Research Methodology for Crash Avoidance Studies

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ABSTRACT

Driving is a complex activity that involves factors associated with the driver, the vehicle, and the road and traffic environment. In this paper are summarized considerations involved in selecting research methodologies to further understand the role that driver, vehicle, and environmental factors play in accident causation and ultimately the extent to which vehicles can be designed to maximize accident avoidance capability. Analytical and experimental procedures for analyzing accident avoidance performance of the driver-vehicle system are discussed.

Work that was carried out for the NHTSA, U.S. Department of Transportation (1), is summarized in this paper. The economic and social cost of traffic accidents is significant and can be minimized by improvements in occupant protection, reduction in accident severity, and ultimately by improving the accident avoidance potential of the driver-vehicle system. This work was conducted as part of an ongoing crash avoidance research program (2) designed to pinpoint driver and vehicle characteristics that contribute to accidents and develop countermeasures that will either prevent or at least minimize the severity of accidents. To accomplish this goal, it is necessary to develop a thorough understanding of the contributions of both driver and vehicle behavior and the associated interaction that leads to combined driver-vehicle system performance.

The approach taken in this study was to first review accident factors and scenarios to identify critical problem areas and relate these to the driving task and demands placed on the driver. On the basis of this review, several general hazard categories were defined that could be used to formulate general experimental scenarios. On the basis of the hazard category framework and consideration of driver behavior and the driving task, research methodologies that range from analysis, to simulation, to real-world observation are reviewed. Finally, the feasibility of various approaches and trade-offs between them are addressed.

ACCIDENT FACTORS AND SCENARIOS

The following list gives several approaches to categorizing accidents that have been taken in the past including temporal classification (3), unsafe driving actions (UDAs) (4), and various situational and environmental classification systems (5,6,p.13).

1. Temporal
   - Direct, proximate, mediate, remote
2. Unsafe driving acts (UDAs)
   - Speeding
   - Improper maneuver
   - Inattentiveness
   - Other
3. Situational and environmental
   - Single vehicle
     a. Maneuver
     b. Loss of control
   - Multivehicle
     a. Own vehicle course/maneuver
     b. Other vehicle course/maneuver

Temporal classification permits accounting for both direct causes that might be selected as dependent experimental variables (e.g., driver response decision, steering action) and intermediate and remote factors that might serve as covariates or independent variables (e.g., environmental conditions and driver factors such as age and various impairments). UDAs focus specifically on driver errors or risk taking, or both (e.g., speeding, inattention), which provide dependent measures for experimental studies, and situational schemes relate more to independent variables (e.g., curve, left turn).

Traffic accident surveys (7) tend to show human factors as the most prevalent contributory factor in traffic accidents. Age and alcohol are the two most important driver classification variables (5). In terms of situational variables, fatal accidents predominantly involve single vehicles, and the majority of single vehicle loss-of-control accidents appears to involve slippery roads and curves. Multivehicle conflicts primarily involve side or rear-end impacts. More in-depth analysis of accident factors, reviewed elsewhere (5), can give considerable guidance in the selection of appropriate experimental scenarios. Consideration of the nature of the driving task can also provide guidance for structuring future research.

DRIVING TASK AND DEMANDS ON THE DRIVER

The driving task provides a general level of workload for the driver, which may influence the driver's ability to detect hazards and deal with critical situations. Driving task demands can be imposed both by the highway-traffic environment and by vehicle-centered task demands imposed by controls and displays. Because the highway-traffic environment workload can be quite variable, vehicle-imposed workload should be minimized through proper ergonomic design of the controls and displays and related task elements. The relationship of vehicle control and display design to driver workload is not well understood and this is a critical area to be addressed in future driver and vehicle research.

To properly address the workload research issue, in addition to general vehicle handling properties, the experimental scenarios must adequately represent real-world driving tasks. In general, the driving task must account for navigation, guidance, and con-

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TABLE 1 Generic Hazard Event Definitions and Related Issues

Category	Circumstances	Driver Behavior Issues
Unexpected intrusions: situations requiring visual detection and significant precrash avoidance maneuvering	Obstacle suddenly and unexpectedly appears on a collision course	Detection time Probability of response alternatives: brake and/or steer, freeze (do nothing) Transient response characteristics
Unexpected or misjudged environmental situation: focus on visibility/perceptual problems and postencounter maneuvering	Excessive speed for road geometry Change in road adhesion Slow-moving vehicles Gap acceptance	Detection Recognition Perceptual accuracy Decision Maneuver responses given above
Sudden change in vehicle response characteristics: situations in which vehicle response characteristics change suddenly and unexpectedly	Component failures (blowout, power steering failure) Road surface anomalies (e.g., pavement drop-off)	Detection of change Recovery and adaptation to new response characteristics
Predisposing variations in vehicle response characteristics: focus on driver adaptability, particularly under emergency situations	Loading Tire pressure Trailer towing Unfamiliar vehicle	Ability to compensate particularly under emergency conditions

trol functions (8). Navigation involves route guidance and following assisted by maps, signing, way points, and perhaps in-vehicle navigational systems. Guidance concerns directing the vehicle along a desired pathway with the assistance of various traffic control devices and other visual cues. Control includes maintaining directional stability, regulating against road and aerodynamic disturbances, sustaining desired headway, following a desired pathway, and avoiding obstacles and other hazards. Control can be further broken down into compensatory, pursuit, and precognitive behavior (9). Compensatory behavior concerns maintaining stable control and regulating against various disturbing influences. Pursuit behavior pertains to previewing and following clearly defined guidance commands. Precognitive behavior relates to internally generated control responses that the driver can call on to handle normal maneuvers and emergency responses required for hazardous encounters (e.g., obstacles, slippery roads).

GENERIC HAZARDS

Generic hazard categories are intended to encompass a class of accident scenarios that involve similar driver behavior. Thus analytical and experimental procedures can be developed to handle a given class of generic hazards. Each hazard category has a central theme and specific driver, vehicle, and environmental characteristics of interest that define independent (experimental design) and dependent (performance measure) variables. Four generic hazard categories have been defined to provide useful scenarios for the development of future research methodologies. A summary of hazard event definitions is given in Tables 1 and 2, and a summary of relevant variables is given in Table 3.

Unexpected Intrusion

This hazard event concerns an obstacle that suddenly and unexpectedly appears on a collision course with the subject vehicle. The central focus of this event is driver precrash avoidance maneuvering. Relevant variables include driver visual detection, control response decision, and transient maneuvering control response; vehicle handling characteristics that include a yaw rate time constant and limiting understeer or oversteer properties; and an environmental kinematic scenario that includes separation distance, closing speed, and relative course of subject vehicle and obstacle. Driver-vehicle performance parameters include response decision, transient control and stability, and conditional probabilities of success or failure given steering or braking responses, or both. Improvements in vehicle handling and direct and indirect vision would be of primary interest here.

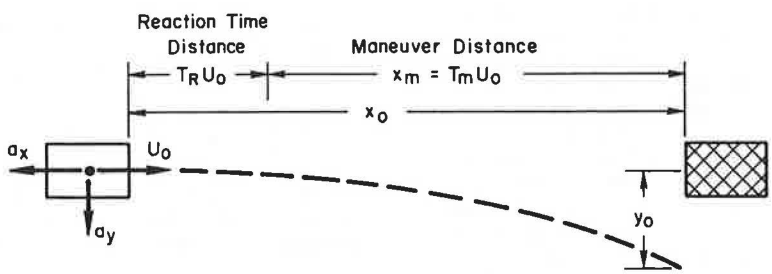
Kinematic analysis (i.e., time-distance relationships) should be carried out to properly set up unexpected intrusion scenarios. Figure 1 shows relationships for a simple unexpected intrusion scenario. The time-to-go relationships in Figure 1 can be used to graphically show conditions under which the driver can safely steer or brake to avoid an unexpected obstacle as shown in Figure 2. Timing of experimental conditions could be selected in a rational way using these kinematic relationships.

TABLE 2 Additional Generic Hazard Event Definitions and Related Issues

Important Cues	Vehicle Subsystem Issues	Driver-Vehicle System Performance Issues
Visual	Steering	Detection time
Motion	Brakes	Control stability
Control feel	Tires	Conditional probabilities of success, loss of control and/or collision give driver response
Auditory	Suspension	
Visual/perceptual	Direct and indirect visibility	Probability of detection
Motion		
Control feel	Warning systems (e.g., radar braking)	Recognition time
Motion	Steering	Detection time
Control feel	Brakes	Adaptation time
	Tires	Probability of loss of control
	Suspension	Control stability
Motion	Steering	Control stability
Control feel	Brakes	
	Tires	
	Suspension	

TABLE 3 Relevant Variables for Generic Hazard Research

Category	Independent Variables Experimental Conditions	Covariates (uncontrolled or confounded variables)	Dependent Variables (measurements)
Driver	Between groups	Driving experience	Control response decision (steer, brake, throttle)
	Age	Visual capability	Control response time histories
	Sex	Reaction time	Psychophysiological measures
	Within groups: impairment (alcohol,	Situation encounters	Subjective reaction
	drugs, fatigue)	Risk taking	Eye point of regard
Vehicle	Visibility	Preencounter speed	Time histories
	Field of view		Path/angular orientation
	Lighting		Angular velocities/accelerations
	Glazing		Translational velocities/accelerations
	Handling		Suspension motions
	Heading time constant		Wheel velocities
	Oversteer/understeer		Performance
	Roll stiffness		Maximum accelerations
	Limit performance		Stability
	Steering feel		
Environment	Visibility	Simulators: none	Obstacle response to subject maneuvering
	Lighting	Field test: weather, lighting	Visibility conditions associated with subject maneuvering
	Photometrics (color, reflectance, contrast)		
	Visual background complexity		
	Obstacles		
	Conspicuity		
	Intrusion timing		
	Maneuvering		
	Road		
	Curvature		
	Surface condition		
	Discontinuities		



Steering Distance for Constant Lateral Acceleration

$$y = \frac{1}{2} a_y t^2 \quad ; \quad t = T_m = \frac{x_o}{U_o} - T_R$$

therefore

$$y_o = \frac{a_y (x_o - T_R U_o)^2}{2 U_o{}^2} \quad ; \quad x_o - T_R U_o = U_o \sqrt{\frac{2 y_o}{a_y}}$$

Braking Distance for Constant Deceleration

$$x_o = T_R U_o + \frac{1}{2} a_x t^2 \quad ; \quad t = \frac{U_o}{a_x}$$

therefore

$$x_o = T_R U_o + \frac{U_o{}^2}{2 a_x} = U_o \left(T_R + \frac{U_o}{2 a_x}\right)$$

Time-to-Go to Obstacle

$$\text{Steering:} \quad \frac{x_o}{U_o} - T_R = \sqrt{\frac{2 y_o}{a_y}}$$

$$\text{Braking:} \quad \frac{x_o}{U_o} - T_R = \frac{U_o}{2 a_x}$$

FIGURE 1 Kinematic analysis for maneuvering capabilities available to avoid unexpected intrusions of other vehicles and obstacles.

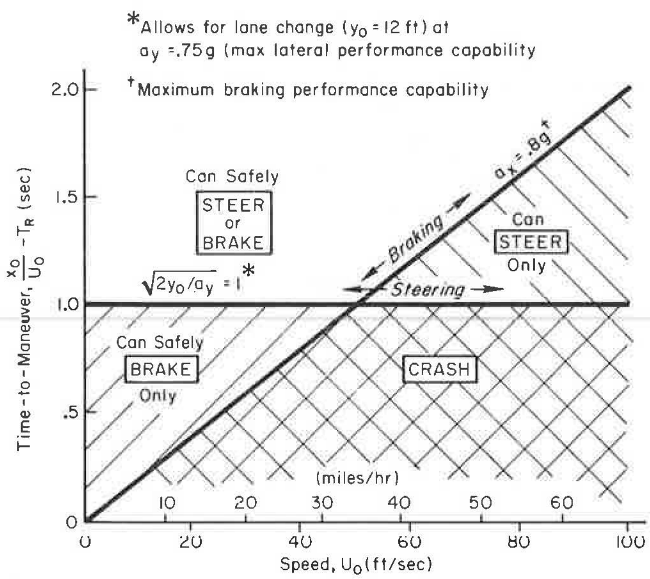


FIGURE 2 Maneuver decisions as a function of speed and obstacle headway time derived from Figure 1 analysis.

Unexpected or Misjudged Environmental Situations

This category focuses on visibility and perceptual factors that lead to misperceived environmental hazards. This category covers hazards ranging from road geometry and surface conditions to interactions with other vehicles and traffic control devices. Driver-centered variables include detection, recognition, and perceptual estimation of hazards on which judgments and decisions will be based. Vehicle variables that relate to direct and indirect visibility subsystems, photometric variables (e.g., luminance, contrast), and conspicuity (target value) are of primary interest. Improvements in direct and indirect fields of view, vehicle-mounted warning devices, and perhaps antilock and radar-controlled brakes would be of interest here.

Sudden Change in Vehicle Response Characteristics

This category concerns vehicle component failures or road surface conditions that would cause a rapid and unexpected change in vehicle response characteristics. Driver factors concern detection and adaptation behavior. Before-and-after vehicle dynamics are important, and environmental factors that cause changes in vehicle response are relevant. Relevant driver-vehicle performance measures include detection and adaptation times and probability of loss of control.

Predisposing Variations in Vehicle Response Characteristics

This category concerns vehicle characteristics different from what the driver is normally accustomed to, which could result from situations such as vehicle loading, low tire pressure, trailer towing, or driving an unfamiliar vehicle. Driver factors include adaptability and past experience. Vehicle handling characteristics are relevant. Environmentally induced workload would also be of concern. Measures of control stability would be of primary interest.

ANALYTICAL AND EXPERIMENTAL RESEARCH METHODOLOGY

Future research in vehicle design should consider combined analytical and experimental methods. Analytical methods can provide the structure that supports and ties together an experimental research program. Analysis and modeling can support experimental programs in various ways, as summarized in the following list, including identification of important experimental variables and test conditions.

1. Problem identification: accident analysis, anecdotal concerns;
2. Problem assessment: analysis and modeling, establish relevant variables, potential countermeasures (CMs);
3. Engineering tests: refinement and validation of engineering models;
4. Preexperimental analysis: specify test apparatus requirements and experimental test conditions;
5. Behavioral test preparation: set up and check out apparatus, establish experimental design and procedures;
6. Conduct tests: observe protocols, subject set, and motivation;
7. Data analysis: reduce data, analyze model relationships; and
8. Model refinement and systems analysis: interpolate and extrapolate experimental data base, analyze CM effectiveness in terms of figures of merit, accident probability, and cost-effectiveness.

Driver-vehicle and system performance models can also serve as a useful adjunct to data reduction and analysis. Finally, system analysis models can be used for trade-off and sensitivity analysis and cost-effectiveness or other figure-of-merit comparisons.

Experimental techniques for observing and measuring driver behavior range from laboratory experiments to open road observations of free-flowing traffic as summarized in the following list.

1. Laboratory
    - Part-task
    - Simulation
2. Instrumented vehicle
    - Closed course
    - Open highway
        a. Self-measure
        b. Traffic interaction
3. Instrumented highway
    - Time-lapse video or movie
    - Radar speed detectors
    - Event sensors and recorders

Laboratory studies can include part-task approaches, in which specific behavior such as visual search and response time are measured, as well as more complete driving simulations, which attempt to recreate a reasonable part of the driving task. More realism can be achieved by observing driver behavior in real vehicles. This can be accomplished by having drivers operate instrumented vehicles on closed test ranges or on the open highway. Observations of the behavior of uncontrolled drivers can also be made using special traffic engineering instrumentation and video or movie recording.

The advantage of laboratory studies is the degree of experimental control that can be achieved. Actual vehicles give more face validity in terms of vehicle behavior, and observation of free-flowing traffic offers the highest realism but minimal experimental control. The road-traffic environment is the most difficult part of the driving task to simulate or control.

TABLE 4 Simulator Versus In-Vehicle Field Test Trade-Offs

Factor	Simulator	Field Test
Fidelity and validity	Costly to achieve complete high fidelity	Vehicle control excellent Hazard scenarios depend on test course instrumentation
Experimental control	Excellent	Difficult to control all variables
Measurement	Variables readily available	Sensors and conditioning needed for each variable
Logistics	Convenient in controlled environment	Related to driving scenario complexity
Safety	Motion and feel systems present some safety problems, may require man rating and subject welfare approval	Accident avoidance maneuvering a problem, probably will require subject welfare approval
Cost	High fidelity very expensive Some possible low-cost substitutes for motion systems	Vehicle instrumentation at modest cost Test course setup could get expensive

APPROACH TRADE-OFFS AND FEASIBILITY

In considering the feasibility of a given approach and trade-offs among approaches a range of factors must be considered. Such factors include fidelity or subjective realism, validity or objective realism, the degree of experimental control, measurement and analysis capability, experimental logistics, safety, and cost. The highest fidelity and validity can be achieved with instrumented vehicle approaches, although achieving a realistic road-traffic environment can be expensive, and safety considerations become paramount when accident avoidance maneuvering is contemplated. Part-task and simulation laboratory approaches have the most appeal from an experimental control and measurement point of view, but costs can increase dramatically with demands for high fidelity and validity. Some trade-off considerations between simulation and in-vehicle field testing are given in Table 4.

Analytical methods including modeling should be considered as a strong support function for experimental studies. A comprehensive research program should consider some combination of analysis, laboratory simulation, and field test approaches, and several examples of such combined approaches are available in the literature (10-13).

CONCLUSION

Considerable attention must be devoted to developing pertinent hazard scenarios and measurement of driver and vehicle behavior. The general driving task should include navigation, guidance, and control components. Imbedded hazard scenarios should be based on accident experience and control for key independent variables such as available maneuvering time for the unexpected obstacle encounter example presented herein. Dependent variables should relate to driver and vehicle behavior and attempt to measure variables associated with detection, recognition, decision, and control. This emphasis on hazard encounters will place significant demands on simulation and instrumented vehicle experimental approaches. The approach is necessary, however, to adequately understand the reasons for driver involvement in and reaction to incipient accident situations and to be able to account for the relative contribution of driver versus vehicle behavior in avoiding or ameliorating the effects of accidents. Because of the complex interaction between driver and vehicle behavior, analytical methods including driver and vehicle modeling may provide an important adjunct to empirical research methods, contributing to all research phases including experimental setup and the collection, analysis, and interpretation of data.

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