Engineering and Psychological Uses of A Driving Simulator

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● THE CONCEPT of a driving simulator has a long history (5, 7, 31). A number of approaches have been made to the problem, some with intent to simulate more accurately and others less accurately, depending on the different uses to which the simulator was to be put. Indeed, some of these devices were not even considered by the maker or user to be a simulator, but rather a tool to create specific responses which happened to have some resemblance to a driving situation. A recent instrument which was intended to simulate motor behavior in driving, and in some respects, perceptual behavior, was the apparatus used to examine the effect of drugs on a skill resembling driving (19). Yet the similarity of the task to driving behavior was not particularly close, even though it may have seemed so superficially. A recent investigation (3) at Ohio State University used an instrument whose purpose was to establish some visual responses to road signs and billboards, and which had controlled motion as input and output elements. This machine, however, was not intended as a simulator of the driving task. Yet it concerned itself with perceptual and motor responses which were in a sense similar to those of driving.

In view of the foregoing contrast, it is important to define the kinds of instruments under consideration. The degree to which an instrument can be viewed as a driving simulator is dependent at least on two things: (1) the intent of the experimenter, which will be reflected to some extent in the perception and behavior of the subject at the controls of the instrument, according to the experimenter's instructions; and (2) the objective similarity of the inputs and outputs of the instrument to the driving situation. If there is any doubt, the intent of the experimenter defines the machine as a driving simulator. Thus a continuum of identity must be postulated, with a decision dependent on intent and construction of the apparatus. To establish a framework, the term "simulator" will be used to mean an instrument in which the subject's action bears a resemblance physically to that in real driving, where the intent of the experimenter is that the subject's action bears this resemblance, and where the subject perceives it as having this resemblance.

Objectives in the traffic field can generally be defined along two dimensions: efficiency and safety.

One of the necessary ways of reaching greater efficiency and safety is to learn as much as possible about driving and traffic behavior. Thus the objectives, at least in this part of the schema, become the acquisition of facts. Now it becomes possible to extend the objectives to details. What kinds of facts? How many? With what limitations? Are they available by other means? How will they lead to greater safety and efficiency? Etc.

The attempt to acquire such facts is called research. A driving simulator should be able to search out facts which would tend to improve within both dimensions the relationship among the objects involved in traffic activities. It should do so by allowing the experimenter to examine in fairly great detail certain existing or planned relationships in this field.

Some of the answers to the question, "Why build a simulator?" were given previously (11, 16), but are worth repeating and amplifying. However, in addition, other related questions can be asked which are at least as important. First, what research cannot be done or will not be done if a simulator is not available? Second, how much will the total strategic program of accident prevention research be hindered by lack of information which could be made available by use of a simulator? The reasons for building a simulator are as follows:

1. A simulator will permit research which is unsafe to do otherwise.
2. It will permit certain research which cannot be done full scale without unthinkable cost, where equivalently useful information takes excessive amounts of time to accumulate, and where great expenditure of effort, time, money, lives, and injury has already occurred because this research was not done. This is research on full-scale highway configurations in advance of use.
3. It will permit research which is physically impractical to do at present by other techniques.
4. It will permit research with a degree of experimental control which is quite impossible to achieve by other techniques.
5. Because of the organized quality of a simulator research program, it can lead to research, if priorities permit, which would ordinarily not be done at all, even though such research could be done by other means.
6. It will permit a whole new experimental milieu for certain inquiries into human behavior which have not until the present been particularly concerned with behavior while driving. These are mostly psychological topics, but can also be medical and physiological.

Some examples of these kinds of research will be given, followed by the answers to the additional questions posed. But because the additional questions involve some fundamental problems, it becomes necessary to digress at this point with a short discussion of theory of values as it relates to accident prevention research.

Values in the Strategy of Planning Traffic Research

Omitting for the moment the uses of a simulator for training, for public health information, advertising purposes, direct selection purposes, etc., consider only the case where a driving simulator is to be used for research.

The range of need for a driving simulator lies on a continuum from low to high, and is dependent on several dimensions of cost and gain. Items of cost may include such things as economic investment, time investment, effort investment, physical risk investment, public opinion effects, etc. There are different realms of dividends, and each of these can be used as a partial measure of the worthwhileness of each of the areas of investment. Some examples of gains are saving of money, information about driver reaction, earlier acquisition of such information, greater amount of information acquired, greater access to information than available otherwise, and greater confidence in the derived information.

For each research task the costs are associated with the gains, and a decision must be made as to the worthwhileness of carrying out the research in the manner in question. The values are again associated when a different method of attack is considered, until a decision is reached to conduct the research in a given fashion or not. Whenever the cost of some items is too great, such as risk of injury or death beyond a certain amount, it does not matter how much gain might result from the research: it is not worth that cost. Certain gains have never been evaluated — perhaps, in this case, one might even say most gains. And when they have been evaluated, the balancing against certain research costs has never been made. In addition, the likelihood of a particular gain being achieved is itself a matter of probability in the research, and in many cases even the very nature of the gain is not known in advance, let alone its magnitude. This follows from the nature of research itself, which implies investigating the unknown.

Thus, decisions as to use of one method or another are based on complex interplay of values and uncertainties. It becomes difficult to say how important any particular research is a priori, and therefore to say how desirable any particular method of conducting that research is.

Limiting Costs for Research Priorities

An attempt will be made to assign some values to certain research which can be done on a simulator before going into the question of the other kinds of research for which a simulator is feasible. Of course, any such assignment is personal judgment. There is every likelihood that someone else would recast the values which are described here.

For purposes of limitation, one can say that there is a black area of no limit of value on certain occurrences to the subject: death, loss of limb, maiming, and most kinds of disabling events. (Excluded are temporary disabling events like induced epileptic seizure, induced sleep due to fatigue, etc.) In most live car experimentation on the highway, an agency is not in a secure enough situation to promise that the subject will not have an accident, let alone incur or produce an injury. The most it can do is promise that all other things being equal, he will have as small a chance as if he were driving under normal conditions for his own purposes.

However, the moment a set of conditions is imposed on the subject or the public which will or might increase hazard to any important degree, either to him or the public, a responsible agency ordinarily does not even make this promise, unless it provides foolproof safeguards both to the public and to the subject. Because one is generally not sure of the range of probabilities in many cases, most public agencies will lean over backwards, and undertake research only when the risk of increased hazard is vanishingly small.

Classes of Research Which Would Be Done on a Simulator

Now, returning to the major question, there are several reasons for building a simulator. Consider them in turn.

1. A simulator will permit research which is unsafe to do otherwise. This is the most important reason. What kinds of inquiry fall into this category, defined as research with ponderable risk of injury? A few have already been mentioned (11). Some examples follow:
   - a. Changing (usually reducing) physical capacity deliberately in order to test the limits of adequate performance.
     - (1) Decreasing visual efficiency. Some examples would be putting on the driver glasses which would decrease acuity; reducing the peripheral field; deadening pupillary response; and imposing glare or inadequate or excessive lighting.
     - (2) Removing or reducing the function of a limb or of motor faculties, including lowered control capacity.
     - (3) Deafening a person artifically; for example, with a masking noise. This should really not be excluded from live car experimentation, because at least the self-trained deaf person can compensate very well.
     - (4) Inducing slight drug overdosage to a person under real drug treatment; for example, slight hyperinsulinism in diabetics, or slightly excess antihistamine or tranquillizer.[1]
     - (5) Think seriously of testing a person with one of the psychotomimetic drugs to see what his behavior would be; for example, with lysergic acid derivatives. It must be pointed out emphatically, however, that one should not draw the inference in any sense that such drugged states resemble physiologically or functionally those which are called truly psychotic states.
     - (6) Treating the healthy subject with standard therapeutic doses of many drugs such as amphetamines, antihistamines, tranquillizers, etc.[1]
     - (7) Dosing with various amounts of alcohol under various kinds of social conditions.[1]
     - (8) Fatiguing a driver excessively.[1]
     - (9) Causing a driver to become sleepy.[1]
   - b. Causing a change in the person's outlook on risk-taking behavior or

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[1]In all these cases the experiment would be done under the supervision of a physician who has experience and competence in toxicology, anesthesia, or other areas which the experiments may require.

his assumptions as to the driving situation.

(1) Rewarding a driver for excessive speed, that is, inducing a state of "hurry" (8).

(2) Stimulating with slight alcohol doses in a normal social situation and requiring driving thereafter.

c. Changing the driving environment by inserting unexpected signs, etc. This is obviously not so dangerous as the previously cited research. However, indications are that it can still be more hazardous than normal driving.

d. Inducing sudden emergencies.

(1) Another car or a pedestrian does something unexpected.

(2) A sudden curve or construction lane, or other environmental surprise.

(3) Induced skids.

(4) Failure of car component, such as brakes, or blowouts.

(5) Sudden distractions, like a child acting up, or obstructing vision.

Some work of these kinds has already been done. Only a few will be reported. In certain studies care was taken to try to prevent an accident, but in others the subjects and experimenters deliberately exposed themselves to increased danger. In one study (10) a back-seat observer noted the behavior of a sleep-deprived driver, but the former also began to get sleepy during the runs, and a third observer with dual controls next to the driver functioned as a safety man. This need for cross-safety measures illustrates the dangers of such research. In another case, attempts were made to force an emergency reaction in a simulated emergency in a live car by means of a dummy of a child suddenly propelled in front of the driver so unexpectedly that he could not avoid an "accident." On one occasion, however, the driver swerved so sharply that he deliberately struck one of the cars set on the street as an obstruction, rather than strike what he thought was a child. In another case (2) it was reported that a small group of experts, in a very uncontrolled situation, tried to see what effect reduction of acuity would have on their driving. They put on plus lenses with respect to their optimum vision, and drove several blocks in the environs of Chicago, including intersections with traffic lights, stop signs, and various directional signs. A study was done in England with two expert police drivers under the influence of high doses of alcohol (28). The drivers rode over a test track, but both of them came close to having a bad accident, with no insight into their danger. Work in the general area of skill decrement is still going on (13, 26, 30).

A second kind of inquiry, but in the same large category, must be examined. It is the case where, during the course of natural events on the road, the investigator observes detailed, within-the-car driving behavior. To be sure, this research is included here because it may involve reduced physical efficiency or altered attitudes toward driving, but more interestingly, it involves driving behavior which would have taken place even without the presence of the observer. Experimentation of this kind is still dangerous, however. Good work has been done (9, 25). But observing such behavior from outside the car is not possible, and where both scene and behavior are to be synchronized, has not been attempted inside the car without an observer. Nothing would prevent development of such techniques, of course, except perhaps expense.

2. A second reason for building a simulator relates to simulation of various highway configurations.

To build highway configurations full scale in advance of use for purposes of research in behavior of traffic or in safety design would involve unthinkable financial cost. It is true that configurations of bridges, ramps, interchanges, approaches, etc., have been examined in the past and are still being investigated. For the configurations constructed and for the traffic circumstances in which they operate, research on these full-scale structures could accomplish the same results as would be achieved by using a simulator with these same configurations and circumstances — and moreover, does so in terms of the ultimate criterion, live driving behavior. Nevertheless, a real limitation is imposed by the fact that as things stand now, such investigations cannot be carried out adequately without long-term observation of accidents (although traffic behavior takes little time to observe), because of the inherently low frequency and unreliable occurrence of accidents.

A far more fundamental point can be raised. Because a simulator with adequate characteristics has not been available until now, many constructions have been carried out which have inadequate characteristics as far as traffic flow efficiency and safety design are concerned. For every design, the civil engineer probably has consulted with the traffic engineer, who described the characteristics he wanted. But because the latter had no empirical evidence for optimal properties, but only theoretical expectation, whenever a new design was to be considered, he had to estimate in terms of experience, the inadequate literature, and personal judgment. Many times these were not enough. As a result, who knows how many hours of traffic delay, with attendant cost to the community government and individuals, have arisen; how many accidents have occurred; how many injuries have resulted; and how many people have died because of inefficient or unsafe configuration?

These matters are well understood by the professionals in the field. That is why they are carrying out studies on existent structures. But they cannot do so full scale on designs which have never been built. If a simulator could be built to pretest road configurations, it would cost nowhere near the amount required to examine a full-scale structure in advance. Probably, if a cost analysis were made, over a period of time the reduction in cost to the community of traffic delay, inefficiency, hospitalization of injured indigents, etc., would exceed the cost of simulator research needed to bring about this reduction. Costs to the individual, of course, are to be counted over and above community costs.

3. There are some kinds of research for which the tools are not available for use right now in a live car, due to certain technical difficulties, although such research is highly desirable. Such research could be done on a simulator. An example of this might be testing brain waves during driving, much in the way that they have been tested in aircraft (27). Small episodes of unconsciousness a few seconds long show up in some people under the influence of alcohol which would not do so normally (23). They can be detected in this way. Behavior by epileptics during induced petit-mal seizures could be observed. None of this is at present possible in real driving research.

4. A simulator will permit research with a degreee of experimental control which is quite impossible to achieve by other techniques.

The problem of experimental control has always troubled those working in traffic safety. It becomes especially important because laboratory duplicability such as is found in the ideal case of behavior examination is not possible in the car. The pedestrian situation changes, the opposing cars change, the behavior of the interacting traffic changes. It is now possible only to describe in statistical terms what happens to gross car behavior at certain places and it is difficult to duplicate the exact approach, intersectional behavior, speed, etc., of other traffic. In the simulator it will be possible to pinpoint behavior for particular traffic events, and estimate population characteristics with respect to these traffic events based on actual behavior in the car, which has not been possible up to this time.

For example, just how do various people behave at a circle with multiple entrances and exits. What are the visual lapses, the visual needs that enter into a complex interaction of this type? Problems like these can be pursued in great detail and with great confidence in the generalizability of the results.

5. Because of the organized quality of a simulator research program, it can permit research, if priorities are so arranged, which would ordinarily not be done at all, even though such research could be done by other means.

A large number of research projects which have not received support as individual proposals, but are considered to be desirable nevertheless, might be undertaken if a fine opportunity of this nature were available. These projects, except for the factor of experimental control mentioned previously, could also be done outside the simulator. But they have not been done in the past because of the slow progress of support for research in traffic safety.

Some variables which might be examined in this kind of research are:

a. Physical variables; for example, fog, rain, road vibrations, temperature, humidity.
b. Personal characteristics of the driver — for example, driver training, attitude, experience, personality.
c. Sensory and motor characteristics of the driver.

6. A simulator will permit a whole new experimental milieu for certain human research which has not been concerned with driving, but where the driving situation offers an excellent opportunity to exploit a good research environment.

Such research topics might be mentioned as isolation, monotony, vigilance, social interaction, artificial stress, emotional involvement, complex perceptual acts, drug effects, etc.

Alternative Techniques of Research

It has been shown that a simulator is needed to carry out certain research impossible to perform adequately in any other way. Does this now imply either (1) that other research would not be done on the simulator, or contrariwise, (2) that the simulator would take the place of other research techniques? To both questions, the answer is yes and no. Again the cost-gain criterion must be applied in each case. Where research not now being carried out could be done outside the simulator only at extreme cost and with only moderate gain, the use of this instrument is justified if it reduces cost, and affords adequate gain. It could then take the place of other techniques. For example, research into the effect of highway configurations on traffic behavior has too great a cost, with full-scale units, for an unknown gain. On the other hand, research on vehicle design characteristics, particularly human engineering of static characteristics, is far cheaper and more efficient with a live vehicle (21, 29). But human engineering research on vehicle characteristics involving the dynamics of traffic is perhaps more safely done on a fixed simulator of the type discussed here. If a test track is used, a dynamic simulator of vehicle behavior, not driver behavior, can be used (18). But behavior of the driver with varying car dynamics has yet to be measured for purposes of safe driving research. (This instrument has been available not much longer than the time necessary to test it thoroughly and determine some of its characteristics. Hopefully, behavioral research can also be done in the future.)

PLANNING FOR SIMULATOR RESEARCH

Preliminary Simulator Configuration

The steps necessary to achieve a faithful simulator with high feedback potential are essentially almost forced. For designs spoken of in the various reviews of related topics such as feasibility statements about systems (6, 16, 17) visual environment reviews (20, 24), and training device literature (4, 12), development from a simpler to a more complex instrument is most often recommended.

Therefore, it is conceived here that development of a complex simulator would take place in such a way as to allow research to be done at each of the various stages of improvement of the simulator. Just such a program is now under way at UCLA. The purposes are many — for validation, for evaluation of cost-gain quantities, for breaking-in and training purposes, for developing maintenance techniques efficiently, for quick payoff, and for other obvious reasons.

Later the skeleton of one example of a research program will be outlined which might be undertaken if a simulator were to be developed. In this outline it will be assumed that a gradual approach to the construction of a simulator has been taken. That is to say that at an early stage only simplified representation of traffic behavior will be possible, and the subject will have a limited amount of feedback from the scene as a result of what he has imposed on it as input. A program outline will reflect the assumption of graduated development.

For example, a first approximation to an initial developmental stage would have a live, running car which the subject controls, resting on a dynamometer whose design will permit suitable input of vibration, sway, pitch, and road resistance; a 120- to

160-deg forward projection and simultaneous rear projection of a traffic environment picked up from a car in real traffic fitted with color camera equipment; limited lateral translation of the experimental scene coordinated with steering behavior; the running engine and other sounds of the experimental apparatus fairly well matched in intensity and spectrum with apparent speed of the vehicle in traffic; and similar straightforwardly simulated characteristics.

Programming

1. Limitations on experimentation.

With an instrument of the type just described, experimentation would be restricted to observing behavior and internal response in situations which permit only a limited variety of response by the driver, because in this form the simulator has poor potential for exhibiting highly variable feedback to the environment. This means that the circumstances of traffic must be one of two things: they should override individual behavioral variations, for example, constraint of speed is forced into a narrow range, say along a speedway; or they must be such as to prevent scenic input from informing the driver of a discrepancy between his behavior and the camera's behavior. One situation which satisfies the latter condition is that the driver be the only one on the road in the given experiment. In other appropriate situations the interaction between drivers must be low. Such maneuvers as passing are avoided.

2. Measurement.

A first concern must be to describe properly the behavior of drivers, with all that this implies as to frequency and distributive characteristics in a single person and between people. To accomplish this, descriptive measures must be developed which are meaningful, reliable, valid, and statistically or mathematically manipulable, to describe not only what happened, but what ought to happen.

Terms would be used such as real error, tracking behavior, variability, perception of error, probing behavior, feedback, backlash, back action, noise (in the sense of communication theory), system, individual differences, perceptual response, threshold, estimate, etc. To illustrate, consider a single function: where a driver is looking at any given time. One might photograph his eyes, using properly oriented axes to determine on a computer the precise spot on the scene which he is looking at; one might use a TV technique (22) which can give an accurate picture of the same thing; one might use a device which would project infrared from below, reflecting from the eye, and landing on a screen which is subject to rapid scanning, where coincidence of beam (s) and scanning element (s) reads directly into a computer the information which can determine position with no degrees of freedom.

Other measures which would have to be developed have been listed (11), but might be mentioned again briefly; detailed driver action, such as behavior related to the accelerator, brake pedal, gear shifting (if used), steering, turn signals, lights, lighter; gross car action such as turning, stopping, starting, parking, avoiding; physiological responses such as head movement, psychogalvanic response, muscle potentials, blood pressure, breathing, force applied, pulse, brain waves.

A standard driving task would be used, with standard situational events which sometimes lead to accidents — intersection, traffic light, curved road, obscured road, etc. Testing would be repeated to determine variability, and then further repeated often enough to establish fairly accurately a description of how a variety of people act in a given situation. The stimulus is always known, the time of stimulus is known, and the reaction can be observed and described, both statistically and in terms of dynamics.

Programming Priority

Ideally it is best to start with permissible cost and maximum gain. But in this case it is assumed that the cost is permissible because the particular stage of simulator development is assumed to have been achieved. Running cost on a simulator of simple design is not much greater than live research. The only restriction, then, is what research can be done with the given simulator configuration. The range of possible research is unlimited, subject to that restriction, but it needs to be arranged according to priority. As part of the cost, at least on a theoretical level, must be included steps to determine how confident the researcher might be in his research results. These steps, to be discussed later, are research procedures establishing validity of the simulator research.

To establish priority of research, the results of statistical and experimental research on accidents are used, where available. What are the greatest known contributors to accidents, injuries, and deaths? Setting aside for a moment the consistency of proper classification, and permitting overlapping classes, the list might include such things as driving and drinking, the single car accident, the intersectional accident, the high speed accident, the bad weather accident, the accident at or after dark, the accident with very young or very old driver, and accidents due to poor driving habits, to name a few.

It is important to know just why, or just how, these accidents came about. They were all due to some improper behavior, either commission or omission. It is not known what that behavior is, under what conditions it occurred, who performed it, how often, how correctible it is, how habitual it is, whether it appears in normal driving, what changes must take place to avoid it, its interaction with other driving behavior, how it can be described and measured, etc.

Research Possibilities

Some other questions should be mentioned which might be investigated in a simulator at an intermediate developmental stage, after validation and normal driving are examined.

Certainly these questions should include an evaluation of the effect of various characteristics of signs — design, placement, frequency of appearance, their relationship to destination, individual variability in response to wording, color, and other physical properties, etc. A program of considerable detail and complexity can be devised to study the effects or effectiveness of signs. Initial experiments along this line have been made at UCLA (15).

With the aid of coöperating assistants and cars, emergency situations could be introduced into a filmed sequence and behavior observed. (The objection that an unsuccessful maneuver on the part of the driver must terminate the sequence is not valid because the important part of the experiment is the observation of behavior during the emergency sequence. Even though the subject must be discharged following the experience, his responses are available for analysis individually and in combination with other persons' responses.) Something like a walkie-talkie system in the two or three cars, with adequate warning to the camera car just in advance of an unexpected maneuver by a car or pedestrian to be photographed, would permit an experience to be safe in the live situation which would otherwise be quite dangerous. This kind of experiment is obviously not feasible when the unknowing test subject drives a live car in live traffic, but would be extremely useful and immediately feasible if he drove in a simulator. It is clear, however, that such devices do not make up for the unfortunate limitations of the programmed character of filmed input.

There are many ways of using film effectively. For example, one could take a person on long rides through the country on highways where he is the only one on the road, and study the effects of various factors. These might include fatigue, sleepiness, alcohol, both depressing and stimulating, carbon monoxide, smoking, and the like.

To study any one of these factors properly would entail a whole research program. What would a skeleton program look like?

1. Assume that all research and pretesting, both instrumental and personal, has been done, and the simulator is operational.
2. Set up behavior measures.
3. Validate most of them in a live car, on behavior which does not increase hazard.
4. Examine behaviors involving use of
   a. Alcohol
      (1) Treat and do not treat with various doses of alcohol.
      (2) Set up different driving environments, such as intersec-

sections, quick stops, poorly visible objects, various signs, and various emergencies.
(3) Select measures from (2) which are applicable. Tentatively, measures might be brain waves, breathing behavior, circulatory responses, psychogalvanic response, muscle action potentials, car control behavior, points of visual regard, points of visual notice, oral questions, questionnaires, and other measures deemed necessary.
(4) Pay particular attention to measures relating to peripheral vision, threshold of movement detection, speed on different occasions, individual differences, frequency of failure to attend, reaction time, field of attentiveness, control behavior, tendency to anticipate, tendency to make assumptions, tendency to take risks, confidence of driving demeanor, compensation for behavior degradation, social reaction, seizures, disinhibition, etc.
(5) Re-examine the findings, relate to an operations analysis of the individual driving situations, and make predictions of accident probabilities of the noncompensator and compensator.
(6) Attempt screening analysis.
(7) Follow up.

b. Drugs, etc. Follow same concept of research attack.

To fill in the details of a program outline such as the foregoing in any one field is not extremely difficult technically, nor is it hard to decide on priorities within a program. But it needs generalship of a proper order of sophistication to deal with the cost-gain problem and to decide on priorities for different programs. But even planning a single program, however feasible technically, is a sizeable research study in itself (1).

In addition, it must be noted that the choice of priorities depends on the organization conducting the research. Differences will surely be found among those whose orientation is strongest toward training, toward medical, drug, and personal factors, toward highway design, toward traffic engineering, and toward license screening.

In a research program such as the Public Health Service might develop, stress would be placed on effects of alcohol, drugs, medical factors, personal attributes, and emergency situations, but over-all the emphasis in each of these would be their safety aspects.

The differences in the programs for a simulator imply that it might be advantageous to have several units, in order for each interested group to be able to do as much research as is necessary in the various areas emphasized by the group.

OTHER CONSIDERATIONS

Validity

A serious objection has been raised to the use of simulators because their validity has not been ascertained. Validating procedures would of course be necessary during and after the construction of any simulating device. It has been said, however, that the expenditure of a large amount of money is not warranted for "pie in the sky," and that more concrete assurance of payoff should be forthcoming before such an outlay is made. No new piece of training equipment used in practice ever has such assurance, or would ever have been built if prevalidation were necessary. In most such cases attempts are made at preliminary validation; in some cases such attempts are not made if the equipment is brand new or cannot be pretested. A new model is usually built on a gamble. An occasional piece of equipment is actually not successful in simulation. That is, its validity is quite low. Most often, however, good enough validation has been found to warrant the building of the simulator.

Interestingly enough, and not unexpectedly, the closer the instrument gets to duplicating the operating situation, the more valid it is, for most purposes. But also, it may be very expensive to have faithful simulation, and it may not be necessary. It all depends on one's purposes.

In the case of this simulator, it is fortunate that there are a number of examples of prevalidation of less faithful machines, and of related instruments. But still, a program of preliminary research would accompany construction of a costly simulator, to rule out unnecessary expense leading to fidelity.

The response to certain other simulators bears witness to their felt reality, particularly in emergencies. Some readers have experienced passenger jet flying in simulators which have visual environment represented. They know how realistic this is. And that system was developed only for narrow visual field presentation. Experienced pilots who ride in simulators which have emergency situations built in are routinely known to experience strong internal reactions during these times, indicating a high degree of stress — sweating, heart rate increase, altered galvanic response, breathing changes, etc.

On the other hand, it can be shown that certain attempts at simulation have produced problems. In the simulation of a helicopter, conflicts of a nature not too well understood were introduced but they were probably conflicts which combined motion and visual cues (12).

Motion cues are important, both in helicopter and in driving simulation. Coordination of automobile acceleration simulation with visual display is now under way at UCLA. But even without motion, UCLA's machine still permitted feelings of reality of an acceptable order for some purposes. Especially was this true of emergency reaction. The realism of such emergencies increases many-fold the feeling of realism experienced during casual driving in a simulator, as the author had occasion to find out when he drove the simplified system at UCLA. During the run the camera car had a real emergency, and as driver, he became rather frightened when the car did not respond to corrective braking and kept on going toward the rear of the car in front, which was stopped for a light. The imminent crash caused a panicky turning of the wheel toward an open space at the side — which was exactly what the camera car had done. He was completely lost in the drama of the emergency. Hulbert has examined galvanic skin responses to such occasions, as an objective indicator of internal response (14).

Other Uses of a Simulator

It has been suggested elsewhere (11) that certain developments might be expected from a simulator. Knowledge of factors related to training will be of great help to driving education theory, as well, perhaps, as to other training activities. The need for training in tasks encountered in the Armed Forces is well-known.

It is not inconceivable that simple, inexpensive devices will be suggested, if they do not actually originate from, a simulator of one sort or another. Whether these will be useful for screening, training, or testing cannot be predicted now. But enough is known now to look for such a development. Certain industries, after techniques are developed for limited displays, could use such devices for advertising purposes. Particular stress should be laid on screening devices and training techniques.

If appropriately managed, demonstrations on an instrument with so much obvious popular interest and appeal could do much to inform the public in public health matters related to driving.

A Note on Cost

It is important to note that a simulator of design described above would probably cost about one-fifth as much as the more complex conception, and would cost about one-fourth the annual amount to run. Thus, not only is this kind of simpler machine feasible technically, but it is considerably more feasible financially.

The Future in Simulation

What effect will a simulator have on the strategy of highway research, and how would research strategy be hindered without this instrument?

It is believed that its presence would be a strong stimulant to interest in safety research for many who have little knowledge or background in this area. With regular scheduling of research, questions would be quickly and easily answered which today must wait for months and years before even attempts are made at answers — particularly human factors questions. Success of one instrument, experience in its operation, and reduced cost of production will all lead to rapid production of other models for other purposes.

Without such an instrument, progress in the field of accident prevention, especially research on driver behavior, would suffer a severe delay. A few such researches which have been attempted were undertaken in spite of the great difficulties attendant on this type of work. Current knowledge about the driver would again increase at a snail's pace. The many statements that such research is needed would be repeated anew.

A whole set of pending decisions regarding screening, licensing, training, traffic engineering, signing, medical restrictions, and other matters would be delayed for a period considerably longer than anyone would like to see.

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Discussion

C.H. HUTCHINSON, Cornell Aeronautical Laboratory, Inc., Vehicle Dynamics Department, Buffalo, N.Y.—The two prerequisites for realizing an acceptable simulator are: (1) the ability to realistically control the simulated vehicle within the environment, and (2) the ability to create meaningful situations that require some form of control action.

The first requirement is directly related to the dynamics of the vehicle — both the lateral or maneuvering control dynamics and the longitudinal or performance dynamics.

The second requirement is concerned primarily with the static and dynamic aspects of the visual display.

The range of situations for which any simulator may be considered as a valid research tool is, of course, a function of how well the sum of the two prerequisites is satisfied.

The word "sum" is emphasized inasmuch as it is the total effect produced by the simulator rather than the individual excellance of components that is important.

The problem, then, of making an a priori assessment of the validity of a simulator is seen to be extremely difficult. In fact, it amounts to an attempt to make a subjective evaluation of a physical device that is not yet in existence. The only apparent path open to the developer of a simulator is to first of all provide the best simulation practicable on an objective level and follow this by an evaluation on the subjective plane.

Certain aspects of an automotive driving situation simulator are now capable of implementation — particularly the control and ride dynamics of the vehicle. The cost of this portion of the simulator may be large but it is a relatively small proportion of the total cost.

A large portion of the performance dynamics — particularly those aspects that result in the indication of velocity — are also presently feasible. Longitudinal accelerations will, however, never be reproduced accurately, they can only be approximated.

The visual display, in contrast with the vehicle simulator must be evaluated to a large extent by subjective methods. Some direct quantitative measurements can be made such as resolution, contrast, brightness and distortion, however, because the scene presented is not real in the same sense as vehicle motions are real, the visual impressions become the determining factor.

At the same time, the visual display is the most expensive portion of the complete simulator system. Thus, the total dollars that must be invested in producing hardware for initial validity studies is relatively large.

The question was asked at an appropriations sub-committee hearing—"How much will it cost and how long will it take to construct such a simulator?" The answer specified a few million dollars during a four-year period. To which the questioner replied, "How can it take so long to spend so little!"

T.W. FORBES, Assistant Director (Research), Highway Traffic Safety Center, Michigan State University, East Lansing—The following discussions of Dr. Fox's paper range from a simple statement of the importance of developing driving simulators to pointing out additional important applications in human factor research and for design and traffic engineers. Finally, the very important "break-through" which the development of driving simulators probably will bring to the whole field of research in highway operations, driver and vehicle behavior and safety is suggested.

Additional comments indicate that others also concur in the importance of the development of such accurate driving simulators. Some feel that the very inconclusive ness of the paper might lead some, in the traffic engineering field especially, to feel that it was over-emphasizing the needs for a driving research simulator. The Committee, however, feels that the need for and importance of such research simulators could hardly be over-emphasized.

Two Types of Simulation Interrelated

In introducing the following individual comments and discussions, perhaps it should be pointed out that the driving simulator involves a different type of simulation from the mathematical simulation of traffic flow by means of electronic computers. The latter, too, is of major importance and is receiving the attention of other committees. Both types of simulation are needed and each will also contribute to the success of the other. The driving simulator will make it possible to test out, previous to construction, new highway designs to see how well drivers will be able to use them and to find defects which would otherwise occur only after the human factor of actual use of the highway would show them up. As indicated in the discussions, a new and much more powerful approach for research on driver behavior and human factor problems affecting highway traffic efficiency and safety will be provided. Resulting measurement will provide mathematical data for use in mathematical models and computer simulation of traffic flow while computer simulation will increase accuracy when added to other techniques in driving simulation. Both together may lead to completely new research approaches.

J.L. MALFETTI, Executive Officer, Safety Research and Education Project, Teachers College, Columbia University, New York City—The writer found Dr. Fox's paper very comprehensive and hopes a simulator program materializes for it would assist in the analysis of the driving task, an area in which there is a dearth of research and not even a reasonable starting place.

J.E. UHLANER, Research Manager, Personnel Research Branch, Department of the Army, Office of the Adjutant General, Washington, D.C.—The development of a driving simulator such as that discussed by Dr. Fox can serve as a tremendous impetus for interest in, design of, and support of much needed controlled research in the area of traffic safety. In addition to the achievement of research objectives otherwise difficult or impossible to accomplish, such a device can serve—perhaps even more importantly—to make research findings readily acceptable to the driving public.

H.W. CASE, Acting Assistant Director, and S. HULBERT, Assistant Research Psychologist, Institute of Transportation and Traffic Engineering, University of California, Los Angeles — The writers read Dr. Fox's paper, and found it very good.

In his paper, Dr. Fox indicates that it would be possible to conceive a simulator of a fairly simple type. Perhaps it should be indicated here that there are two devices now in operation at UCLA, one of which is a simulator almost of the type described and on which actual experiments are being run.

The writers have sent the author certain suggestions for minor changes and suggested a reference to Forbes' early work that might be appropriate since it predates both De Silva's and Vincent's work. Under "A Note on Cost," we get the impression that the author is saying that it would be more feasible to build a simple machine from both technical and financial viewpoints. It is believed he means that probably the first step toward obtaining a complex and highly developed simulator would be to build one or more simple ones, but not that they would fulfill the same research needs.

The over-all presentation is an important contribution toward advancing the simulator program and the author is to be highly congratulated.

S.M. BREUNING, Associate Professor of Civil Engineering, Michigan State University, East Lansing — Although the paper is very exhaustive, the writer feels that the psychological uses are stressed much more strongly in this paper than the engineering uses. Initially driving simulator has meant little to the writer and was considered a machine with little use for the engineer. However, in thinking about the simulator during the last few months, he is beginning to get enthusiastic about the potentialities in the traffic engineering and in the geometric design fields. It is believed that there is great need to acquaint other engineers with the potentialities of the simulator.

A graduate assistant who read the paper said that he did not comprehend from the paper that the simulator might use an actual three-dimensional model rather than just films. It appeared to him that all simulators would use films for presentation of the environment through which the car is driving. In other words, the concept of driving an actual model car on a small-scale model scenery did not become clear to him. This is a point that could be easily corrected in the paper, and one might suggest that a photograph of the model demonstrated in Washington might do well for this purpose.

L. BRODY, Director of Research, Center for Safety Education, New York University, New York City — Dr. Fox's paper is the best statement on the subject that the writer has read.

A few specific comments: (1) The writer subscribes fully to the author's statement that a simulator will permit research which is unsafe to do otherwise and that this is its most important justification. With regard to impracticality and limited control of other research techniques, the writer is not sure that this has been fully explored. For example, it is felt that the use of dual-control cars in off-street test areas is also applicable to at least some of the conditions listed. While full realism would not be achieved, such a program might come closer to it than a simulator. (2) Dr. Fox states that a first concern must be to describe properly the behavior of drivers and emphasizes the need to set up behavior measures. The writer agrees, and by implication this means that the development of a simulator is secondary. (3) The author justly highlights the dynamics of traffic. This presents a real challenge in the development of a simulator. Needless to say, where the latter employs motion picture film, the filmed driving situations to which the subject responds are a stimulus pattern sequence that is fixed by the film and imposed on the subject, whereas the selective choice by the driver of the stimulus patterns to which to respond is an important feature and determinant of real driving dynamics.

J.E. BARMACK, Assistant Vice President, Dunlap and Associates, Inc., Stamford, Conn. — Some detailed reactions to this paper are:

1. Under "Classes of Research Which Would Be Done on a Simulator" there might be added the interaction effects of delayed sleep, alcohol, darkness, and the unstimulating road. This combination turned up rather heavily in our own study.

2. Again the writer would suggest a category of studying the interaction of alcohol with certain biographical and personality characteristics.

One of the important advantages and shortcomings of a simulator is that the experimenter selects the driver and the situation. In the real world the individual selects the environment and the accident selects the driver.

One of the issues that may be examined is the relationship between broken homes, drinking and accidents. Is the drinking a response to grief or whatever the disrupted home generates? Can we impute the accident solely to alcohol? Is there some selective interaction between broken homes and drinking which makes the performance of individuals from a broken home more vulnerable? How can we account for the fact that some individuals who had been drinking can sustain vigilant sets and others cannot? What factors differentiate the individuals who decide to drive or not to drive after drinking? What factors differentiate individuals who speed with alcohol vs those who drive carefully?

These are some of the issues which have impressed people as close to the types of accidents which are of concern. A series of studies on these factors can help overcome the intrinsic "selective" shortcomings of the simulator approach.

R. MICHAELS, Research Psychologist, Bureau of Public Roads, Washington, D.C. — Dr. Fox has written a rational analysis of the needs for and values of a driving simulator. It is a combination of a philosophy of research and on operational program for the conduct of research that is rarely seen in the highway research field. A philosophical paper, however, has a couple of disadvantages. One is that it stimulates the reader to find flaws in the logic. (This reader has found only a few over which to quibble.) A second disadvantage is that it stimulates the reader to read between the lines.

In regard to logic, the definition of a simulator seems disconcerting. Dr. Fox implies that a simulator simulates according to the intent of the experimenter. This apparent subjectivity is quite shocking. Actually, a simulator is a device whose transfer function is analogous to the real system which it mimics. Such a device simulates insofar as the input-output equations approach those of the real system. It would seem that this is the continuum along which simulation should be scaled, not a researcher's or observer's biases.

The basic aim of any driving simulator is to reproduce the machine-environment system so closely that the behavioral determinants of over-all system functioning can be operated on independently. In conceiving of a simulator two problems present themselves. One concern is the machine-environment part of the system. Is enough known about its interactions to develop a rational model of its behavior? To this there seems to be a qualified positive answer. The second question is do we know how (or what) to analyze human behavior within the constraints of the driving system? Here the answer is probably much more nearly the negative. This in itself constitutes the ultimate need for a near perfect machine-environment simulator. If some basic knowledge were available about the performance equations of the man-machine system (opposed to the machine-environment system) research on driving without total simulation could be undertaken. Ignorance about driving performance forces a demand for near-perfect simulation.

Thus, the proposed simulator represents a basic research tool and its availability does not automatically insure valuable results. It is here that the writer parts company with the program proposed by Dr. Fox. The list of studies he presents implies, at least, that the simulator is a device for discriminating among factors affecting driving behavior. The writer would contend that the real power of this simulator is to aid the scientist in the generation or discovery of the equations of human performance that determine over-all system performance. Anything less leads only to the normalizing of behavior. It is not enough, for example, to tell a highway engineer that a diamond-type interchange is better than a partial cloverleaf. He needs to know the behavioral criteria that must be employed in order to optimize interchange design. It is the criteria that the research scientist must supply, not normative comparisons of one design vs another, or one group of people vs another.

Implicit in this paper are two values of a simulator which are of a transcendent importance for the goals stated previously. One is the experimental control that can be exerted over the research. From a purely technical standpoint, field studies of driving can rarely be carried out with adequate control over all the system variables. Such field studies, therefore, have low reliability and lead to generalizable conclusions of only the crudest sort. With a simulator and good science this restriction can be lifted, and definitive research is possible. The consequence for highway transport can be tremendous.

Second is the freedom that a simulator gives to the scientist. With this device, the scientist will be able to pursue the logic of his research to a conclusion inconceivable in any other way. In the long run, it is this freedom that will lead to a precise, operational, statement of driving system performance. And it is at this point that it will be possible to tell the engineer not which is a better design, but rather what behavioral considerations determine optimum design. The consequences of this for increasing the efficiency of highway transportation are also tremendous.

The writer thinks that the studies enumerated in this paper will not ultimately be the ones carried out with a simulator. Those who have the conception that a simulator will be used for accident prevention, design data, or driver licensing will very early be disabused. Such engineering considerations will derive as an indirect consequence of scientific research done with a simulator. Furthermore, as has been the case historically, the advent of a powerful research tool quickly leads to a sophistication in scientific experimentation which moves far outside of lay comprehension. This will be doubly salutary: first because it will allow the research scientist to expend his energy on research and will insulate him from the pragmatic concerns of the managers, publicists, and salesmen. Dr. Fox's paper is a remarkable document in this respect, for it shows clearly the pressure under which he has been put to satisfy these people's material demands. It is fortunate to have a man of Dr. Fox's persuasiveness. Most scientists are not so apt; they see no necessity to justify the very patent needs that this tool will fulfill.

The second salutary benefit of this ultimate research will be that it will force an increase in sophistication in many areas of the highway research field. In this regard, there are some striking similarities between certain research in the highway field and the field of optics and sound. These latter, for many years, were considered "dead" fields of physics, ones for which all the important answers were known, and engineering considerations the only ones left. With the advent of more powerful tools of analysis, these areas are reawakening interest, drawing in more active and original scientists, and ultimately generating more sophisticated uses. The driving simulator can do the same in some phases of highway research. If this occurs it would be a most desirable consequence of inestimable benefit to all of highway transport.

In this discussion of Dr. Fox's paper, the writer has tried to read between the lines, and has read more perhaps than the author intended. There is little that he said that can be quarreled with. He has been more pragmatic in the program he states in this paper than the writer thinks he will be when the simulator is available. But he has, in general, stated well the need for tools in this field of research. If his statement furthers the progress toward them, everyone will owe him a great debt.

D.B. LEARNER, Human Factors Group, Research Laboratories, General Motors Corporation, Warren, Mich. — (The following was contributed as expressing Dr. Learner's point of view on driving simulators. It is taken from a paper by him on "Development of the GMR Minimum Analog Driving Simulator" presented before the Institute of Radio Engineers, March 25, 1960, in New York City.)

> In the brief history of man-machine system simulation it has been characteristic that practically all applications of this approach may be categorized as either operator training or control system research. Training simulators have generally been developed in an effort to provide familiarization with specific new tasks that an operator is likely to encounter. In recent years

there has been a divisive trend in the development of such task training simulators. This results from one point of view that believes the whole environment must be simulated to the last degree of realism, as characterized by the current DC-8 simulators. On the other hand there are those that believe part task simulation for training purposes has great value in most applications. This approach simply means that certain elements of the task are simulated so that the operator may be realistically acquainted with critical procedures.

Research simulators however have primarily been developed in an effort to learn more about the interaction among man, the vehicle he controls, and its operating environment. Here too there has been a divergence of opinion related to the extent of realism required to simulate an operational system. If the prime importance of research simulation is viewed as determining man-machine interactions, and the effects of varied vehicle dynamics on operator performance, then it seems realistic to believe that mimimum simulation may be as adequate for research as it is for training.

Whether the simulator has been constructed for training or research purposes, one required provision is for some method of validating the results of simulation with the real world counterpart. Such provisions for determining the extent of relation to the real world are often lacking in both training and research simulators. In fact if any single area of research on simulation techniques should be underscored as deficient it is the state of the art of simulation validation.

When the problem of a driving simulator is considered it must be viewed against the background of the cost of simulation relative to the cost of a full-scale automobile. The problem is one of conducting controlled investigations of driving performance under systematically varied conditions. There seem to be three alternative procedures for investigating problems of driving performance and these may be classified as descriptive studies, full-scale studies, and laboratory studies. Related to each of these solutions are a number of advantages and shortcomings. Descriptive studies in the operating system of today have a number of significant advantages. A multitude of variations and observations may be made at minimum cost. However, systematic variability is clearly impossible under operating conditions. If for no other reason than the utility of highway transportation systems prevents the imposition of experimental conditions that may lead to inefficient use.

Full-scale simulation studies have a variety of advantages. Such studies have been carried out for some time with variable stability aircraft and are currently under way with a similar variable stability automobile. Such an approach allows for wide variation in system dynamics and control configurations. However this full-scale simulation must always operate within the constraints of the environment. Furthermore there are significant research problems that cannot be comprehensively investigated with a full-scale simulator on the road. Such problems mainly fall in the area of safety, fatigue and vigilance.

A third approach to controlled investigations of driving performance would be to carry the entire system into the laboratory and reproduce every detail. Many disadvantages of the foregoing alternatives would be eliminated under these conditions. At the same time it seems unrealistic to spend large sums of money on simulating an item that can be purchased at a local dealer for $ 3,000 or less. As a result some estimate of the extent of realism required in laboratory simulation must be attempted.

It should be pointed out these solutions are not necessarily mutually exclusive. All three approaches should be used and cross-validated from one mode to another.

(The remainder of Dr. Learner's paper discusses the three requirements which were thought necessary for the GMR Minimum Analog Driving Simulator; namely, accurate response reproduction, validity and flexibility allowing simulation of the wide variety of vehicles. The design of the Minimum Analog Driving Simulator is described with attention to the way in which the environment, the vehicle and the vehicle controls are simulated to satisfy the criteria and requirements. Copies of his paper may be requested from General Motors Research Laboratories, Warren, Mich.)

CLOSURE, Bernard H. Fox — It is gratifying to know that the respondents are in agreement about the great importance of pursuing simulation techniques. Drs. Forbes, Malfetti, and Uhlaner have underscored this importance. It is further gratifying that the committee has felt the subject to be of great enough potential value to spend time on making judgments. The author appreciates very much the chance to take advantage of their rich experience and valuable criticism.

Dr. Case and Dr. Hulbert, being in the center of progress on simulation methods, are correct in inferring my intent in the description of the simpler types of simulators. These types are without doubt less useful, and can give fewer — and often not as good — answers to the questions which one would like to ask about driving behavior. Simulators which are highly programmed like the current motion picture devices worked on at UCLA are peculiarly limited in the variety and types of questions which they can answer about driving behavior, as was pointed out in the section on "Limitations on Experimentation" under "Programming." But as they infer from this section, greater usefulness and greater versatility by far can be found in a device which will permit not only unprogrammed action by the subject's vehicle, but unprogrammed interaction of great variety with other parts of the environment, usually other cars. Such a device, from the present vantage, is considerably more complex. Furthermore, it is much more expensive, in part because it requires a great deal of original and developmental research, and in part because of the more extended structural requirements for such a complex simulator: computer, environment, pickup and transmittal device, and vehicle simulator.

Professor Breuning is apparently regretful that the balance of emphasis went toward psychological rather than engineering uses of simulating techniques. Rather than planned imbalance, the reason for the emphasis was more a matter of ignorance on the author's part. An experimental psychologist is likely to see more clearly the human factors applications of simulating techniques than the engineering applications. But far from choosing to maintain such a state, the author encourages most warmly the contributions of other disciplines to a discussion of potential of simulating techniques. Certainly such contributions will increase the urgency of the need to carry forward work in simulation.

His suggestion that a picture of one advanced concept of a simulator be added is excellent. It is appended, with a brief description of the way this particular simulator is intended to work.

Dr. Brody's comments are most welcome, but more important, they point up a communications problem. Certainly adequate research itself is the objective, and not the means of reaching it — simulation or other approaches. It was for this reason that so much of the paper's emphasis related to the various problems which might be attacked by simulation. It was a failure of communication if the paper seemed to imply that research using other techniques, such as on-the-road research, was impractical or had limited control in toto. Simulation, like any other method of research, has a place if it can produce research results in which researchers have as much confidence as those arrived at by other means, other things being equal. It must be admitted, regrettably, that in many cases on-the-road research does have limited control, and is impractical. In such cases, if simulation can correct those difficulties, and not introduce worse ones, it is preferable to less adequate research. On the other hand, as Dr. Brody has pointed out, where a particular attack on a question would produce results which are scientifically as acceptable as those produced with another attack, the former should not be discarded without very sound reason. Perhaps the comparison between simulation and other techniques might be placed into the whole context of comparison between any two techniques. The discussions under the headings "Values in the Strategy of Planning Traffic Research;" "Limiting Costs for Research Priorities;" and "Alternative Techniques of Research" would have more impact if their applicability to comparison between particular techniques were emphasized more. The author agrees with Dr. Brody, and feels that where possible, under the criteria of an acceptable cost-gain equation, as mentioned in these discussions, nonsimulation techniques can also be applied.

Dr. Barmack's suggestions were very stimulating. Without a doubt, if research into the variables which he mentions as important can be done, it should be done. While most of these variables (delayed sleep, alcohol, darkness, monotony, and biographical and personality factors) and their interaction were mentioned briefly in a previous paper (Goddard and Fox), it certainly does no harm to re-emphasize the need to study interactive effects, particularly when tentative results of two independent researchers* have shown interaction between personality attributes and effects of alcohol.

Dr. Barmack has done research which seems to point to certain personal variables as extremely important ones in the field relating drinking and accidents. He would like to see more research done on these variables. He mentions that advantages and disadvantages exist when subjects are selected by the experimenter rather than by membership in a criterion group. He then stresses the disadvantages, ignoring the advantages, and implies directly, in his last statement, that doing studies which attempt to answer his series of questions would help overcome the selection difficulty which inheres in the use of simulation techniques. One might almost infer an intent to say that simulation studies on these matters would be less valid because of the selection difficulty.

Assume that a sample is drawn based on a hypothesis about certain variables, and it is selected according to a predictor difference. An attempt is then made to relate the existing predictor difference to a criterion difference. In this case the predictors would be broken homes, drinking patterns, and personality, and the criterion would be accidents. This kind of research is spoken of as a prospective study. When a sample is drawn according to its membership in a criterion group and the relationship is examined between criterion measure and sample characteristics which are later determined, even when one starts with a hypothesis of relationship, this is called a retrospective study. Both kinds of study are possible with simulation techniques and with other techniques. Dr. Barmack's objection to predictor selection of subjects implies that he does not want to pre-select them as in a prospective study, but would rather have them select themselves because they became separated from others as a result of their criterion characteristics. This is precisely the way his study was done, and is definitely the description of a retrospective study. But if he were to attempt to examine more exactly the relationship of the pertinent variables to the criterion, the only way to avoid all bias and to create an unconfounded design would be to do a prospective study. It is in this very selection that simulation techniques excel, because the selection allows control of the variables to be investigated, and permits all the advantages of a prospective study. In this sense prior predictor selection and later criterion selection are more, rather than less advantageous than prior criterion selection and later predictor selection.

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*Drew, G.C., Colquhoun, W.P., and Long, H.A., "Effect of Small Doses of Alcohol on a Skill Resembling Driving." Med. Research Council Memo. No. 38, Her Majesty's Stat. Off., London (1959); and Barmack, J.E., Public Service Research Institute, Stamford, Conn.

Only two kinds of studies, in the present context, cannot be done by simulation: (1) those in which driving behavior by the individual or his accidents are not the criterion, for example, questions #1 and #5 in Dr. Barmack's list (it has never been presumed by anyone that a simulator could be of any use in such cases); and (2) those which involve behavior states which are not producible in the laboratory, such as grief or transient emotionality of certain kinds. Subjects reflecting degrees of the latter variable are as available or as unavailable to the simulation experimenter as to anyone else. For the former the natural sequence of events may be altered, whereas it need not be for the latter. For all other questions which Dr. Barmack posed, studies can be done by simulation techniques as well as by other techniques. In this connection, the accident selects the individual more, rather than less easily with simulation than with other techniques, because there are more critical events possible, and the driver has an accident as a result of his driving habits, just as in the real world.

Nevertheless, it is well to restate Dr. Barmack's point. It is important to examine interactive aspects of alcohol effect beyond those which might be considered purely perceptual or perceptual-motor, particularly personal history and personal attributes. The author maintains, however, contrary to what he perceives to be Barmack's implication, that simulation techniques offer as great or greater opportunity for controlled studies of accident tending behavior than naturalistic study, even with respect to many of the more molar aspects of the person. It is just as easy to test a person from a broken home in the laboratory as on the road. (The probable relative success of such tests or techniques of conducting them are not at the moment under discussion.)

And to be sure, prospective studies on a simulator take much less time than similar ones using a real accident criterion.

Dr. Michaels' comments are most provocative and gave the author much pause. In the same way that he has done, the author tried to examine them for between-the-lines and for in-the-lines intent. Different portions of the comments produced different reactions.

His first remarks produced the reaction that as little as one can argue with a postulate, still less can one argue with a definition. The writer and the author have agreed on different criteria for defining a machine as a simulator. But it may be possible to show reasons for taking one view or another.

In deciding on the degree to which a machine is to be regarded as a simulator, the author believes that one needs the combined value of at least two measures: the intent of the investigator and the objective similarity of the instrument inputs, outputs, and their relation to the driving situation. Dr. Michaels seems distressed that the author considers the first important and writes as if the author did not recognize the second. He says that the second is the criterion of importance, seeming to ignore the fact that the author included it as a basic part of his definition of measure. Thus on one basic measure both have insisted on the same thing.

In respect to the other, it is possible to ask two questions: (1) To what degree should a machine be regarded as a simulator? and (2) To what degree does a machine simulate? The author believes that Dr. Michaels is answering the latter question, and that he is answering the former. The second question already assumes a value for the measure of the investigator's intent, but does require a measure of input-output similarity. The first question, on the other hand, requires both measures.

Another problem, however, which bears on the difficulty of measuring such similarity, and which may make a comparison of input-output equations not the best measure of how well a machine simulates, is the problem that has to do with how different zero is from zero. Assume that one simulator has no acceleration input and simulates travel over a moderately curvy, hilly road, with considerable stop and go travel. It has fairly good sound simulation, however. Another simulator has essentially a constant sound output close to threshold, but represents accelerations fairly well. The author does not say that a comparison is impossible, but the process of making bananas and apples into fruit, which is the obvious step of transforming disparate measures into a common measure, is a difficult job. The process may even result in an artificial communality more difficult to handle and assess in measure than a subjective evaluation of likeness, where the judgment is based on input-output equations in part, but considers other things. At any rate, the problem is not so straightforward as it seems.

To keep the record straight, invent an example where intent of experimenter is crucial in the decision to regard a machine as a simulator. This case shows that equation similarity becomes irrelevant when the instrument is not used as a mimicking machine, and that intended use will determine how important the likeness may be. Assume that optokinetic nystagmus is induced by various configurations of vertical bars, none of which has a counterpart in real life. If the machine imposes a motor task simultaneously, just because the experimenter on nystagmus needs a motor task, and this machine is available, and not because the task happens to resemble driving, has one the right to call the machine a driving simulator? But let the experimenter focus attention on the efficiency of using the machine as a car, and let the nystagmic stimulus be used as a distractor, however poorly it resembles the environment and however badly conceived, then one gets a little closer to the machine's use as a simulator.

Humility in this field is very necessary, however. It is important to point out that merely showing two factors to be better than only one of them may not be enough. Probably someone can show that a third or fourth is required. Therefore the author suggests that the importance of these two factors — similarity and experimenter's intent — may be great or relatively small. Research of the future must determine this.

There is some question about a statement made in the paper which Dr. Michaels also subscribes to. It says that the better the simulation, the more valid the simulator. Some evidence in the field of training* brings this statement into question. We are fairly sure that it is not universally true, but can presume that it is generally true. These exceptions, however, point to the need of a great deal of research.

Dr. Michaels ascribes to me the statement that a simulator is a device for discriminating among factors affecting driving behavior. He then denies that this is a major objective in doing studies on a simulator, asserting that the major objective is to determine equations of performance in order to apply them to a system of performance. These may then be used, he implies, to tell the engineer what behavioral criteria must be applied for optimum design of any road configuration.

It is important to note that one does not necessarily do research on determinants of driving behavior for the exclusive purpose of helping to design roads. It is also possible to help the safety and efficiency of travel by means of enforcement techniques, regulatory systems, signing systems, licensing requirements, removal of drug effects, physical restrictions for drivers, etc. These would all be helped by research directed to other information than a performance system. The author agrees, however, that those who would expect immediate payoff in some of these fields will probably be disappointed. A simulator, except in a few places, is not a quick return device.

A purely descriptive characterization of driver behavior given in terms, say, of car behavior and person behavior (measuring such things as performance, risk, attention field, perception, personal condition, and their relation) can lead to many decisions without necessarily using a systems performance description. Here the author acknowledges gratefully Dr. Michaels' insight between the lines. It is not necessary to stress that nothing prevents both a systems attack and a descriptive attack — this is not to say that quantitation is excluded from the description — from being combined objectives of simulation techniques. Even if this were not between the lines of his comments, the author would feel compelled to make the point. In the lines of his comments was the specific suggestion that system description of behavior will probably be an ultimate goal. The author agrees wholeheartedly. The question of ultimate value of descriptive research such as is discussed in the paper is another matter.

While the author is less sanguine about the ability of the simulation researcher to insulate himself from practical matters, as Dr. Michaels suggests that he do, the author agrees that if he were able to do so, the ultimate aid which he could give to transportation needs would be multiplied significantly in the long run. It is hard to convince the practitioner of this, however.

In sum, there has been less disagreement between the writer and the author than might appear from the discussion.

Dr. Learner's remarks are over-all correct. I would make one or two suggestions. While it is true that a car may cost only \$ 3,000, it takes considerable expense to

* Drew, G.C. Personal communication (1960).

do research on this piece of equipment. One needs, at various times, people skilled in engineering, instrumentation, psychology, data analysis, etc. In addition, the instrumentation itself needs development and construction. There is no doubt that work on a real car is less expensive than work on a fixed simulator of high fidelity. Yet this leads to a second point.

Dr. Learner's classification of research into driving performance makes no provision for less than high-fidelity fixed simulation. In the same way that it has been found that in training there are cases where full-scale simulation is best and cases where limited simulation is best, so in research one may expect to find the same thing. Depending on the objective of the research, the validity of the simulator in respect to the measures to be undertaken, and other entries in the cost-gain equation, it is likely that certain researches can be undertaken with limited performance laboratory simulators, others with very faithful laboratory simulators, others with on-the-road simulators, and still others with on-the-road real cars.

It is for this very reason that the author has been at such great pains in this commentary to point to the need for simulation techniques rather than a simulator (although he was not at such great pains in the original paper. But see the section on "Programming Priority.") These techniques, of course, include the kind of work that Dr. Learner has been carrying on.

One more thing which bears on the use of simulation in conjunction with live car research needs emphasis. Even if certain research can be done by means other than simulation, it has often not been possible to do such work. The reason is not of the greatest importance. Possibly it had to do with cost, possibly with past failure (not necessarily inability) to develop techniques, possibly with other things. But if simulation techniques were available, and a program of research were entered on, it is very likely that one could schedule research activities which are needed but haven't been done.

The author gets the impression that Dr. Learner's sights are more sharply focused on problems of driver relation to car handling, vehicle characteristics, and dynamic car behavior than on some of the other researchable features of driver perception and performance, although he has not completely ignored the latter. Some of his points are cogent if taken against the background of car characteristics. They must take their place in importance alongside other considerations when seen in the context of the whole spectrum of possible driver research. Fundamentally the author and the writer are in agreement on the place of on-the-road research relating to car characteristics, as seen from the section on "Alternative Techniques of Research."

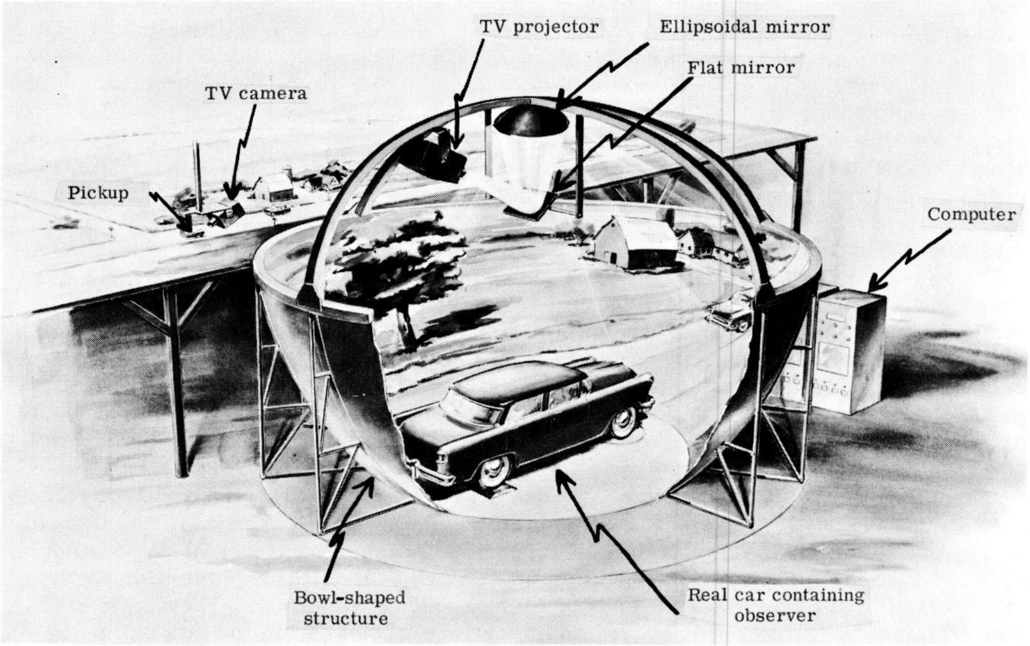
Aside from a few considerations mentioned previously, the author is very much in agreement with Dr. Learner's analysis of the general picture.

The author has a last general between-the-lines comment. The point was brought to the attention of a group which was meeting under the auspices of the Automotive Safety Foundation during a presentation by Dr. G. C. Drew, who did work with a point source of light simulator for the British Medical Research Council at the facilities of the Road Research Laboratory. It was the suggestion of the group that one should not attempt to promote "the simulator" or "a simulator," but rather "simulation techniques." Merely pointing out, as I did in the sections on "Preliminary Simulator Configuration" and "Research Possibilities" under "Planning for Simulator Research," and "Validity" under "Other Considerations," that several simulators need to be built at several levels of fidelity, each with its own design to achieve its own purpose, is not enough. Researchers must constantly be on guard that the professional, and particularly the lay public do not conceive that there is one instrument, one design, which the researchers would like to see created. For this reason, throughout the preceding discussion, the author has been careful in phrasing references to simulators and simulation. It is simulation techniques which are needed, not a particular simulator.

The author's thanks go again to the committee members for their interest and the further light they have thrown on the simulation problem.

A number of approaches to fixed simulation can be taken: point source of light, film, models, etc. Different techniques of transmitting the original image and projecting it are possible.

The conceptual schema pictured here is one which was described in some detail in a study done by the Cornell Aeronautical Laboratory for the Public Health Service. (The photograph depicts the same conception which appears as the frontispiece of the study: "Automobile Driving Simulator Feasibility Study," Cornell Aeronautical Laboratory, 1958; project direction, C.H. Hutchinson.) The notion of a reflecting vertex of a conic section was partially developed by the Bell Aircraft Co. and is still under investigation by the Cornell group.



In this conception a model of a road scene with small model cars forms the input to a receiving element or pickup, which is in the position of the driver's car in the model. The pickup is shown directly ahead of the TV camera on the road. Its mirrored surface is the outside of a skewed section of a hyperboloid of revolution, with the vertex pointing forward in order to allow that portion of the surface with best resolving power to receive the most important part of the scene . The image of the road scene is received by the surface of the pickup and is reflected into the TV camera above the road scene, shown pointing at the vertex of the pickup. This image is transmitted to the TV projector above the bowl-shaped structure onto a flat mirror, which throws the distorted image from the pickup upward to another specular surface. This mirror is the inside of an ellipsoid of revolution which is related geometrically to the pickup hyperboloid so that the image which the latter picks up becomes undistorted to the viewer inside the car when projected onto a screen from the ellepsoid as shown.

The person sits in the real car occupying the bottom of the bowl. When he manipulates the controls of the car, the pickup on the scenery behaves in respect to the scenery as it would if a person were doing the same things to the controls of a car on the model itself in the location of the pickup. The pickup is slaved directly to the controls of the subject's car — brakes, accelerator, steering wheel, etc.

Under these conditions the movement of the subject's car is unprogrammed: he can make the pickup, corresponding to the model car under his control, do anything he chooses in response to traffic, road characteristics, signing, etc. Contrasted with this, in a film version he has very little control over what he can do with respect to the driving environment, other than what the camera did which photographed the scene originally.

A computer is also shown. It would function to program scenery changes and traffic movements and to analyze responses of the subject or car.