Some Technical Considerations In Driving Simulation

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● A REVIEW of the literature shows a number of possible approaches to constructing a driving simulator. Most of these have been mentioned before: film (6), point source of light (1, 2, 11), direct optical viewing (12), TV transmission (8), etc. The troubles with some of these have been discussed at some length (7, 9). The author would like to discuss one aspect of the total simulation problem which has not been treated in the literature. It is a serious consideration, which might well affect basic long-range planning for simulator research.

This problem arises in that conception of a simulator which uses a model as the source of environmental input. In many conceptions, a TV setup is used to transmit the scene to a visual projection for the subject's viewing, with whatever adjunctive techniques might be required. The device pictured in the paper, "Engineering and Psychological Uses of a Driving Simulator" (3), shows one way of using models. Others are known and have been used. The description of model use in that paper is an adequate example of a method which would be applicable to the discussion in the present paper. It should be emphasized, however, that it is only one such example.

The question has been asked whether it is possible, with the model technique, to simulate driving long distances. Such a task is very difficult. Even though it has been concluded, and rightly so, that a combination of model and film, or model and other associated techniques, would be much less expensive than a full model technique (3, 4, 5, 7), it is still necessary to examine the latter thoroughly to see just what might be involved. This examination, it is hoped will justify the conclusion mentioned.

The idea to be discussed here was first introduced, to the author's knowledge, at a meeting in 1958 at which were present James Goddard, Fletcher Platt, and the author. A problem inherent in this idea is examined and two possible solutions given. Other problems will be mentioned.

In order to be able to go long distances on a model setup, one of the things that might be helpful would be to avoid the necessity of creating a full model panel for every mile traveled. Obviously a full model would be quite impossible, say, for more than a few miles. To avoid the necessity, it was suggested that substitutable model elements be used in the total scene. The Cornell Aeronautical Laboratory later coined a useful phrase to describe this process. They called it "terrain synthesis."

A model scene could thus be transformed into another if the model elements were removed and replaced by others. Various means of doing this have been considered. One of these might be computer programming of terrain in advance, removal of terrain elements to a terrain bank by automatic mechanism under time control and position control of the computer, and replacement from the same bank. After the TV pickup representing the moving car has traversed the scene, the panel is transformed into a new scene by this technique and made suitable for another trip over it by the TV pickup, which has meanwhile traversed another panel.

Certain other ideas were added. For example, Cornell Aeronautical Laboratory has suggested that storage could be arranged as part of a panel. A scenic element could be quickly replaced by rotating it around an axis imbedded in and parallel to the plane of the panel. Building walls of different colors inside and out could be swiveled on such a pin axis to give different building appearances quickly and simply. All of the foregoing devices combined could produce a programmed situation where it would not be necessary to build a long line of successive different model panels over which a pickup would have to travel to simulate long drives.

First, it may be instructive to look at some of the figures involved. Because it would be so difficult to achieve the extreme detail which would be needed, it is almost impossible to conceive of a model whose scale ratio would be much greater than 100 to 1. On the other hand, in order to limit the size of the panels on which the models would be set, it is almost inconceivable that one could go to a scale ratio much smaller than 50 to 1. These limits give an approximate order of magnitude within which computation of other estimates can be made, say 75 to 1 as the model size.

Even with panel substitution, however, the need for at least two or three panels remains. The size of a panel might be governed by ease of moving or changing. At a 75 to 1 scale, a world mile is equivalent to about 70 ft of model, probably the upper limit for panel size. In a 300-ft building, 200 ft would accommodate three panels endwise. The problem, then, is how to devise a technique so that panels will be replaced and the pickup will be able to move along continuously, going from one panel to the next repeatedly.

Two methods come to mind, although no doubt there are many other techniques for accomplishing this task.

One method involves longitudinal relative movement of the pickup which represents the car. The pickup moves along over a panel which slides backward simultaneously at greater than pickup speed. Maximum pickup speed is the equivalent of a live car speed of about 70 mph. The pickup may move as it likes below this speed. At a scale of 75 to 1, the panel would thus actually move more than 1.4 ft per second at maximum speed. This speed may be regarded as relatively large or not large, depending on the engineering of the situation – both computer and mechanical. That the latter is a consideration here will become clear. The rearward movement of the panel is important because one must provide a means for the pickup to maintain continuous motion. Simultaneously, another panel, after having been stocked with terrain elements, is in position ready to replace the original panel, so that the car will have a panel onto which it can cross when it reaches the end of the first one. When it crosses the panel junction, the second panel, now the carrier panel, begins its rearward movement. At the same time a third panel, having been in the process of acquiring synthesized terrain from the computers, now starts to move toward the soon to be vacated position of the current carrier panel.

An interval must be allowed for such panel substitution, which would take place either from below or from the side. If the pickup moves at maximum speed, a further interval must be provided for the replacement panel to move into position before the pickup reaches the end of its carrier panel. This is the reason that the carrier panel must be able to move at a speed greater than 1.4 ft per second.

A second method can be used which, in terms of engineering considerations, is perhaps more feasible in some ways, even though somewhat more complicated equations of motion are required.

Assume that two panels are laid end to end. The pickup starts at the juncture of the panels, going outward on the carrier panel. With respect to the surrounding terrain, it travels in a straight line until it reaches the end of the panel road and then crosses over onto the next carrier panel. But in order that motion with respect to the panel coordinates of travel shall be a continuous straight line, the panel itself must have been reoriented so that the pickup moves toward the receiver panel at the time of crossing, not away, as it started to do. This situation is achieved by a continuous rotation of the panel through 180 deg around an axis at its centroid while the pickup travels along the panel. Even at maximum pickup speed, no interval is needed with this method for insertion of a panel holding new terrain, provided that the terrain substitution process itself takes less than a minute or so. If it takes more, then three or more panels may be necessary.

Assume that the pickup moves uniformly just fast enough to traverse the panel during a single half rotation. The resultant true motion can be expressed by simple parametric equations, describing a rosette petal whose vertex is the real point of departure. The vertex is also the real point of arrival after the pickup traverses the length of the whole panel. At the half-way point, the real motion of the pickup is at 90 deg to direction it faced when starting, which was straight along the length of the previously stationary panel. Thus the pickup's greatest longitudinal absolute excursion is one-half a panel length.

When the pickup crosses over onto the receiving panel, the latter begins its rotation around its centroid axis, and the pickup (if at the same constant speed) again describes a rosette petal.

If the driver controlling the pickup decides to travel at a uniform speed such that the panel has rotated through its 180 deg before the pickup reaches the end of the panel, a spiral is described by the pickup, again definable by simple parametric equations, up to the point when the 180-deg rotation is complete. From that point the panel remains stationary and the pickup's true motion is again a straight line until it crosses onto the next panel.

It is obvious that if the pickup changes its speed during the trip along the panel, the equation of motion becomes complex. Certainly, in any case the situation implies a computer to handle the input, output, and feedback relations between pickup and real car. This is true whether the first or second method is used. The situation is made even more complex if the pickup moves laterally with respect to the model road.

The engineering problem is enormous. Think of moving a 70-ft panel at the proper rate of speed with no distortion and with perfect juxtaposition of model surfaces; removing and replacing farm houses, signs, road features, etc., over a 70- by 7-ft area within 1 or 2 min; and controlling the pickup with a movement tolerance of less than 0.003 in. If one were to consider reducing the panel size because of its unwieldiness, say to 35 ft, the time of changing terrain and substituting panels would be reduced, but not in half. Substituting panels takes about the same time for large and small panels, so that the time saving is only in terrain element substitution.

The difficulty of accomplishing the total task can at the present only be guessed at, because, to the author's knowledge, no one has made any actual engineering design attempts along these lines.

Certain problems arise in using a model and in combining film and model which must be considered by any designer or planner.

One of the most important is the closeness of tolerance with which a model using TV pickup must be built. If an object in the model field moves 0.003 in. laterally with respect to another, the relative equivalent change in the projected visual scene is about ¼ in. Whenever abnormal motion occurs, it becomes quite noticeable if it occurs rapidly, as might be the case in the model situation. Vibration or poor tolerance can cause such abnormal motion. Ordinarily a small object's limited motion, if its contours do not have especially high contrast with the field, is not particularly noticeable. However, an automobile model in this model scene will usually be a rigid object. If this is the case, a ¼-in. abnormal motion in the image becomes easily detectable inasmuch as the object in question occupies a considerable visual angle.

It is possible to produce accurate tolerances for visual purposes with a TV pickup, as demonstrated by the Link and the Curtiss-Wright jet simulators, where the same problem arose. But the objects in their field do not move suddenly with respect to the field; only the pickup moves. This difference may be critical in designing a model type of simulator for driving.

The question of how much detail must go into the construction of terrain and vehicle elements in the scene is a crucial one. No one has tested various degrees of detail under different conditions of magnification, closeness of the scene to the viewer, and speed of objects in the scene. It is likely that limits of good detail would not be excessive technically, but particular needs might influence costs to a profound degree. The question must be answered by research.

One way out of the dilemma of long trips using models as has been suggested (3, 4, 5, 7), is to alternate periods of using model and film or other inexpensive display. When interaction with other cars takes place which demands feedback to the scene, models would be used (except for simple feedback such as lateral position in a lane, or going faster or slower: these are possible with filmed images). On all other occasions film or other inexpensive display would be used. Whereas this technique reduces model cost considerably, it does not remove the need of having models to begin with, together with a control mechanism for the TV pickup.

Another problem of interest arises because it is desirable to have nonprogrammed rather than preplanned control of some cars with which the driver interacts. If they do require nonprogrammed control, the question of display and control devices for the control personnel comes up. Such needs increase the cost of the mechanism, although not in exceedingly great measure. The techniques for permitting control must involve a number of decisions of importance — number of control displays, accuracy of display and control, etc. An interesting part of this problem is that the control personnel must not have before them the same scene as the experimental driver sees. They would probably see the model scene enlarged from above or from a distant pickup.

It will be important to look at costs in the present case, because the greatest expense entailed in the creation of this conception of a simulator, that is, a terrain model using TV pickup and projection, will probably lie in the model making, TV pickup movement, and model change. If no synthetic terrain were involved (that is, if only fixed panels were used), the cost would be far too heavy in the model building (always assuming that extended driving is required).

It has been suggested that the width of panels be reduced in size to save cost, and that films or other inexpensive projections be presented at the sides of the model to blend in with the visual projection received from the model. It is the author's opinion that while such a suggestion was made from a desire to reduce costs, one should make the more serious point that to try to create a simulator with input from a model only would be impossible in a practical sense, not merely disadvantageous, or uncomfortably expensive. It is not so much that a technique of melding film, for example, and model is desirable; it is that cold figures put out of the question the use of full models. The reason is that a model of this type, requiring buildings with razor-sharp edges — a necessary technical feature here (10) — costs on the order of $200 per square foot. For a 70-ft panel, extending over a world distance of a mile, if one were to represent ⅓ mi of terrain on either side of the road, giving a 5,000 sq ft model panel, one would need to spend $1,000,000 per panel. Even with grosser detail at a distance, which might lead to as little as one-half price per unit, three panels would be inordinately expensive. To create the terrain substitution system would still involve building a number of elements two or three times greater than the number containable in three panels. All of this cost is materials expenditure, over and above any research or developmental costs which have been quoted with some confidence for certain aspects of the developmental program (7).

Thus the designer is forced to use a narrow model width and blend the model scene with the remainder of the scene, which has been filmed or otherwise inexpensively projected. The latter is that portion of the total scene which is affected by very little or no input from the driver, and which should feed little or nothing back into the driver's world of action and reaction except to give him perceptual orientation. Assume that instead of ⅓ mi of world scene (that is, 35 ft of model, on either side of the road), the model only encompasses, say 75 world yards on either side of the 25-yd road. This space would give a total model width of something like 7 ft. Now a panel will cost about $100,000, somewhat more reasonable than $1,000,000 or even $500,000. To this must be added the cost of film projection, film registration, film editing (there will have to be careful lateral editing to achieve good melding with the model), and the extra initial cost of setting up a technique for joining the two parts of the scene properly. The total will still be considerably below the ultimate cost of a full model system if the latter were to be built.

The figures used here are very rough. If a different scale size is taken, say 100:1 instead of 75:1; and a different lateral extent of scenery, say 400 ft instead of 525 ft; the cost of a panel a world mile in length would change by an order of value to something like $40,000, as opposed to $100,000 (7, p. 89). Other costs which are at present also guesses have to do with the kind of terrain, cost of unit terrain area, and similar matters. It is obviously a matter for research to decide what limits of lateral model extension are required or sufficient for the perceptual tasks involved, as well as other problems such as mentioned previously.

As far as is known no one has attempted detailed alternative analyses of engineering costs associated with the requirements described, even with respect to conceptual designs, let alone actual designs. Such cost analyses are badly needed.

The problem of combining film projection and model projection takes different forms for different techniques of alternating panels. If a linear panel motion is used, the projection can be stationary in space, with the panel motion and pickup motion in synchrony along the panel axis. In this case the absolute motion of the pickup along the panel axis, as well as the projector motion, would be zero. On the other hand, one might transmit to a moving projector or reflector with compensated position. Other means are also possible.

If rotating panels are used, the difficulties become greater. The direct attack would be to have the projector move with the pickup, both on the rotating panel. However, projection channels could be set up outside the panel and the projection moved by combined electronic and optical means. A number of other attacks can no doubt be conceived.

One major problem, which is not likely to be solved early, is the good enough simulation of city traffic. Fortunately, work in other areas can proceed without its solution. First, it will not quickly be solved because it will not be attacked early. But the more important reason for a late solution will probably be the fact that it is a most difficult problem. Pedestrian involvement can probably be handled by combining of TV images, using known techniques. But in respect to cars or other objects situated a few feet away, very serious difficulties will be encountered.

It has been suggested that a simpler device with only night driving might be a feasible first step toward multi-situation simulation. The problems attending the simulation of car, street, and sign lights are considerable — particularly car lights. Although the author is familiar with at least three occasions when "skull sessions" were held to try to dream up ways of handling these questions, it is probable that none of them has been described in published material. They are worthy of any scientist's mettle.

Aside from the questions brought up in the foregoing, a number of items await research before answers will permit plans for design of any of several more advanced simulation methods. These items are mentioned in some detail in the review by Molnar and Lybrand, as well as by Hutchinson. In the visual field they have to do with color, intensity, definition, contrast, resolution, field magnitude, etc.

In sum, a vast area has been opened up for the broadest scale approach by research and development teams. This area, the whole notion of driving simulation, deals with a large number of theoretical and practical problems in many fields: light, sound, mechanics, electronics, thermodynamics, human engineering, industrial engineering, psychology, cost analysis, management planning, research programming, etc.

It would be of the greatest interest to follow, and if possible, be a part of, the inevitable progress among the many fields and techniques contributing to driving simulation.

REFERENCES

1. Havron, M.D., and Butler, L.F., "Evaluation of Training Effectiveness of the 2-FH-2 Helicopter Flight Trainer Research Tool." Psychological Research Associates, PRA Report 56-17, NAVTRADEVCEN 1915-00-1 (1957).
2. Drew, G.C., Colquhoun, W.P., and Long, H.A., "Effect of Small Doses of Alcohol on a Skill Resembling Driving." Medical Research Council Memo. 38, Her Majesty's Stat. Off., London (1959).
3. Fox, B.H., "Engineering and Psychological Uses of a Driving Simulator." HRB Bul. 261, (1960).
4. Goddard, J.L., and Fox, B.H., "The Driving Simulator." Preprint, SAE (June 1958).
5. Hulbert, S., and Wojcik, C., "Driving Simulator Research." HRB Bul. 261 (1960).
6. Hulbert, S.F., and Mathewson, J.H., "The Driving Simulator." Inst. Transport. and Traffic Eng., Univ. of Calif., Reprint No. 65 (1958).
7. Hutchinson, C.H., "Automobile Driving Simulator Feasibility Study." Contract No. SAph 69692, for U.S. Dept. of Health, Education, and Welfare, by Cornell Aeronautical Laboratory, Buffalo (1958).
8. Link Division of General Precision, Inc. Notes on a simulator for training jet pilots using a TV transmission system.

9. Lybrand, W.A., Havron, M.D., Gartner, W.B., Scarr, H.A., and Hackman, R. C., "Simulation of Extra-Cockpit Visual Cues in Contact Flight Transition Trainers." Air Force Personnel and Training Research Center, Randolph AFB, Texas (1958). Also: Molnar, A.R. and Lybrand, W.A., "Basic Development Accomplished on Wide-Angle, Non-Programmed, Visual Presentations." NAVTRADEVCEN, Vols. I and II (1959).
10. Thomson, K.F., Personal Communication, U.S. Naval Training Device Center, Port Washington, N.Y. (1959).
11. Vincent, D.F., "The Institute's Apparatus for Testing and Training Drivers." The Human Factor, 10: 64-65 (1936).
12. H.A. Wagner Co., now a subsidiary of Curtiss-Wright. Constructed a pilot model of a system using as an image source a miniature tank platoon environment.