may have higher-frequency components, which would not affect overall driver-vehicle tracking performance (i.e., lane position and speed control). Curvature, heading, and lane position error measures relate to steering performance, whereas speed measures relate to speed control. Side task measures relate to monitoring performance and response to discrete events. Performance measurement intervals can be specified and data collected over multiple measurement intervals (e.g., every 2 min for 20 min).

Automated orientation and training features were added to the simulation to make experimental procedures and data collection more efficient. Questionnaires can be administered by the simulation computer on the display monitor. Subjects respond using a keypad that avoids the potential intimidation of a computer keyboard. A voice reproduction expansion card is incorporated to allow the simulation computer to administer training. Voice messages are recorded on the hard disk as files. These files can then be recalled by the simulator orientation and training program to present verbal instructions and interactive remedial training.

APPLICATION

As part of a study on the assessment of truck driver fatigue, baseline tests were run on a group of long-haul drivers using the part task driving simulator (Figure 5). Driving tasks presented to the driver were to control speed at a steady 55 mph and to maintain proper lane position. Drivers were required to drive on a straight road for 20 min with no events occurring other than the appearance of arrow and horn symbols in the side mirror subsidiary task. Because the objective of this test was to measure fatigue, the driving task was purposely designed to be monotonous. Instabilities in the steering and speed control tasks were set at low levels, 0.15 and 0.016 rad/sec, respectively. Subsidiary task symbols appeared on the average every 20 sec. The driving task lasted 20 min and performance on the steering, speed control, and subsidiary discrete response tasks was averaged over 2-min intervals.

Simulator performance was compared between two groups of 32 drivers each. One group was reporting for their driving

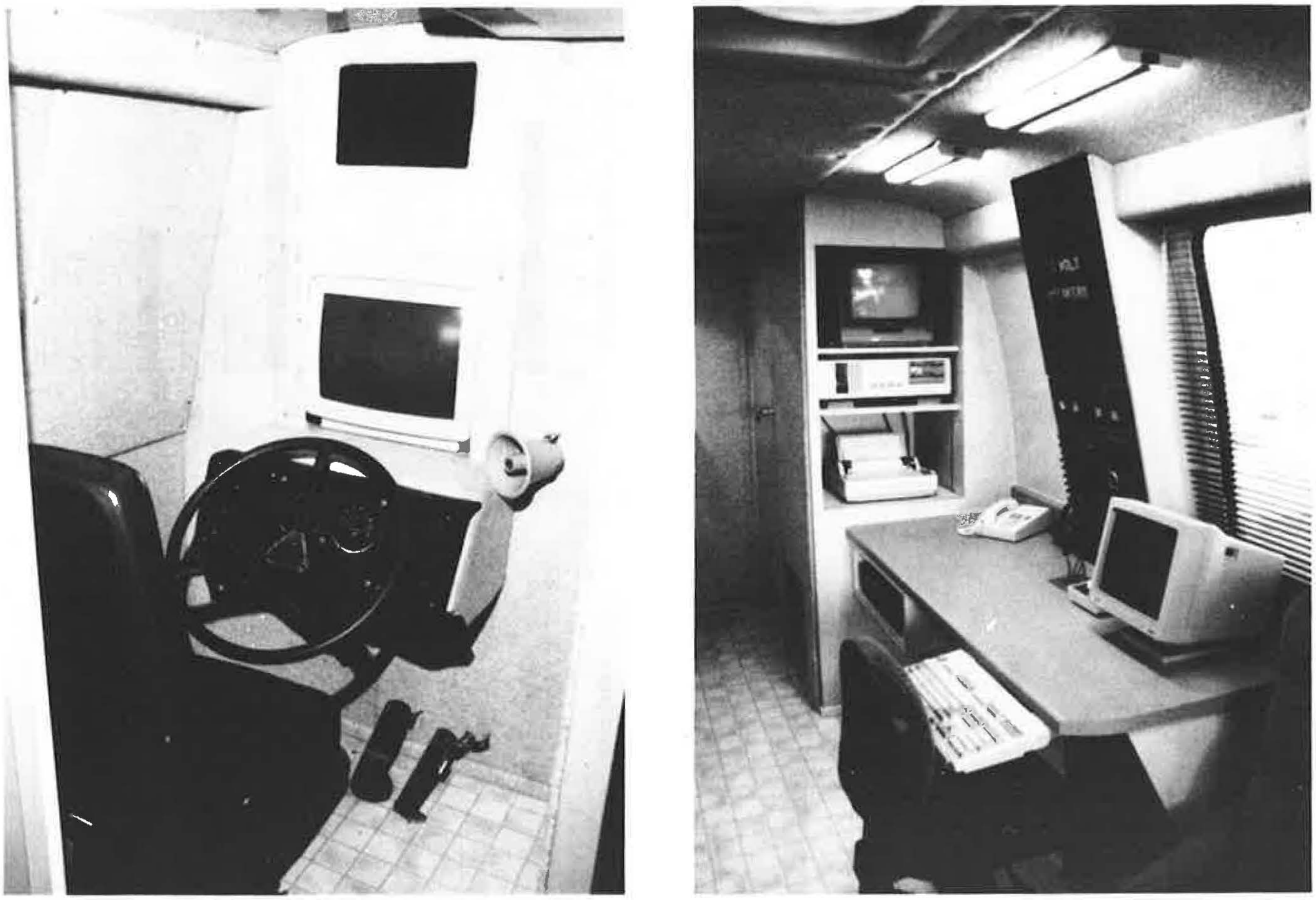

FIGURE 5 Part Task Simulation Setup: cab (*left*) and computer area (*right*).

shift, whereas the other group had returned from an 8- to 10-hr driving shift. Each driver was given a short orientation to the project and administered a pretest questionnaire by the simulation computer. The computer then automatically administered training on the task, including practice with each of the controls. Voice reproduction from the simulation computer first summarized the use of the turn indicators and horn in the side mirror task, then required their operation in response to the arrow and horn symbols. If controls were used incorrectly, the computer would correct the subject with a voice message and continue training. Training with steering only and speed control only was administered followed by combined control of steering, speed, and the subsidiary task. On successfully completing training, each subject was administered the 20-min data collection run.

Results of this application were successful. All subjects were successfully trained automatically by the simulation computer, and no simulator sickness was reported during or after the 20-min performance measurement drive. Significant differences in group performance were found for measures of steering control, speed control, and the subsidiary task discrete response. These performance results are shown in Figure 6. Typically, the performance of the before driving shift group stabilized after the first 2-min performance measurement period, whereas the after driving shift group never stabilized throughout the 20-min driving test. A between-group analysis of variance comparison of these effects showed the effects to be highly significant ($p < 0.005$).

CONCLUSION

Low-cost microcomputer technology can be effectively applied to the implementation of part task driving simulation. Although this simulator does not have the capability for full-fidelity simulation, there are a range of applications that make this low-cost approach attractive. Microcomputer technology can easily accommodate vehicle math models, roadway visual displays, and sound effects. Automated orientation and training features can also be implemented with voice reproduction capability as a means of increasing operational efficiency. This approach is suitable for research in diverse fields, such as the fatigue study discussed, and studies of other driving impairments (e.g., alcohol and drugs), and could be extended to study driver decision making and work load.

Microcomputer technology can also be extended to accommodate additional simulation features. The vehicle math model can be expanded to cover limit performance conditions in which tire force saturation leads to loss of control. Roadway scene display scenarios can be expanded to cover gap acceptance situations involved in turning and merging. Given more complete driving scenarios, this simulation approach might

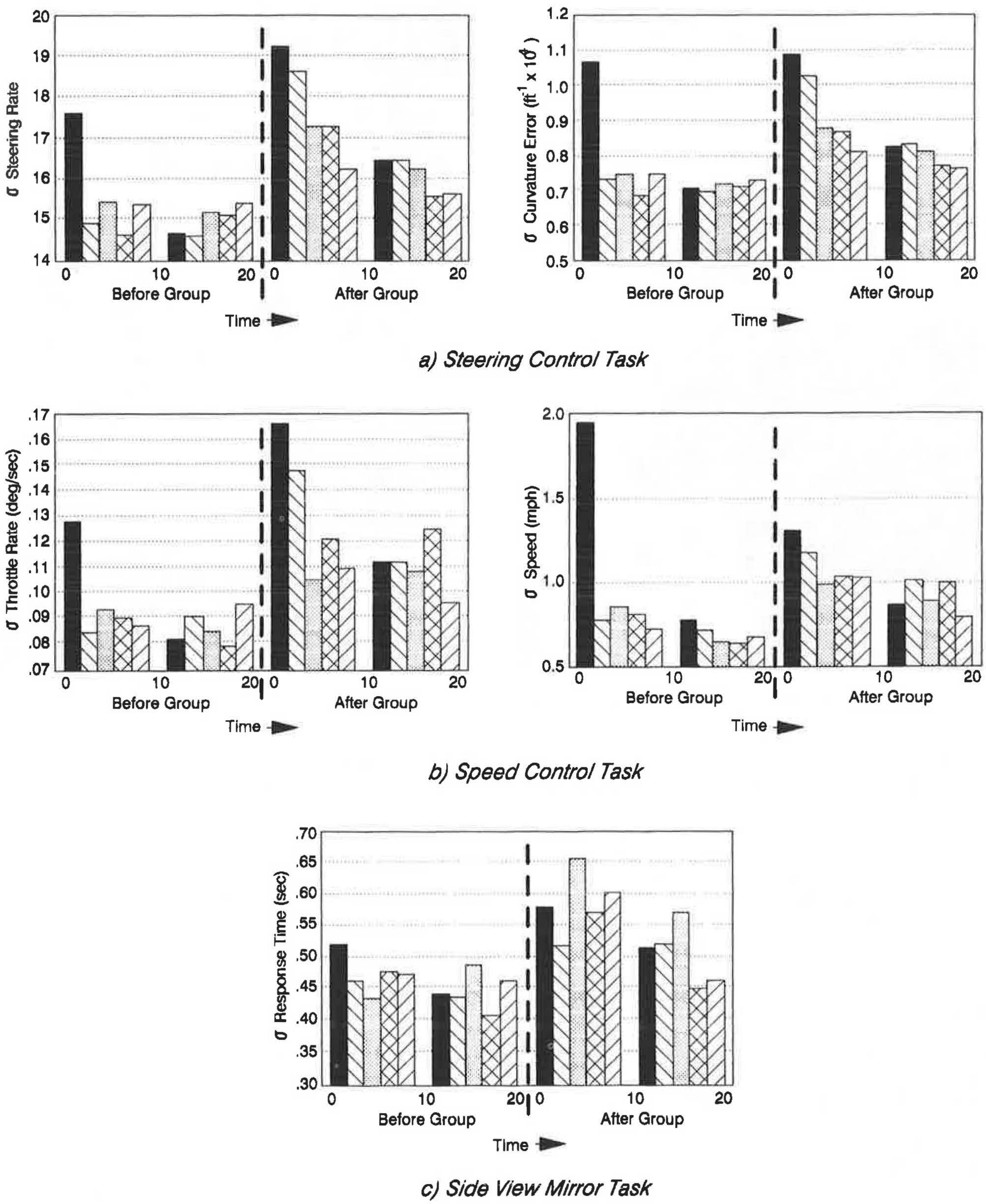

FIGURE 6 Test results summary.

have some limited use in driver training. With the rapidly expanding capability of microcomputer technology, it is expected that low-cost, PC-based part task simulation will become viable for an increasing range of applications in the near future, and may eventually be able to assist in driver training and licensing.

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