Development of the KAKEN* Driving Simulator

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•THE NECESSITY of synthetic research in the area of traffic is rapidly growing, as indicated by the major topics at the Williamsburg Conference (1) and National Conference on Driving Simulation (2). As is well known, the automobile driving situation consists of three major factors: driver (man), car (machine) and environment; these interact in a complicated way in both time and space. In view of this, a system research approach is necessary to find out the relationships between stimulus and response, or between input and output. Therefore simulation techniques must be included as one of the promising methodologies in human factors research (3).

Undoubtedly, the car driving situation is a kind of man-machine system which is quite different from systems such as the task of flying by instruments or a simple vigilance task where environmental factors, including noise, play a minor role among the components. On the contrary, driving behavior is quite "unprogramed," and environmental factors in this case will always include large amounts of uncertainty and unexpectedness. Thus, in the driving situation, the use of the term "man-machine processing system" is proper (4).

The greater the complexity or number of uncontrollable factors in the system components, the greater will be the usefulness and importance of simulation techniques and modeling.

DESIGN PROJECT

The importance of simulation techniques has been fully discussed by Hulbert and Wojcik and Fox (5, 6).

In 1959, when the Traffic Safety Laboratory was established at the Scientific Police Research Institute, the original plan to construct a driving simulator as a research tool was proposed. In promoting the design project there was concern with performance, cost, and maintainability (7), and an acceptable balancing point was found with the following items (Figs. 1, 2, and 3):

1. A real car with a simulated environment technique is used for achieving the maximum degree of feeling for driving.
2. For the visual display system a motion picture technique was adopted; the projection area will cover approximately 50° horizontally.
3. For ease and economy of operation 16-mm films are used.
4. A feedback mechanism between car speed and film speed is to be constructed.
5. Handling torque and a self-returning function are provided.
6. A feedback mechanism between the angular displacement of the steering wheel and the light direction of the projector is actuated by a power servo-motor.

VEHICLE DYNAMICS

The KAKEN* Driving Simulator consists of three major parts: vehicle dynamics, visual display system, and recording system. A passenger type car (Toyopet Corona, 1500 cc) was selected for the simulator car for ease of remodeling and because of the limited space of the simulator room. The main remodeling changes were as follows:

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*Japanese abbreviation of the Scientific Police Research Institute.

Figure 1.

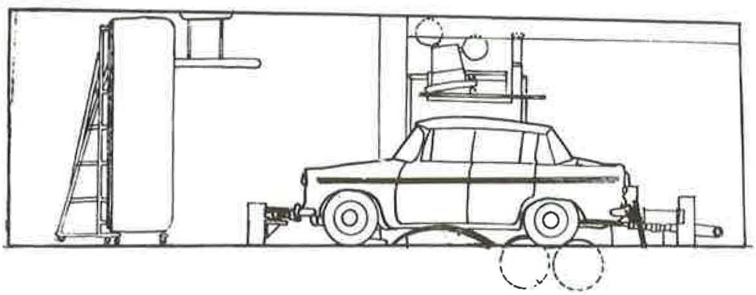


Figure 2. A cross-section of KAKEN driving simulator.

Figure 3.

1. To simulate the self-returning function of the steering wheel, the steering system is spring loaded.
2. To give drivers the actual feeling of "driving," and to avoid some transitional phenomena of the simulator car, special bumpers are attached at the front and rear ends, which absorb the reaction forces on starting and stopping.
3. A forced cooling system is used for the radiator and a continuous water flow is circulated in it.
4. To avoid risk of CO in the simulator room, a refueling pipe (50 mm in diameter) is connected to the exhaust pipe, and gas is guided to the outside of the building. Draincocks are also attached.
5. Intensities of the headlights, rear lights, and flashers should be reduced to an optimal brightness. Also, a low frequency oscillator will be used for the horn.

A twin free-roller system is used to transmit the torque from the rear wheel revolutions with maximum efficiency. In an attempt to achieve the highest fidelity for the system, the radii and widths were carefully calculated according to the characteristics of the simulator car (inside radius—0.24 m, width—0.80 m). Tensile strength is enough for driving at 100 km/h (62 mph).

VISUAL DISPLAY SYSTEM

The aim of introducing the motion picture technique here was to get high simulating fidelity and to reduce maintenance cost.

Actually, an analog simulator with a cathode ray tube like General Motors (8), or the miniature projection technique by the Institute of Transportation and Traffic Engineering (9) have interesting prospects, but they are still not practical. Also, a silhouette projection such as the SIM-L-CAR (10) seems inappropriate as a research tool, even though the visual feedback mechanism is superior to a film display.

For preliminary photographing of actual road conditions a motor-driver 16-mm movie camera (Bell and Howell 707) was provisionally set on the hood of the car, but test runs are being made to determine the best camera position. The projector is a Bell and Howell 7379, which produces few flicker phenomena at low-speed projection (Fig. 4).

Much effort was spent on the synchronization of car speed and film-feeding speed (number of frames per second) at the time of projection. As is well known, the feedback loop between human output and the environment plays an important role in a man-

Figure 4.

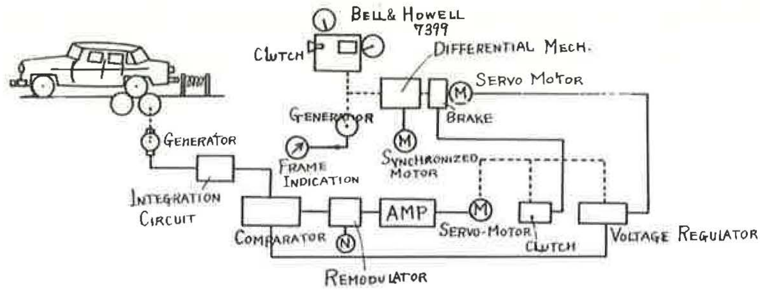


Figure 5. Block diagram of the synchronization of car speed and film feeding speed.

machine system. Especially, reproduction of the feeling of speed and acceleration is an indispensable factor in achieving high fidelity in driving simulation. Unfortunately, the film display is a programed system, but as far as possible an unprogramed situation is being maintained through this synchronization.

A following procedure is programed: When the simulator car starts, a voltage change is transmitted to the voltage regulator and actuates a servo-motor, balancing the output voltage. Then the servo-motor of the projector is actuated. When the car stops, the output of the voltage regulator tends to zero and a clutch starts to work. In this circumstance the projector works at a speed of only 8 frames/sec with power from a synchronized motor and gives the driver a feeling of very slow-speed driving. An almost linear relationship between car speed and film-feeding speed is achieved; e.g., 0 km/h = 8 frames/sec, 40 km/h = 32 frames/sec, and 60 km/h = 48 frames/sec (maximum speed) (Fig. 5).

To reduce cost and to satisfy the broad demands of the visual problem, a photographic speed of 24 frames/sec and a constant driving speed of 40 km/h was used. The superiority of this combination of projector and car speeds is discussed later.

To gain a wide visual field, an anamorphic lens (Prominar 16-A) is attached to a wide lens (1 in. focal length) and a projected area of 1.15 m (height) × 3.08 m (width) is obtained. At present, the feasibility of a superwide lens (0.5 in. focal length) is being tested. These lenses are usually used both in photographing and projecting and a curved vinyl screen is used. In the projection both sides of the screen are slightly out of focus but this situation follows the lack of focus of peripheral vision in normal driving.

RECORDING SYSTEM

The recording system is divided into three major parts: vehicle dynamics, physiological responses, and motion analysis. At present an integrated recording system between these parts has not been completed and they are recorded separately.

In respect to car dynamics, the car speed, braking force, accelerator pressure, steering wheel movement, and signal from the film are continuously recorded. As to physiological phenomena, galvanic skin response, electromyogram, and respiration rates are recorded. Driver's behavior (eye movements, hand movements, body sway) are under surveillance by means of closed-circuit TV and scored.

RESEARCH PROGRAMS

As mentioned earlier, systems research is a promising approach in road traffic analysis. The current research is concerned with the study of simulation fidelity through measuring human adaptability, speed, and distance judgements. A feasible study on skill decrements in the long range driving situation is programed.

FUTURE DEVELOPMENT PROJECTS

Linkage Between Wheel Movement and Visual Display System

Without the completion of the linkage between wheel movement and visual display system, a real "feeling" of car movements could not be obtained. In this regard, a

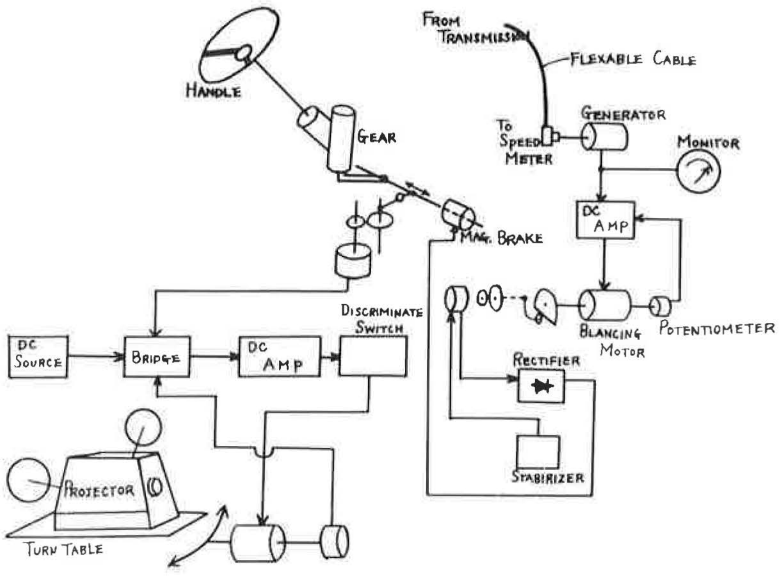


Figure 6. Block diagram of linkage between wheel movement and projector.

tentative linkage system is being designed which connects the angular displacements of steering wheel and the direction of the projector's beam through the electrical output amplified by servo-amplifiers. At the same time, variable handling torques are obtained for every handle position. The time lag of tracking performance for the turn-servo will be ½ to ¼ sec, and the range for the turntable movements will be ± 30° (Fig. 6).

Integration of Recording System

To analyze the interaction between the complex psychological and physiological phenomena and the traffic conditions, an integrated measuring and recording system is absolutely necessary. A remodeled 8-channel recorder, "POLYGRAPH" (Sanei Measuring Co.), will be furnished next year.

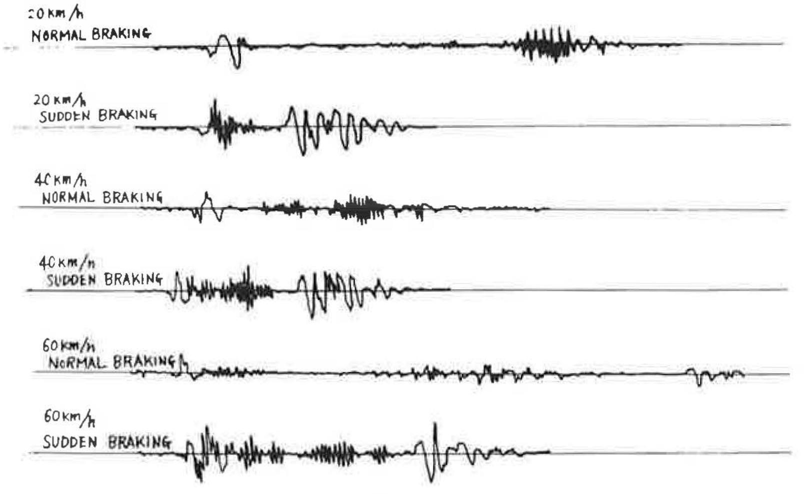


Figure 7. Fore and aft vibrations (rear sheet floor).

G-Forces Simulation

Because human beings are fairly sensitive to acceleration and deceleration forces, a carefully designed simulation system is desired. Discrepancy between the times of the visual stimulus and g-force will cause drivers to feel sick. As indicated in Figure 7, the present configuration of the driving simulator completely cancels the g-forces in the forward and lateral directions. These phenomena are due to the characteristics of the coil springs, and as a result, drivers are unable to feel g-forces. In this situation, inasmuch as this compensatory function in the forward direction was provided for, further simulation elements like UCLA's tilting chair probably will be added for the next project.

Although the presence of behavior dependent on illusion should be avoided in simulation techniques (7), a fairly large amount of body sway in the lateral direction by the "driver" on curved roads was found, even though the car was actually fixed. Clarifying the relationships between the amount of the driver's body sway, specification of road curvature, and car speed will be another interesting problem in human factor research. To some extent, the human induction mechanism toward the visual display will help the present research aim and will aid our judgment when we consider adding g-force simulation.

Rear Picture Projection

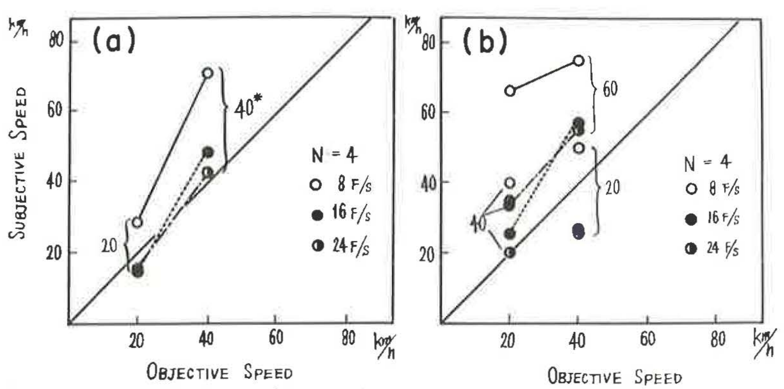
In car-passing or car-following behavior, a visual display system for the rear view would play an important role, but at the moment technical problems of film making and the continuity of experimentation do not permit pursuance of the problem. Presumably a careful study will be required to accomplish that objective.

AN EXPERIMENTAL STUDY ON SPEED JUDGEMENT

To find out the optimum film speed and car speed at the time of photographing, an experimental study was carried out. As a criterion car speed judgment by experienced drivers was studied.

First, a noiseless test road (a straight 800-m road with two lanes) was photographed at the Road Research Laboratory, Chiba Prefecture, with a 16-mm camera (anamorphic lens attached). Nine different experimental conditions (car speed—20 km/h, 40 km/h, 60 km/h × film-feeding speed—8 frames/sec, 16 frames/sec, 24 frames/sec) were tested. After arranging in a random order, the films were projected in the simulator room.

The experimenter drove the simulator car at a constant speed and asked the subject who sat next to the driver to judge the speed of the simulator car or film projected in front of him. The speedometer was viewed only by the experimenter (driver) in order



*Indicates car speed at photographing.

Figure 8. (a) Normal reproduction conditions, (b) different speed reproduction conditions.

to maintain a constant speed. The film speed and the speed of the simulator car were correlated as in the foregoing list.

Two experimental series (20 km/h and 40 km/h driving) were performed and the subjects who looked at the scene had to judge the speed in 10 km/h units (10 km/h, 50 km/h, etc.). Four subjects with long driving experience were used.

The film which was taken at 24 frames/sec showed the highest fidelity of reproduction for both the 20-km/h and 40-km/h speeds (Fig. 8a). In other words, the original car speed in the film taken at 24 frames/sec was estimated at the same speed in the simulated condition. The film taken at 16 frames/sec was fairly good, also. In a speed reduction condition (film taken at 40 km/h and projected at 20 km/h), a constant speed judgment was found in the film of 24 frames/sec. But both the 8-frames/sec film and the 16-frames/sec film diverged from the original speed (in Fig. 8b). In the case of increasing speed, the subjective judgements with the film at 24 frames/sec tended to be underestimated (Fig. 8b).

It was therefore concluded that the film photographed at a speed of 24 frames/sec had freedom and fidelity superior to the two other speeds. The car speed at the time of photographing was provisionally chosen to be 40 km/h for the present purpose.

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