Skill Training for Collision Avoidance

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The purpose of this two-phased study was to determine the feasibility of training drivers to acquire the skills needed to avoid critical-conflict, motor-vehicle accidents and to develop the procedures and materials necessary for such training. Basic data were derived from in-depth accident investigations and task analyses of driver behavior. A specification was prepared for curriculum development and performance measurement. A prototype bimodal simulator was developed as a training tool for acquisition of key perceptual and decision-making skills, and a concept was defined for behind-the-wheel training on an advanced driving range that included surrogate vehicles to create critical traffic conflicts. Results of the study indicate that such training is theoretically feasible and, if implemented on a large scale, could result in a substantial reduction of multivehicle accidents.

The study reported here resulted from a decision by a panel of driver-training specialists (1) that none of the advanced driver-training programs appears effective in reducing the large number of critical-conflict accidents. A critical conflict is defined as (a) a conflict between two road users that will result in a collision unless one of the two parties responds correctly, (b) a possibility that a collision can be avoided or ameliorated if one party makes a correct response, and (c) a compressed time interval that precludes recourse to normal driving skills.

The basic purpose of the resulting program was to investigate the feasibility of training drivers to avoid imminent automobile accidents (phase 1) and to develop the methods and materials necessary to accomplish such training (phase 2). This project used a tripartite team: The Institute for Research in Public Safety (IRPS) of Indiana University conducted an in-depth analysis of accident situations (2, 5, 6), the National Public Services Research Institute (NPSRI) of Central Missouri State University (CMSU) conducted task and behavioral analyses of a set of potential accident situations (3), and the URS/Matrix Company directed and synthesized the results of phase 1 (12) and conducted the phase 2 investigations.

DATA

Phase 1 of the study focused on determining the nature and frequency of traffic-conflict accidents, whether conflict-avoidance techniques were available, and whether sufficient accident reduction was possible to warrant the definition and development of a training program. Parallel analyses were conducted by IRPS and CMSU.

Accident Situation Definition

The accident data base used by IRPS was 372 accidents that involved 613 vehicles in Monroe County, Indiana. Four major accident situation categories were defined, and the number of vehicles involved are listed as follows:

1. Group 1.0—degraded vehicular performance (21),
2. Group 2.0—environment or driver-induced emergency (102),
3. Group 3.0—multivehicle collision (488), and
4. Group 4.0—other (2).

Among the 372 accidents studied, there were 115 (31 percent) nonconflict or single-vehicle accidents (groups 1.0, 2.0, 4.0), and the remaining 257 (69 percent) were conflict accidents (group 3.0). Further analysis of the 257 accidents in group 3.0 (488 drivers) revealed 17 major accident situations that were then subclassified into a total of 40 types of conflict situations.

Another situation taxonomy was developed to parallel the in-depth accident analyses and was based on previous driver-task analyses (9) and previously published accident data, i.e., multidisciplinary accident investigations (MDAI) case summaries. After all possible conflict situations in the task analyses were identified, the situations were diagrammed and analyzed to identify additional conflict possibilities and were then categorized and classified. The five basic situations that resulted are as follows:

Vehicle Situation	Definition
Lead	Rapid closure with a vehicle or obstacle ahead
Following	Rapid overtaking by a following vehicle
Intersecting	Approach of two vehicles on an intersecting course, i.e., right angle
Converging	Convergence of two adjacent vehicles
Oncoming	Approach of two vehicles on a (head-on) collision course

The two sets of situation taxonomies, i.e., one analytic and one empirical, were then synthesized, and the relative importance of each was established. Figure 1 shows that, of the nine resulting basic situations, intersection conflicts occur more than twice as often as any other situation.

Conflict Nullification Potential

During the in-depth analysis of the accidents comprising the situation groups, investigators attempted to determine whether the drivers perceived the danger in time to attempt evasive actions as well as whether evasive actions were attempted. In group 3.0, 223 drivers (44.7 percent) did not perceive the danger in time. For all 613 drivers, 259 (42.25 percent) did not perceive the danger until it was too late. This finding supports the original report (5), which concluded that inattention is a major causal factor in accidents, and has interesting implications for driver education, licensing, and performance research.

By applying the definition of conflict developed for this study, we further classified conflict accidents in terms of avoidance probabilities. The result was that 47 percent of conflict accidents were determined to have certain (≥0.9) or probable (≥0.7) potential for avoidance by a driver-induced maneuver. Another 9 percent of the accidents were possible candidates for evasive actions (0.5 to 0.69). Thus, the total pool of accidents subject to analysis (and potential amelioration) in this project is 47 to 56 percent of all conflict accidents (32 to 38 percent of all accidents).

Maneuvering Potential

Both analysis techniques were directed at identifying a maneuver taxonomy. As expected, some form of directional or velocity change can be used to avoid any of the conflict situations. There were 31 usable maneuvers empirically derived (Figure 2), and one additional variation came from the task analysis. All the maneuvers are variations of magnitude, timing, and sequence of steering, braking, or accelerating. In current training programs, neither accelerating nor turning 90° is offered as an avoidance maneuver that is a viable option.

The probability of success (PS) for each maneuver in each situation was estimated by using a rating technique (2). Several findings are of note. A straight-ahead stop was rarely the preferred maneuver in a critical-conflict situation. It is interesting to note the lack of preference for this maneuver. First, any situation in which straight braking will avoid the collision is not considered to be a critical conflict, since straight braking is a normal driving skill, as previously defined. Of course, if there is no place to move, the driver must attempt to brake as effectively as possible. Second, in a conflict, especially converging or intersecting, vehicles may be so

Figure 1. Synthesis of two situation taxonomies.

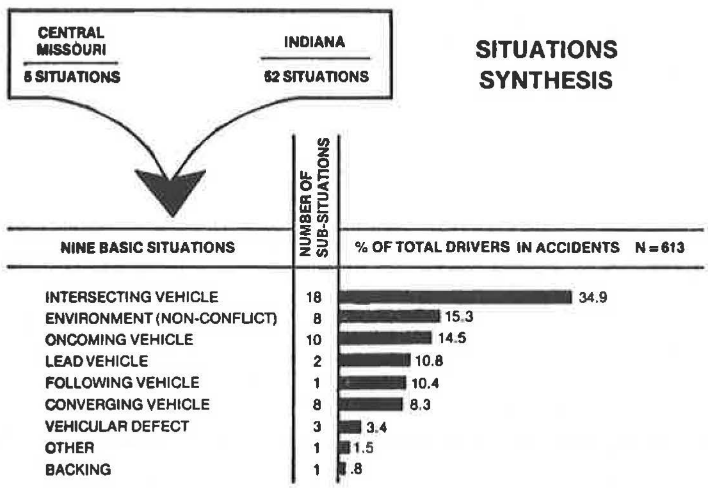
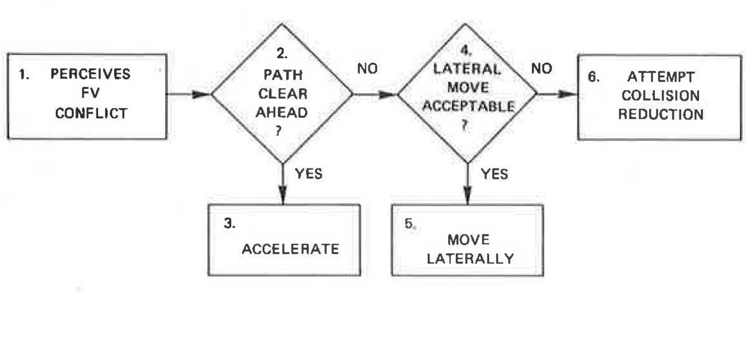


Figure 2. Maneuver taxonomy.

DIRECTION: \ SPEED	0 = Constant	1 = Braking	2 = Decelerating	3 = Combined braking and decelerating	4 = Accelerating	5 = Decelerating then accelerating	INTENT:
0 = Steer straight only	•				•		To continue past object
1 = Steer straight only		•		•			To stop before object
2 = Steer straight then right		•	•	•		•	To continue past object
3 = Steer straight then right		•		•			To stop before object
4 = Steer straight then left		•	•	•		•	To continue past object
5 = Steer straight then left		•		•			To stop before object
6 = Steer right then straight	•	•	•	•	•		To continue past object
7 = Steer right then straight		•		•			To stop before object
8 = Steer left then straight	•	•	•	•	•		To continue past object
9 = Steer left then straight		•		•			To stop before object
10 = Steer straight only					•		To reverse direction

Combinations of direction and speed are expressed as a decimal. Direction is to the left of the decimal, and speed is to the right, e.g., 6.4 indicates to steer right then straight, use acceleration, and continue past object.

Figure 3. Driver behavior in following-vehicle conflicts.



close that braking guarantees a collision. The highest PS of avoidance in such situations may be acceleration. An unresolved dilemma is that, if both drivers respond with this avoidance behavior, the potential benefits will be cancelled. However, with more than 42 percent of the drivers unable to perceive the danger in time to attempt an avoidance maneuver, the likelihood that only one driver would respond by accelerating is very high. Third, this finding does not imply that braking is not crucial to avoidance, but rather that braking must usually be performed in conjunction with some lateral movement. The skill of braking while maintaining steering control is particularly important in light of the finding (2) that 45 percent of the drivers in conflict situations locked up their wheels sometime during their avoidance attempt. Fourth, the empirical analysis included only those attempts that failed, i.e., those attempts that resulted in an accident. There are probably many more near-miss situations in which effective braking did avoid an accident.

These qualifications indicate that the brake-only maneuver will continue to be important in driving, but in many conflict situations it is not the best accident-avoidance technique. Future training must consider the type and emphasis of braking technique to be included, particularly since 38 percent of the accident-involved drivers in conflict situations who do have the time to attempt an evasive maneuver will attempt such a maneuver (steer straight only and brake with intent to stop before object). Another finding of interest was the apparent value of acceleration as an avoidance maneuver. Among the 18 substitutions composing the intersecting situation, there are three situations that can be avoided by straight-ahead acceleration and two by lateral movement combined with acceleration. In the following-vehicle situation, the maneuvers most likely to avoid an accident are accelerating straight ahead or ahead and turning to the left or right.

As anticipated, many of the situations have several maneuvers that are close in their PS ratings. A driver's decision to go right versus left, stop before, or continue by a conflicting vehicle is strongly influenced by the characteristics of the impending collision. Since this variance in constraints is highly specific, it could not be considered in the situation taxonomies. Instead, an environmental constraint or hindrance rating was applied concurrent with the PS maneuver estimate, which resulted in a proportion index for each maneuver in each of the situation categories. A new set of PS maneuvers was calculated to include environmental hindrance. In general, an environmental hindrance to the maneuvers (averaged across situations) is present from 7 to 26 percent of the time. It is not surprising that steering maneuvers, particularly to the left, had the highest hindrance proportions. The implication of this factor is that training will have to produce a more flexible, adaptive capability in drivers if the drivers are to select the best responses in terms of traffic and environmental situations, rather than simple, stimulus-response chains.

Behavioral Requirements

Task analysis and experimental observations were used to derive the behavioral requirements of accident avoidance. Each of the five major situations previously mentioned was analyzed from a behavioral viewpoint, and a flow of behaviors was charted along a time line. Behaviors that were either marginally useful in a compressed time conflict or redundant were eliminated. The result was a catalog of the minimum behavioral and information-processing sequences necessary for avoidance in any of the five situations (Figure 3 shows the behavioral process for one conflict situation). When all situations had been analyzed, behaviors were cataloged and prioritized. While frequency of occurrence is often of interest, location in the behavioral flow and dependence of subsequent behavior on output information from preceding behaviors are more indicative of behavioral significance in successful accident avoidance. Over two-thirds of accident-avoidance behaviors entail information processing that must always occur before any motor response is initiated, and this response is further delineated into perceptual and then response-selection behaviors.

Current accident-avoidance training programs place a heavy emphasis on training driver motor skills; however, these programs offer little or no training in the other areas. Perceptual and response-selection behaviors should receive an increased proportion of the training emphasis; motor-skill training should be performed in a high-fidelity setting that demands use of perceptual cues so that appropriate responses can be selected. Each of the skill types may initially be trained separately; however, at some point, all components will have to be incorporated into the training program so that realistic sequencing, timing, and interacting can be developed. Beyond that, a question still unanswered is what amount of practice, in any of the behavioral areas, is required for an effective and lasting transfer of training to real-world driving. The answer appears to involve achieving valid performance criteria, rather than determining the needed amounts of training time.

Perceptual Skills

Four perceptual skills were found to be involved in each behavioral area. In terms of frequency of use and criticalness of accuracy, judging the intervehicle closure is of paramount importance and is an element in all five conflict situations. Second is judging the clearance between the driver's vehicle and another vehicle or object. Third is determining the direction of vehicle motion. (This seems rather obvious, but in certain situations it may be difficult to determine.) Fourth is perceiving the surface condition.

Response Selection and Motor Responses

Six basic response selections were identified and are given below:

1. Braking versus moving laterally,
2. Moving right versus moving left,
3. Accelerating versus braking,
4. Choosing a braking technique,
5. Moving from or toward a conflicting vehicle, and
6. Choosing among types of collisions.

It was found that all of the six choices did not have to be considered in every conflict situation. The accident data also suggest that drivers will first pick their path and then change their velocity. The task analysis indicates that the sequence of choices should vary, depending on the situation, but the strategy to be used in making a response selection is not yet known.

The motor skills (responses) are similar to those already well known in accident avoidance training. The basic responses for car control are evasive steering, rapid braking, rapid accleration, skid recovery, and impact recovery. The ancillary responses are vehicle oriented—observation and signals—and body position—front, rear, and side impact. However, evasive steering includes the potential use of a 90° turn, which requires a somewhat different use of controls.

Learning Perceptual and Response Selection

The ability of drivers to acquire the motor skills for accident avoidance has been demonstrated; however, such a demonstration for relevant skills for perceptual and response selection is not available. Therefore, by using a limited capability-fidelity simulator and motion pictures of two conflict situations, a small number of subjects were pretested, trained, and then posttested. The skills that indicated an evidence of learning include

1. Perception—In intersecting-vehicle conflicts, the subjects learned to distinguish between an accelerating and a braking situation by using cues of position, distance, and change in viewing angle.
2. Response selection—In lead-vehicle conflicts, the subjects learned to select a braking or steering response that is based on a complex response-selection process.
3. Motor response—In lead-vehicle conflicts, the subjects learned to carry out quickly the observational responses that are needed to detect the presence or absence of a vehicle or vehicles that follow closely or are in adjacent lanes.

The skills that did not appear to be learned through use of the simulation process include

1. Perception—In lead-vehicle conflicts, the subjects could not judge closure with the lead vehicle, which was primarily due to the lack of speed cues.
2. Motor response—In lead-vehicle and intersecting-vehicle conflicts, the subjects were unable to properly perform evasive steering and modulated-braking responses when these responses had to be carried out concurrently with perception, response selection, and observational responses.

Potential Benefits

A benefit analysis was made by calculating the potential reduction in accidents that would have been realized if one of the drivers involved in each traffic-conflict accident had correctly implemented an avoidance maneuver that had a high PS for that conflict situation. The average PS of avoidance was calculated for each accident situation category by identifying the two maneuvers for each contributing situation that had the highest PS and by averaging them for the accident situation. The resulting PS was then multiplied by the number of instances within the accident situation category where at least one of the involved drivers perceived the danger in time to attempt an evasive maneuver. This determined the potential number of accidents within that accident situation category that could have been avoided. The reductions were then summed for the composite accident category (Table 1).

Since it is not realistic to assume that training would always enable a driver to correctly choose and apply the highest PS maneuver, levels of 25 and 50 percent training effectiveness were selected for analysis purposes. Table 1 gives the percentage contribution of each accident category to potential accident reduction. It is unlikely that training effectiveness will ever be greater than 50 percent; therefore, the maximum program effectiveness would be 10.4 percent reduction in all accidents. This situation does not consider the environmental hindrance variable that ranged from 6 to 26 percent, or the unknown amount of benefit to be gained among single-car accidents. Considering all these factors, a realistic estimate of accident reduction potential that results from accident-avoidance training appears to be 5 to 10 percent of all accidents. In 1974, that would have meant avoiding between 780 000 and 1 560 000 accidents. Based on the 1973 and 1974 accident data, the following is the accident-reduction potential for 50 and 25 percent levels of training effectiveness.

	Accident Reduction		
Description	Number Avoided	Percent Reduced	Cost Reduced ($)
1973			
50 percent level	1 726 400	10.4	2 100 800
	1 600 000	10.0	2 020 000
25 percent level	863 200	5.2	1 050 400
	830 000	5.0	1 010 000
1974			
50 percent level	1 622 400	10.4	2 007 200
	1 560 000	10.0	1 930 000
25 percent level	811 200	5.2	1 003 600
	780 000	5.0	965 000

Greater accident severity was slightly overrepresented in the Indiana University data because of the MDAI system constraints and the nature of the data collection process. However, there appears to be no reason to suspect that only less severe accidents will be avoided as a result of training. For comparison purposes, as given above, a uniform cost per accident was assumed based on data from the National Safety Council (10, 11). Based on the analytic, empirical, and benefit analyses presented above, there was adequate justification and promise to continue the program into phase 2.

DEFINITION AND DEVELOPMENT OF TRAINING PROGRAM

Phase 2 of the accident-avoidance, skill-training project (AAST) included defining the course objectives, preparing the curriculum and performance measurement specification, and developing some critical components of the envisioned training programs.

Definition of Training and Testing Requirements

In this task, a specification was developed to enable accident-related task analysis material to be transformed into a driver-training curriculum. The topics addressed by specification are as follows:

1. Instructional objectives
    a. Knowledge
    b. Skill
    c. Effective
2. Material requirements
    a. Student aids
    b. Teacher aids
3. Training support requirements
    a. Personnel
    b. Standard training equipment
    c. Special devices, e.g., driving simulators
    d. Facility and resource needs and essential exercise areas

4. Prerequisite trainee capabilities quantitatively specified for

   a. Training program
   b. Training event or maneuver within the program

5. Measurement devices and instruments

   a. Skill
   b. Knowledge

6. Administration of training and testing

   a. Guidelines
   b. Manuals
   c. Instructional and testing conditions

Since each conflict situation required the driver to implement a slightly different arsenal of avoidance skills (perception, response selection, motor response) to achieve conflict nullification, the instructional approach selected was based on conflict characteristics, rather than skills per se.

The training program concentrated on accident situations that contributed significantly to accident experiences by deleting the converging-vehicle situation from consideration. Of the five basic conflicts, those that involved converging vehicles occurred least frequently. In addition, the characteristics of the situation differed primarily in terms of path angles from the intersecting, lead, and following-vehicle conflicts. The final selection of conflict situations to be treated included a decision to split the intersecting-vehicle situation into two discrete topics characterized by the threat versus obstacle nature of the conflict. (Note that the other three conflicts are either a threat to the driver or an obstacle to the progress of the driver's vehicle.)

Integrating the five conflict situations with the skills to be trained and the training techniques to be employed (Figure 4) required use of a modal-submodal format in which each of the five conflict situations composed a module of the training program. The skill factors and training modes were integrated at the submodal level.

To the five conflict-situation modules were added two others modules: (a) one to orient the student to the course and to develop advanced vehicle-handling skills, and (b) another to administer a comprehensive performance test. Figure 5 shows the structure of the training program, together with the factors that lead to this format. Figure 6 shows how the modal format was extended to the submodal level, based on the mode of instruction. One of the attributes of this format is flexibility of administering the program. Figure 7 shows how the nominal training program can be modified, in terms of sequence and length of instruction, to accommodate local resources and requirements. The specification (4, 7) that resulted from these efforts must still be considered preliminary because it has not yet been validated through conduct of a training program.

Requirements are set forth in the specification that are expected to assure that the training course will aid student drivers, who face conflict situations in executing ing workable accident-avoidance strategies. Avoidance strategies to be taught and learned are, or are adaptations of, those recommended by Indiana University (2) for the conflict situations defined. Actually teaching the execution of successful strategies will be accomplished by classroom instruction, simulation practice, and driving range practice. Classroom instruction will be used solely to impart knowledge and establish in the student the proper subconscious set considered requisite to the subsequent acquisition of vital perceptual, decision-making, and operational skills. Both simulation and driving range practice will be used to extend and internalize the knowledge gained in the classroom to develop the three vital skills.

Perceptual skills have sensory and cognitive components. Hence, both components must be developed if the driver being trained is to be able to detect and recognize the presence of conflict. Thus, driving simulation and two independent levels of driving range practice sessions were used to accomplish this objective.

During the beginning practice on the driving range, the driver develops an ability to modulate vehicle control inputs during extreme maneuvers. These maneuvers will allow the driver to maintain or regain a safe car orientation and provide a first interaction with perceptual realism. Descriptively, these maneuvers include practice of advanced vehicle-handling maneuvers, e.g., skid recovery, slalom exercises, and lane switching. The perceptual skills learned will contribute to the driver's ability to track vehicle orientation in a full-scale static environment.

For multi-vehicle-conflict situations, the student is subjected to equipment familiarization sessions and conflict-nullification training in the simulator. The visual feel of entering various conflict situations is experienced by the student in a film presentation of various traffic conflicts. The student drives the simulated car by using the vehicle controls provided to negate any conflict encountered. Although the simulation lacks one-to-one perceptual realism, student drivers should learn to

1. Recognize some of the significant perceptual antecedents to conflict situations,
2. Perceive and extrapolate the relative locations of other objects, and
3. Select and execute appropriate evasive maneuvers based on acquired visual data.

During the more realistic advanced sessions on the driving range, the rudimentary skills gained during the simulation practice should be forged into operational skills that are more useful in an actual driving environment. When the student executes accident-avoidance strategies on the range, he or she will learn to integrate the simple operational skills already learned into effective, complex control scenarios that will be appropriate to the dynamic threats the student is facing.

As the student is developing perceptual and operational skills through simulation and range practice, he or she will also be developing decision-making skills. The simulation and advanced practice sessions on the driving range will be beneficial for this purpose. Both of these training techniques place the student in multi-moving-body conflicts in which a complex array of perceptual data are sampled and integrated. The driver must extrapolate the positions of all moving bodies with respect to the fixed environment, recall car-maneuvering capability, and decide on the appropriate control inputs. This task must be done repeatedly, until the faced conflict is nullified.

Simulator Definition and Development

A key element of the proposed curriculum for AAST was the availability of a suitable simulation system. The need for a driving simulator that could be used for training students to acquire collision-avoidance skills was established and is based on the postulated economic

Table 1. Accident reduction potential by accident category.

Accident					Percentage of Reduction at Effectiveness Level					
					50 Percent			25 Percent		
Category	Conflict Situation Number	Number	Number Perceived in Time[a]	Potential Number Avoided	Accident Category	Total Multivehicle Conflicts	All Accidents	Accident Category	Total Multivehicle Conflicts	All Accidents
Head-on	3.6; 3.7	39	34	18.10	23.2	3.7	2.4	11.6	1.8	1.2
Rear-end	3.8; 3.9	60	48	25.43	21.2	5.2	3.4	10.6	2.6	1.7
Intersecting vehicle	3.1; 3.2; 3.3; 3.4; 3.5	113	91	24.28	10.8	5.0	3.2	5.4	2.5	1.6
Adjacent vehicle	3.10; 3.11; 3.12; 3.13	27	17	7.44	13.8	1.5	1.0	6.9	0.8	0.5
Other multivehicle	3.14; 3.15; 3.16	7	7	2.31	16.5	0.4	0.3	8.2	0.2	0.2
Total multivehicle conflicts[b]		246	197	77.56		15.8	10.3		7.9	5.2

[a] Number of accidents in which one driver perceives the danger in time to attempt an evasive maneuver.

[b] Excludes some multivehicle accidents that involved other contributing factors.

Figure 4. Factors to be integrated into accident-avoidance training and testing curriculum specification.

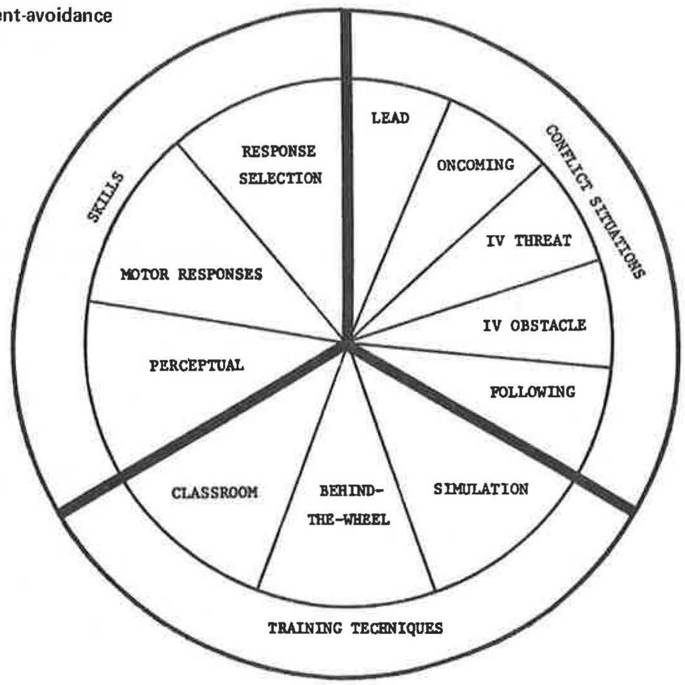


Figure 5. Modal organization of training program.

MODULES	I. ORIENTATION & GENERAL ADVANCED SKILLS II. COLLISION AVOIDANCE • INTERSECTING VEHICLE THREAT III. • INTERSECTING VEHICLE OBSTACLE IV. • FOLLOWING VEHICLE THREAT V. • LEAD VEHICLE OBSTACLE VI. • ONCOMING VEHICLE THREAT VII. COMPREHENSIVE COLLISION AVOIDANCE TEST
CHARACTERISTICS	• ACCIDENT DATA (TYPES & RATES) → MODULES • CONTINUITY AND FLEXIBILITY • ONE PROBLEM AT A TIME • BASIC SKILLS → ADVANCED SKILLS → AVOIDANCE SKILLS • MODULAR ORGANIZATION CONTINUED AT SUBMODULAR LEVEL • EXPAND OR CONDENSE ACCORDING TO RESOURCES AND NEEDS

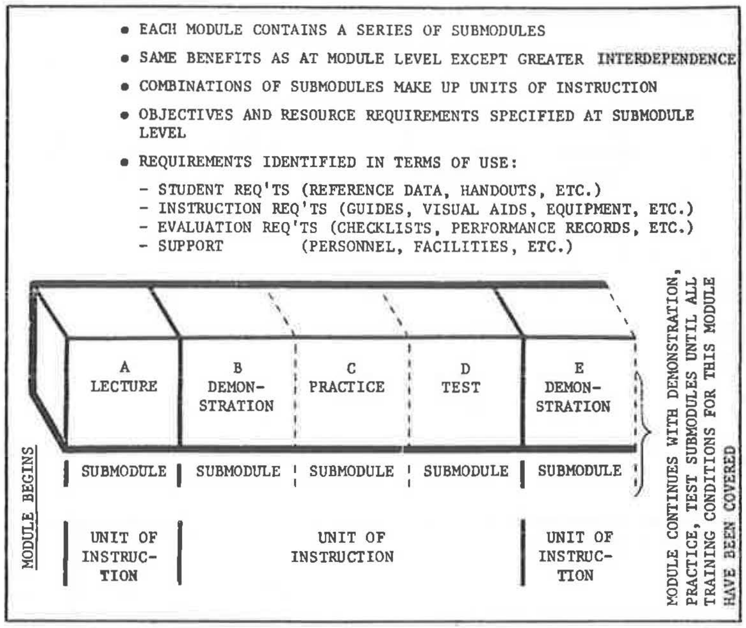
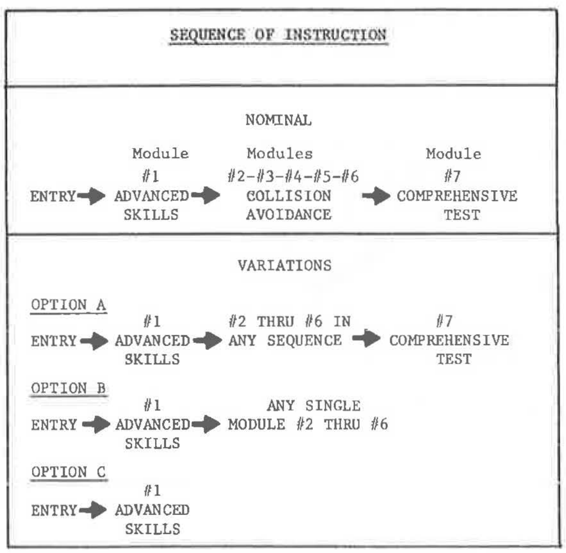


Figure 6. Submodal organization of training program.

Figure 7. Flexibility of instruction sequence and length.



requirements of an operational AAST program. With such a program, large numbers of students would be involved in many repetitions of many different situation-learning trials. It was judged impractical to attempt such an operational program by using only behind-the-wheel training, if a suitable simulation method were available as a supplement or a substitute.

It was postulated that, to be effective, any approach selected would have to equip the student drivers to

1. Predict the specific point of impact of two vehicles,
2. Determine viable roadway and roadside vehicle-placement alternatives,
3. Select an appropriate conflict-nullification strategy, and
4. Execute the strategy selected.

Many of the simulation and driving range practice techniques reported in the literature are extremely realistic, in some respects. Unfortunately, none provided the needed combination of interactiveness and one-to-one perceptual fidelity at a reasonable cost. A training technique had to be defined that would provide these two qualities. Since real-world driving provided these two qualities, the question to be answered was, How can we safely replicate traffic conflicts between an automobile under the control of a (student) driver and some other automobile (not under student control)?

It was hypothesized that there might be a primary, trainable key skill required to nullify multivehicle conflicts that was not being addressed in existing training programs and that would not be dependent on those characteristics of existing methods of film simulation, which were found to be unsatisfactory. Further evaluation of the accident, task, and behavioral analyses revealed that, for the training of conflict-nullification skills to be feasible, students would have to learn to recognize the existence and the nature of an impending collision. In turn, this recognition would require the ability to extrapolate the velocities of the involved automobiles and predict the point of impact. Identification of a way to develop driver skills for extrapolation of velocity became the principal requirement for simulator definition. By changing the training emphasis to develop specific but limited skills, the need for realistic perceptual cues was diminished. The basic design requirement was for a display that accurately communicated to the student the velocity of two automobiles. One of the automobiles on that display would have to be under the student's direct control. The other automobile would be controlled by the instructor. Most film presentations and the other two-dimensional, perspective-view generators were unacceptable because of inherent velocity distortion characteristics. These factors resulted in the identification of the need for a two-dimensional, plan-view, iterative trainer. By using such a training device, the velocity components were able to be communicated to the students.

The simulator that was developed is bimodal because of the two distinctly different types of presentations that are used for driver training. First, through-the-windshield movies of the roadway scene and the events were projected on a display immediately in front of the driver. This portion of the simulation is only used

Figure 8. Operational layout of bimodal simulator.

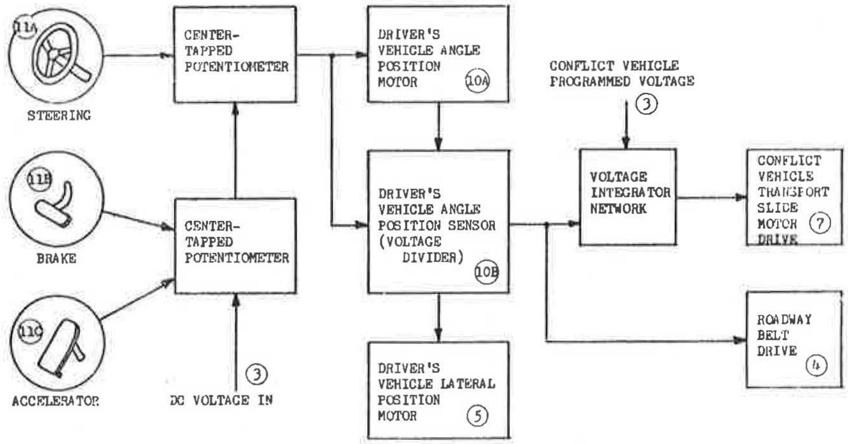
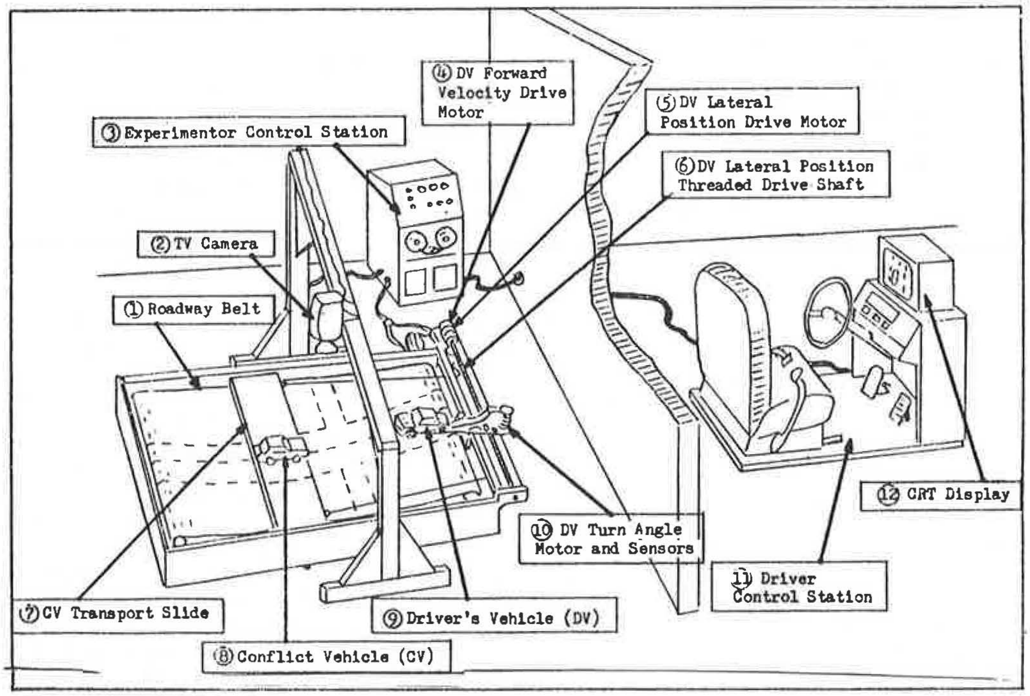


Figure 9. Functional flow of plan-view generator.



during the early training trials. The movie presentation is used to impart a feeling for the perceptual antecedents of collisions, and to stage the setting for the impending interactive session. No subject control over the unfolding events being viewed could be exercised. At the point in the simulation where subject control is desired, the first (movie) presentation is terminated and the second is activated. This second mode consisted of a plan view of the two vehicles engaged in conflict. At this point, the simulator is partially under the student's control, and interactive feedback is provided for the student. Both the perspective view of the roadway scene and the plan view of the unfolding conflict situation are displayed on a television screen that is installed before the subject is in the remote driver's station.

The bimodal-simulator configuration, shown in Figure 8, has four major subsystems:

1. A plan-view generator for simulating the traffic conflicts,
2. A driver-control station,
3. An instructor-control station, and
4. A video system.

The plan-view generator portion of the system can use either computer-generated graphics or, as was done for purposes of prototype demonstration, can be electromechanical. The principal components of the electromechanical plan-view generator are scale-model vehicles, a moving roadway belt, a transport slide mechanism for the conflict vehicle, and the motors and sensors needed to position and move the other components. The instructor can exercise control over all components from the experimentor control station and can permit the student to control the driver-vehicle parameters.

Figure 9 shows the functional flow of driver-control inputs to the plan-view generator components. The brake pedal and the accelerator pedal operate a single center-tapped potentiometer to ensure that, when those two controls are in the null position, the plan-view generator automatically effects a driver-vehicle velocity of of 56 km/h (35 scale mph). This control assures that the scheduled conflict results in a precisely defined accident, barring any subject control input.

If the subject imparts any steering control to the vehicle, an associated voltage is sent to the driver-vehicle angle-position motor, which begins to change the angle of the vehicle in respect to the longtitudinal axis of the roadway belt. This change is at a rate proportional to the angle of the steering wheel as well as to the position of the accelerator and brake pedals. As the vehicle changes its angular orientation, the angle-position sensor (mechanically coupled to the vehicle-position shaft) drives the accelerator or brake pot output voltage, according to the sine and cosine of the vehicle's angle.

The electromechanical, plan-view, conflict generator used is capable of moving the vehicle along subject-ordered paths at subject-chosen rates of speed. Further, by internal mechanisms, the generator is capable of incorporating the movements of a conflict vehicle. Details of the configuration and operating characteristics are given elsewhere (7). The video portion of the system has the following primary components: a closed-circuit television camera, a video tape recorder, and a 22.8-cm (9-in) television screen. Video tapes having prerecorded sequences of the filmed perspective-view conflicts are used in both the interactive and noninteractive portions of the training session. The sequence begins with the prerecorded segments by having the training instructor depress the play switch on the video tape recorder. When the subject's interactive participation is to being, the instructor depresses the record controls on the recorder and activates the plan-view generator. Thus, not only is the plan view of a particular developing conflict presented to the student by the television camera, the recorder, and the closed-circuit television camera, but the vehicle-movement activity that takes place on the generator during each learning trial is also recorded for future reference, analysis, and student feedback.

Advanced Driving Range

The concept of an advanced driving range stems from the need for collision-avoidance training to be as real as possible to develop the perceptual, cognitive, and operational skills needed for efficient accident-avoidance behavior. The following alternatives that appeared to be available to satisfy this need.

1. Conduct training in real vehicles in real traffic conflict situations—This approach was rejected for obvious reasons of student, instructor, and bystander safety; astronomically high property damage costs; and an inability to control the frequency or characteristics of the traffic conflict.
2. Conduct training in real vehicles on a closed driving range—While this approach does allow control of the training situation, the safety and cost factors would not be sufficiently ameliorated to be practical, leading to its rejection.
3. Conduct training in a high-fidelity simulator (6d.f.) in which all real-world parameters are faithfully reproduced—Such simulators can be built, as we know from the experiences of the National Aeronautics and Space Administration and the U.S. Air Force, at great expense. Even with the financial resources that have supported the development of such simulators, these are still subject to severe criticism regarding inadequacies in simulating real situations (8). However, assuming, that simulators could be built that satisfied all perceptual and motor requirements, the costs of manufacturing in sufficient quantities—and with the associated facility and computer support requirements—to make them available for training the general driving population nationwide resulted in the dismissal of this alternative as impractical.
4. Conduct training in some other way that faithfully reproduces the significant psychomotor parameters, reduces the hazards to an acceptable level, is amenable to training staff control, and can be accomplished at a reasonable cost—This alternative was selected and defined as the advanced driving range concept.

The characteristics of the training concept for the advanced driving range were defined as follows: Collision-avoidance training would be conducted on an automobile driving range where pedestrian and other motor-vehicle traffic can be eliminated and where there are few, if any, surface obstructions. Such facilities already exist in many parts of the country, and where they do not, the major acquisition cost is for open land. Even this cost can be reduced by locating suitable, existing roadways and closing them off to traffic while training is in progress. In this concept, the student driver will operate a standard automobile, either compact or midsize. Automobiles currently in use for driver education would be entirely suitable. The final requirement of a controlled, safe, real-collision situation can be satisfied by providing a low-mass, remotely controlled, surrogate vehicle in a real-vehicle size. This surrogate vehicle is the key to the advanced driving range concept and fills the role of the conflict vehicle discussed in the section on the bimodal simulator.

The surrogate vehicle should approximate the size, shape, and appearance of a typical subcompact car, but it must present little in the way of hazard to student drivers and must be damage-resistant to impact by a full-size automobile. Finally, it must be able to execute a preestablished series of maneuvers at the distretion of the training instructor. For practical purposes, this solution safely provides all the training advantages of the real-world conflict, i.e., such a vehicle could be used to engage the student in those conflicts identified during phase 1. Moreover, the experience of those conflicts would be interactively and perceptually real. The student driver could actually crash into the other car without sustaining injury or inflicting property damage, if he did not successfully nullify the presented conflict. In fact, except for not eliciting the same degree of subject-perceived risk and a debilitating startle response, the experience on an advanced driving range would be precisely real. Thus, from a face validity standpoint, a training program such as that would provide the means for answering the important research question: Is it feasible to develop an effective accident-avoidance training program for critical conflict situations? Because this is the case, the driving range practice exercises that should be employed have already been defined in the curriculum specification, even though the feasibility of the surrogate vehicle has not yet been demonstrated. The majority of any future work in this area should be directed toward preparing instructional materials, supplying appropriate program support equipment, and providing operational surrogate vehicles.

CONCLUSIONS AND RECOMMENDATIONS

The principal products of phase 2 are as follows:

1. The accident conflict and maneuver taxonomies developed during phase 1 should be verified so that the basis of a collision-avoidance, skill-training program can be formulated;
2. A comprehensive curriculum and performance measurement specification that is both sufficiently detailed and flexible should be developed before the training

program development and adaptation to local needs and resources are compiled;

3. The bimodal simulator that is to be used for training drivers in key collision-avoidance skills should be defined, developed, and preliminarily tested;

4. The method for in-vehicle training in collision-avoidance techniques that satisfies requirements for safety, reality, low cost, and training staff situation control (the advanced driving range concept) should be defined; and

5. The research problems that must be addressed before an addident-avoidance, skill-training program can become a reality should be identified and, if possible, resolved.

The principal conclusion reached during this program is that accident-avoidance skill training is necessary, is feasible, and can be accomplished at a reasonable cost. The products of this study, in both phases 1 and 2, are believed to provide the basis for continuation of this development program area under the continuing sponsorship of the National Highway Traffic Safety Administration.

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System-Safety Techniques Useful for Transportation Safety

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This paper reviews existing system-safety techniques in terms of their applicability to the current transportation structure, status, and available data; their ease of comprehension; and their usefulness in reducing accidents and fatalities. The two techniques of failure mode effects and criticality analysis and fault-tree analysis are reviewed, explained, and modified for use in transportation safety studies. When applied at each level or activity cycle of a transportation system, these two techniques provide safety specialists with tools that lead to concern for safety at every stage of a project from conception through facility operation. The cohesive approach that is suggested by the concept of system safety is well-suited to the needs of transportation safety. As a methodology, system safety must be adopted and its technical and managerial analyses applied at the modal facility level.