Computer Simulation of The Automobile Driver

A Model of the Car Follower

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Driving simulation has generally involved an artificial representation of the environment and an interface for the presentation of the simulated environment to human subjects. For at least the better structured part-tastks, the development of a single system capable of simulating both the driver and the environment could eliminate this severe interface problem. This study is directed toward the development of a digital computer program of the information processing type which simulates the behavior of the individual driver in interstate highway car following.

Objective measurements and verbal reports were collected in a series of car-following runs on the New York State Thruway. A preliminary information processing model was prepared in flowchart form. Quantitative detail was added to the model using data extracted from existing literature and from a psychophysical experiment conducted on the Thruway. Programing and testing of the model is planned.

•DRIVING an automobile encompasses extremely complex patterns of behavior, involving sensory and perceptual processes, decision making, and psychomotor skills. Current knowledge of the effects of the variables influencing this behavior, and of their interactions, is limited. For many aspects of the driving task, the relevant variables have not even been identified.

These considerations suggest at least two approaches to the study of the driving task. An analytical approach is required to help identify the variables involved in automobile driving. Experimental studies are required to determine the effects of specific combinations of these variables.

In general terms, the ultimate objective of the analytical approach taken in the present research is a formal description of the driving task, in a form which allows a determination of the exact implications of this description, and of variations in this description. Thus, this research is directed toward the formulation of a model of the driving task. The model should assist in the selection of a manageable subset of variables for experimental study, as well as improve general understanding of the driving task. This paper describes a methodology used in modeling driver behavior as applied to the car-following part-task.

The driving task is of sufficient complexity to warrant use of the most powerful analytical techniques available. The approach taken in the current study is computer simulation. The reasons for selecting computer simulation, and more specifically the complex information processing (CIP) approach, are briefly discussed in the following paragraphs.

A computer program is both a flexible framework for the construction of a model and a convenient device for objectively determining the implications of the model. The program can readily combine conventional mathematical models, where these are

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postulated as approximations to observed behavior, with complex logical processes where these seem more appropriate. Theorized elementary processes may be represented as sub-programs and combined in a variety of larger programs to simulate various interactions of the sub-processes.

Perhaps the most important qualities of the computer model result from the formal structure required by the computer program. The program must be complete and logically consistent or it cannot be processed on the computer. Computers are designed with no tolerance for ambiguous instructions or faulty logic. Further, the entire program is available for direct inspection and is thus a complete and detailed record of every assumption in the model which it defines.

The specific techniques selected for the modeling of the driver's task, which will be referred to hereafter as the CIP approach, are those associated with Newell, Shaw and Simon (1). Some of the many applications of this approach are reviewed by Reitman (2).

Two distinguishing characteristics of the CIP approach are the use of verbal reports elicited from subjects performing the task to be modeled, and the programing of complex logical processes as contrasted to conventional mathematical functions. The collection of verbal reports is an old idea in experimental psychology. A tendency to rely on the content of such reports as reflections of internal states of the organism led to the abandonment of the technique by the behaviorist school, which has since begun to accept the reports themselves as data ("verbal behavior").

The CIP approach makes use of the content of verbal reports. It does not, however, use this content directly in answer to experimental questions. Instead, the reports supplement, and often unify, experimental data and analytical study in the formulation of a computer model. The model can then be tested for validity by comparing its predictions to experimental data. The value of the verbal reports is thus measured by their usefulness in the formulation of a valid model.

The use of logical processes in the computer model lends flexibility to the form of the model, as compared to approaches which are directed toward particular forms of mathematical functions. The form of the CIP model tends to stay closer to the hypothesized behavioral processes, which remain recognizable in the computer program. Revision of the model can more readily involve re-evaluation of hypotheses about the underlying processes, rather than parameter adjustment exclusively.

The CIP approach has generally been concerned with the detailed behavior of individual persons rather than overall measures of group performance. This emphasis, and an effort to treat all behavior as deterministic rather than include random elements in the model, has led to the inclusion of larger numbers of parameters than conventional models of equivalent behavior. This not only enables study of the sources of variability in the behavior modeled, but permits an evaluation of the effects of variables which do not even occur in conventional models.

CONTROLLED OBSERVATION OF CAR FOLLOWING

The part-task selected for study was car following, more specifically defined as maintaining a "safe and comfortable" distance behind a specified vehicle on a four-lane, divided, limited-access highway. A series of controlled observations were made of drivers performing this task on the highway. Both verbal reports and objective performance measures were collected.

Method

Apparatus.—A 1955 Buick sedan was used as the following vehicle. A bicycle-wheel generator-tachometer attached to the rear bumper provided a voltage signal to a meter inside the vehicle. The meter displayed the following-car velocity in miles per hour. A potentiometer connected under the hood to the accelerator linkage received its energizing voltage from the automobile battery. The output of this potentiometer was displayed on a voltmeter inside the vehicle, providing an ordinal measure of accelerator pedal displacement.

A motion picture camera in the following vehicle photographed the lead vehicle. A "target," consisting of two vertical poles and a crossbar, was mounted at the back of the lead vehicle. The vertical extent of the target on the motion picture film was used to determine the inter-vehicle separation. The same camera photographed the velocity and accelerator position meters, through a mirror mounted on the dash.

A tape recorder was used in the portion of the study involving verbal reports. A timing device in the following vehicle flashed a light in the field of view of the camera every 20 sec, and simultaneously sounded a buzzer, which was recorded on tape with the verbal reports. This permitted synchronization of the picture and sound records.

Procedure.—The observations were conducted on the New York State Thruway. Before entering the Thruway, the subject (S) drove the test (following) vehicle on local roads for approximately 6 mi. He then parked at the Depew entrance to the Thruway, where he was instructed to begin following the lead car, maintaining a "safe and comfortable" distance. If, while driving on the Thruway, the following distance was so great as to result in other vehicles cutting in between the lead and following cars, S was asked to select a distance which would tend to prevent these occurrences.

After a 10-mi practice period, test car velocity and accelerator pedal position, and inter-vehicle separation were recorded for 8 mi. S was then instructed to report any change he detected in lead car velocity, inter-vehicle distance or relative velocity, to explain any change in his accelerator control, his use of the brake, or the velocity of his car, and to give any other relevant information about his observations and thoughts. Verbal reports were elicited for the next 22 mi. For the following 8 mi, the verbal reports were recorded on tape and the objective data on film. The task analysis was based primarily on these last 8 mi.

Three laboratory technicians served as Ss. One maintained distances which led to frequent cutting in of other vehicles between the lead and test cars, and his data were not analyzed. Verbal reports were collected from two psychologists under conditions similar to the test runs and those of the more verbal one were used to supplement the data obtained with the two technicians.

Results

The verbal reports were summarized and categorized to provide an indication of the elements in the environment to which the subjects stated they were responding. Descriptions of their control actions and intents were also noted. Table 1 summarizes all verbal reports obtained from one or more of the 3 Ss whose reports were analyzed.

Tables showing the correspondence of the verbal protocols to the objective data, for 5-sec intervals, were prepared for 2 Ss. Table 2 presents a 30-sec example of these data for the S who gave the more detailed report.

A wide range of observations was encompassed by the verbal data. There was considerable duplication from subject to subject, indicating that the small sample used probably covered much of the range of verbal behavior obtainable in this situation. A

TABLE 1

SUMMARY OF VERBAL REPORTS

Element	Observation
Lead car velocity	Increasing, increased, decreasing, decreased, constant, estimate (quantitative), description (qualitative)
Gap	Increasing, increased, decreasing, decreased, constant, estimate (quantitative), description (qualitative)
Test car actions	Accelerating, increasing gas, decelerating, reducing gas, leveling off speed, coasting, speed estimate (quantitative), matching speed to lead car's, closing gap
Test driver actions	Checking rear view mirror, checking side view mirror, adjusting rear view mirror, surveying landscape
Traffic	Passing cars, relative speed description for passing cars, vehicle which may cut in, behavior of passing drivers, vehicle following test car, projected action of following vehicle, no following vehicles
Road scene	Good view of road, poor view of road, curve, grade, overpass, bird crossing road, roadside maintenance, service area, exit
Signs	Caution (deer crossings), speed limit, distances to cities, service area, exit

TABLE 2

SAMPLE DATA TABULATION

5-Sec Interval	Verbal Report	Distance (ft)	Test Car	
			Velocity (mph)	Accelerator
1	I'm driving about 150 ft behind our lead car.	298	55.5	0
2	We're on fairly level ground at the moment;	278	56.5	0
3	I see ahead of us, however, that we will be dropping down a slight grade:	321	57	7
4	The next mile or two seems to be somewhat downgrade. The lead car is pulling ahead just a little bit and I'm accelerating to	315	61	2
5	close in the gap. I'm possibly doing	321	61	1
6	about 60 or 62 mph now; the gap is closed in and I'm leveling off.	315	60.5	0

difference in the fluency of the subjects was also noticed. One S gave several quantitative estimates of the gap, naming distances which were consistently about one-half of the actual distances.

The verbal reports contained numerous references to the lead car and to the gap. These references implied that the driver was responding differentially to these two elements, correcting for changes which had occurred in the size of the gap and adjusting his velocity to compensate for changes which were occurring in the velocity of the lead car. This distinction between responses to the lead car and responses to the gap is maintained in the model.

In general, the verbal reports, supplemented by objective performance indices, are sufficiently detailed and consistent to serve as the basis for a description of the driver's behavior in the car-following part-task. A computer model of this description was prepared in flow-chart form.

THE MODEL

The procedure in constructing a model is to work from the general, broad categories of behavior to the more specific behavior patterns. For example, in the present task, three general categories of behavior were identified: (a) selecting the direction of observation, (b) noticing an element in the environment, and (c) responding to the environment. Once these categories are identified, it is possible to describe the behavior in greater and greater detail until a level in the model is reached where elements such as the change in lead-car velocity or the content and location of a road sign are being described.

A detailed description of the model, together with the 22 flow charts which have been prepared, is presented elsewhere (3).

The main program, or executive routine (Fig. 1), sequentially executes three major subroutines. These subroutines determine the driver's direction of observation, specify the element in the environment which he notices, and produce a response to the noticed element. This three-subroutine cycle continues until a subroutine indicates that the run has ended.

The subroutine which determines the driver's viewing direction makes this determination on the basis of priorities assigned to elements in the various directions and acceptable time lapses between looking in various directions. The noticing of elements in the environment is dependent on priorities assigned to these elements by other subroutines.

A general response routine (Fig. 2) brings in an element response routine appropriate to the element in the environment which is noticed. The gap response routine is shown in Figure 3. These routines use the specific characteristics of the element, its momentary description, as the basis for selecting a response. Before a response involving velocity change is executed, a subroutine checks the acceptability of the intervehicle separation, according to criteria based on overall gap preferences and the momentary situation (Fig. 4). When a velocity change is called for, subroutines (Figs. 5 and 6) select the pattern of change according to the current velocities of the two cars, the current gap, the desired gap, and the time allotted for correction of the gap. The routines illustrated constitute a hierarchy of subroutines concerned with the driver's

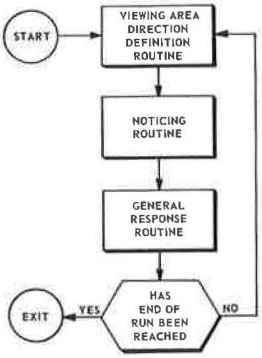
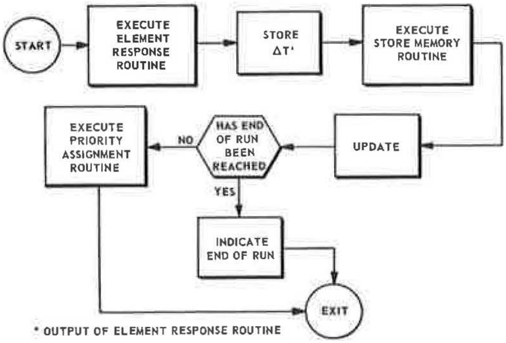


Figure 1. Executive routine.



* OUTPUT OF ELEMENT RESPONSE ROUTINE

Figure 2. General response routine.

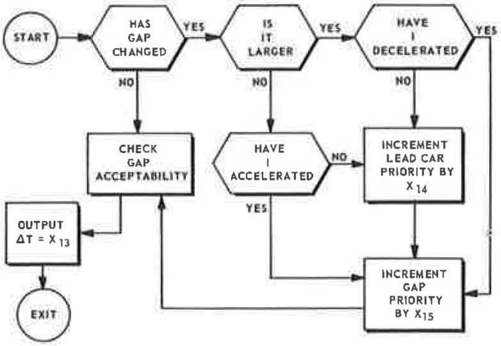


Figure 3. Gap response routine.

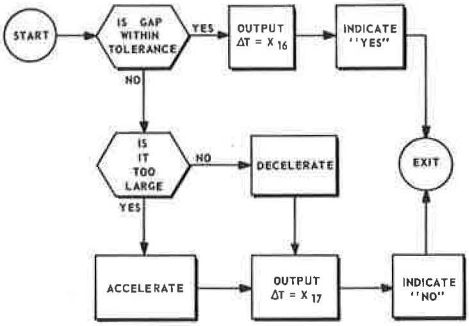
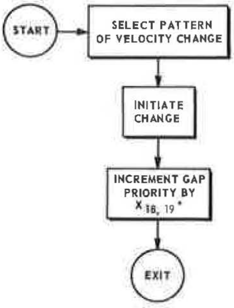
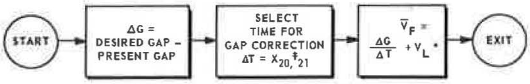


Figure 4. Check gap acceptability.



* X_{18} FOR ACCELERATION;
X_{19} FOR DECELERATION

Figure 5. Accelerate (or decelerate).



$\bar{V}_F$ = AVERAGE VELOCITY OF FOLLOWING CAR DURING GAP CORRECTION
V_L = AVERAGE LEAD CAR VELOCITY

* THIS IS A FIRST APPROXIMATION TO A MEASURE OF THE ACCELERATION PATTERN

‡ X_{20} FOR ACCELERATION;
X_{21} FOR DECELERATION

Figure 6. Select pattern of velocity change.

responses to elements in the environment. Other systems of subroutines are concerned with the selection of the viewing direction, noticing elements in the environment, and assignment of priorities to elements in the environment.

In addition to these routines, which attempt to simulate driver behavior and may be referred to as "psychological" routines (4), there are the "bookkeeping" or "nonpsychological" routines which are concerned with updating the environment. These routines keep track of the external inputs to the driver and of the changes in these inputs which result from the simulated behavior of the driver.

The accuracy of the model in predicting the behavior of individual drivers under specific circumstances is dependent on the inclusion of a sufficient number of the relevant parameters and the determination of the correct values of these parameters. Most of the parameters are single numbers, concerned either with time intervals or with the priorities for noticing elements in the environment. Several are more complex and require special subroutines to compute their values. These are the decision functions and threshold functions.

Parameters

Perception and Response Times.—These are small time increments which would be difficult to measure but for which reasonable estimates could be made. An initial version of the model might use an average discriminatory reaction time, such as 0.3 sec, for the value of each of these time intervals. These values could be refined through further experimentation. The effects of varying these time increments over reasonable ranges might be explored in the exercising of the model.

The perception and response times which appear as parameters in the model are as follows: (a) noticing an element in the environment, (b) perception of no change in lead car velocity, (c) perception of change in lead car and selection of response, (d) observation of gap, (e) decision that gap is acceptable, and (f) initiation of gap correction.

Criterion Times.—A second type of time parameter, which might be expected to have a greater effect on the car-following part-task, is the criterion time. Criterion times are times allowable between various events and times allotted for or required for various processes, other than simple perceptions and responses. These times will also require experimental determination. The following effects of variations in these times on the output of the model should be of interest: (a) maximum time between looking ahead, (b) maximum between looking in the same direction, for directions other than ahead, (c) maximum between observations of gap, (d) minimum for reading a sign, (e) time allotted for correcting gap by acceleration, and (f) time allotted for correcting gap by deceleration.

Priority Increments.—In the model, the noticing of elements in the environment, and therefore the responses which are made, depends on the priorities assigned to these elements. These priorities are not directly observable and could at best be indirectly inferred from verbal reports as to which elements are eliciting responses. It appears necessary, for the present, to restrict priority increments to one or two levels. These levels would be somewhat arbitrarily assigned as the values of the following parameters: (a) lead car, if velocity has changed; (b) lead car, if gap change is attributed to it; (c) gap, if changed; (d) gap, if following car has initiated acceleration; and (e) gap, if following car has initiated deceleration. The element which is to have a priority increment is named first.

Other Numerical Parameters.—It is assumed that if the priority of an element in the present direction of observation exceeds a specified value, the driver will tend to continue looking in this direction. An arbitrary specification of this value would be required, such as minimum priority which prevents change in viewing direction.

A final parameter, which can be specified from available data, is maximum distance for reading a sign. This value would, of course, be dependent on the parameters of the sign (e.g., letter size, contrast) and driver characteristics.

Decision Functions.—Two major decisions required in the model are the selection of the desired gap and the selection of a pattern of velocity change, by the following driver. Suggestions as to the form of these functions may be found in the literature and in the data collected during the controlled observations. Most of the studies in the literature involve conditions clearly different from the part-task defined in the present study, and their results must be applied with caution. The controlled observation data, although taken under relevant conditions, were not collected for the purpose of accurately estimating parameters, and give only a rough estimation of their values.

Threshold Functions. —The major threshold functions in the model are the threshold for the detection of a change in the size of the gap and the threshold for the detection of a change in the velocity of the lead car. These thresholds are not readily disginguishable in the "real world" as the two changes tend to be correlated.

Laboratory studies of the velocity difference threshold have generally involved small objects, short distances and stationary observers (5). It appears necessary, therefore, to conduct research on such thresholds in the actual highway situation. In an experiment conducted on the New York State Thruway specifically to provide threshold data for use in the model (3), subjects were instructed to respond to velocity changes by a lead car initially traveling at 55 mph. Responses occurred in 4 to 6 sec to velocity increases of 6 to 9 mph and in 5 to 7 sec to velocity decreases of 3 to 6 mph. The design of this study is an example of the use of the model to specify areas requiring further research.

CONCLUSIONS

The situations in which verbal reports have been used in the development of computer models of behavior generally do not involve the occurrence of events requiring responses at intervals which are independent of S's behavior. In a preliminary study, Braunstein, White, and Sugarman (6) found that useful explanations of individual responses could be elicited from the driver while he performs a specified part-task. The controlled observation portion of the present study confirms the feasibility of collecting continuous verbal reports in a situation in which the need for response is determined by external events. The most fluent S talked during all but two 5-sec intervals during an 8-min run. There were approximately 50 distinguishable response classifications in the verbal repots of 3 Ss.

The major processes inferred from a study of the verbal reports, supplemented by the objective data, were described in flow-chart form. Sub-processes were also flowcharted, until a level of detail was reached for which flow charts no longer appeared useful. The preparation of a model of the car-following part-task not only proved feasible, but was also found to be a useful method of consolidating existing knowledge of the driver's task and of pointing to the direction in which this knowledge most requires extension.

In general, the applicability of the complex information processing approach to the development of a computer model of the task of the automobile driver was confirmed. The next logical step is the coding of the model and its exercise on a digital computer. Further experimental studies are required to provide better quantitative estimates of the parameters of the model. A validation study, comparing the predictions of the model to new samples of observed behavior, will be necessary before practical applications of the model are recommended. Finally, the extension of these techniques to other parts of the driving task should be explored.

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