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IVHS Technologies Applied to Collision Avoidance: Perspectives on Six Target Crash Types and Countermeasures

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ABSTRACT

The NHTSA Office of Crash Avoidance Research (OCAR), in conjunction with the Research and Special Programs Administration (RSPA) Volpe National Transportation Systems Center (VNTSC), has underway a multi-disciplinary program to: identify crash causal factors and applicable countermeasure concepts, model target crash scenarios and Intelligent Vehicle Highway System (IVHS) technological interventions, provide preliminary device effectiveness estimates, and to identify countermeasure research data needs. To date, five major target crash types (representing, in the aggregate, more than half of all crashes) have been examined:

- Rear-End
- Backing
- Single Vehicle Roadway Departure (SVRD)
- Lane Change/Merge
- Signalized Intersection/Crossing Path

Independent work is also underway to address the drowsy/fatigued driver problem, an example of a target crash defmed by its cause as opposed to its configuration. This is the sixth crash type described in this paper.

This paper presents the results to date of the countermeasure assessment; or “front-end analyses.” The paper reviews “lessons learned” from these studies and portrays the research in the context of the ***overall NHTSA IVHS Plan*** and planned programs to develop IVHS countermeasure ‘performance specifications. The ***heuristic*** nature of front-end analysis is emphasized; it is a process that attempts to obtain “first order” assessments of countermeasure feasibility and to generate questions to be addressed by further research. As more data become available, these first-order assessments can be refined.

INTRODUCTION

NHTSA has underway major research programs to facilitate the development and implementation of cost-effective IVHS technologies for improving the crash avoidance capabilities of drivers and vehicles. These programs are discussed ***in*** the ***NHTSA IVHS Plan (1).***

One key element of the plan is IVHS countermeasure assessment or "front-end analysis." Much of this work is being performed in conjunction with the Volpe National Transportation Systems Center (VNTSC) of the Research and Special Programs Administration (RSPA), with contract support from Battelle Memorial Institute (Contract No. DTRS-57-89-D-00086), and its subcontractors ARVIN/Calspan and Castle Rock Consultants. Countermeasure assessment examines the "logic chain" between available technology and the prevention of target crashes. The mechanisms of intervention of candidate technological solutions are examined in the context of target crash scenarios and the capabilities, limitations, and common errors of drivers. This approach identifies preliminary countermeasure functions which, in turn, permits assessment of applications of technology and identification of associated R&D needs. It is not the intent of the program to exhaustively examine all possible countermeasure concepts or technologies. It focuses on "first generation" IVHS crash avoidance concepts that exist today or are likely to be technologically feasible within the next five to ten years.

These preliminary crash problem analyses serve as input to the development of performance specifications for IVHS crash avoidance countermeasure concepts by identifying preliminary functional requirements of countermeasures and associated research data needs. NHTSA's near-term program will develop performance specifications for systems for preventing rear-end, single-vehicle roadway departure, intersection, and "encroachment" (i.e., lane change, merging, and backing) crashes. Other performance specification programs scheduled to start before the end of N 1994 include vision enhancement systems and emergency medical service automotive collision notification systems.

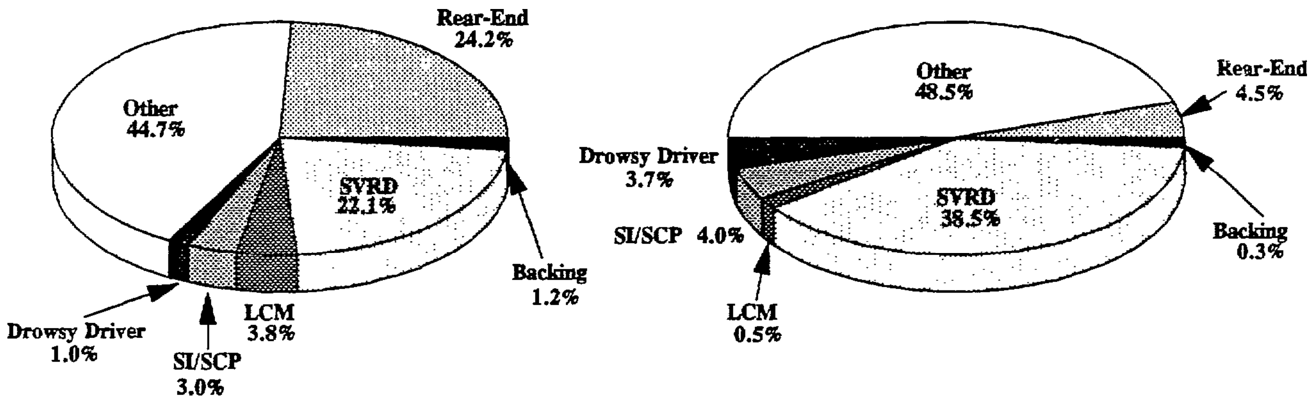
This paper presents an overview of the preliminary target causal factor analyses and other elements of the countermeasure assessment research. Individual reports on each crash problem are in preparation and will be published as they become available. The paper provides problem size statistics for all six crash types, and then addresses each crash type individually, describing typical scenarios, causes, applicable countermeasures (primarily vehicle-based), countermeasure technologies, and modeling methodology and results. Finally, the paper summarizes research and development data needs relevant to the six crash types as a whole.

BASELINE PROBLEM SIZE

Figure **1** shows the number of police-reported crashes (1991 GES) and fatal. crashes (1991 FARS) for the six target crash types for all vehicle types combined. For several of the crash types, the data encompass only that portion of the overall crash type for which "first generation" IVHS crash avoidance countermeasures are likely to be feasible. For example, the backing crash problem assessment includes only "encroachment" (i.e., slow closure) crashes and not crossing-path backing crashes (e.g., vehicle backs out of driveway and is struck by moving vehicle on street). The reasons for these and other restrictions will become apparent in the discussion of crash scenarios, causes, and applicable countermeasures.

Figure 1
Relative Problem Sizes:
Six IVHS/Crash Avoidance Countermeasure Target Crash Types

Crashes **Fatal Crashes**



Note in Figure 1 that drowsy driver crashes are ***shown*** as a separate crash type, although there is actually some overlap with the other crash types shown (in particular, SVRD crashes). The other five crash types shown are all mutually exclusive. Figure 1 shows that rear-end and SVRD crashes are the most numerous of these six types, although in terms of fatal crashes SVRD crashes are the most numerous.

Signalized intersection/straight crossing path (SI/SCP) crashes are just one subtype of the larger intersection crossing path category. Overall, intersection/crossing path crashes **(i.e.,** signalized and unsignalized, straight crossing path, and left-turn across path) represent 21 percent of all crashes. A current problem analysis is addressing SI/SCP crashes; future analyses will examine other intersection/crossing path crashes such as unsignalized intersection/straight crossing path crashes and left turn across path crashes.

Figure 1 presented problem size statistics for all vehicle types combined. However, crash problem sizes can be very different for different vehicle types. For all six of these target crash types, passenger vehicles represent more than 90 percent of the overall crash problem in terms of crash involvements. Thus, in terms of potential ***total*** benefits, passenger vehicles are the most important platforms for high-technology countermeasures to prevent these crash types.

However, the picture is often very different when one considers potential cost-benefits of countermeasure implementation. In terms of potential cost-benefits, the most promising platform for vehicle-based IVHS crash avoidance countermeasures will often be combination-unit trucks (i.e., tractor-trailers). Overall, combination-unit trucks constitute about one percent of registered vehicles and about two percent of crash involvements. This over-representation in crashes is due primarily to the high mileage exposure of combination-unit trucks; the average truck-tractor compiles about 60,000 miles per year versus about 10,000 miles per year for passenger vehicles. Thus, even though their overall crash rates ***per vehicle mile traveled*** are less than one-half those of passenger vehicles, their expected number of involvements per vehicle is much greater.

Single-unit trucks (i.e., "straight" trucks like dump trucks, delivery trucks, etc.) have a mileage and crash involvement picture that is much more similar to passenger vehicles than to combination-unit trucks. One partial exception is backing crashes, where single-unit trucks have expected numbers of involvements per vehicle that are nearly five times greater than passenger vehicles (but still less than one-half those of combination-unit trucks).

Another factor making combination-unit trucks an attractive platform for crash avoidance countermeasure implementation is the higher severity of their crashes. Overall, approximately two percent of the crash involvements of combination-unit trucks are associated with a fatality to some person involved in the crash. Only 0.4 percent of passenger vehicle crash involvements are associated with a fatality in the crash.

For vehicle-based crash avoidance countermeasures (lasting the life of the vehicle), a revealing statistic relevant to the issue of potential benefits and cost-benefits is the **expected number of involvements during vehicle life (I_{LIFE}).** A simple formula for estimating this statistic is:

$$I_{LIFE} = \frac{\text{Annual Involvements in Target Crashes X Average Vehicle Life}}{\text{\# Registered Vehicles}}$$

This statistic may be calculated based on all crash involvements, all involvements in a particular target crash type, or on involvements in target crashes in a ***particular crash role,*** such as the backing vehicle in a backing crash. For specific crash types (and especially for specific vehicle roles), this value is typically low; i.e., less than 0.2. For such low values, the statistic can be treated as a ***probability*** estimate to answer the question, "What is the probability that a vehicle will "need" the countermeasure to this crash type/role during its life?" Figure 2 presents expected involvements for the six target crash types for passenger vehicles and combination-unit trucks. The Figure 2 values are based on 1991 GES and vehicle registration figures (projected over the lives of vehicles) and on average vehicle operational lives (2). A particular vehicle role is specified for four of the six crash types; i.e., rear-end (striking vehicle), backing (backing vehicle), drowsy driver (vehicle with the drowsy driver and lane/change merge (vehicle making this maneuver). Of course, there is only one vehicle "role" in SVRD crashes. . For SI/SCP crashes, available data do not reliably identify the "subject" vehicle (i.e., the vehicle violating the signal), so the I,, statistic provided represents all involvements in this crash type.

Figure 2
Expected Involvements (I_{LIFE}) During Vehicle Operational Life
Six Target Crash Types/Roles, Passenger Vehicles and Combination-Unit Trucks

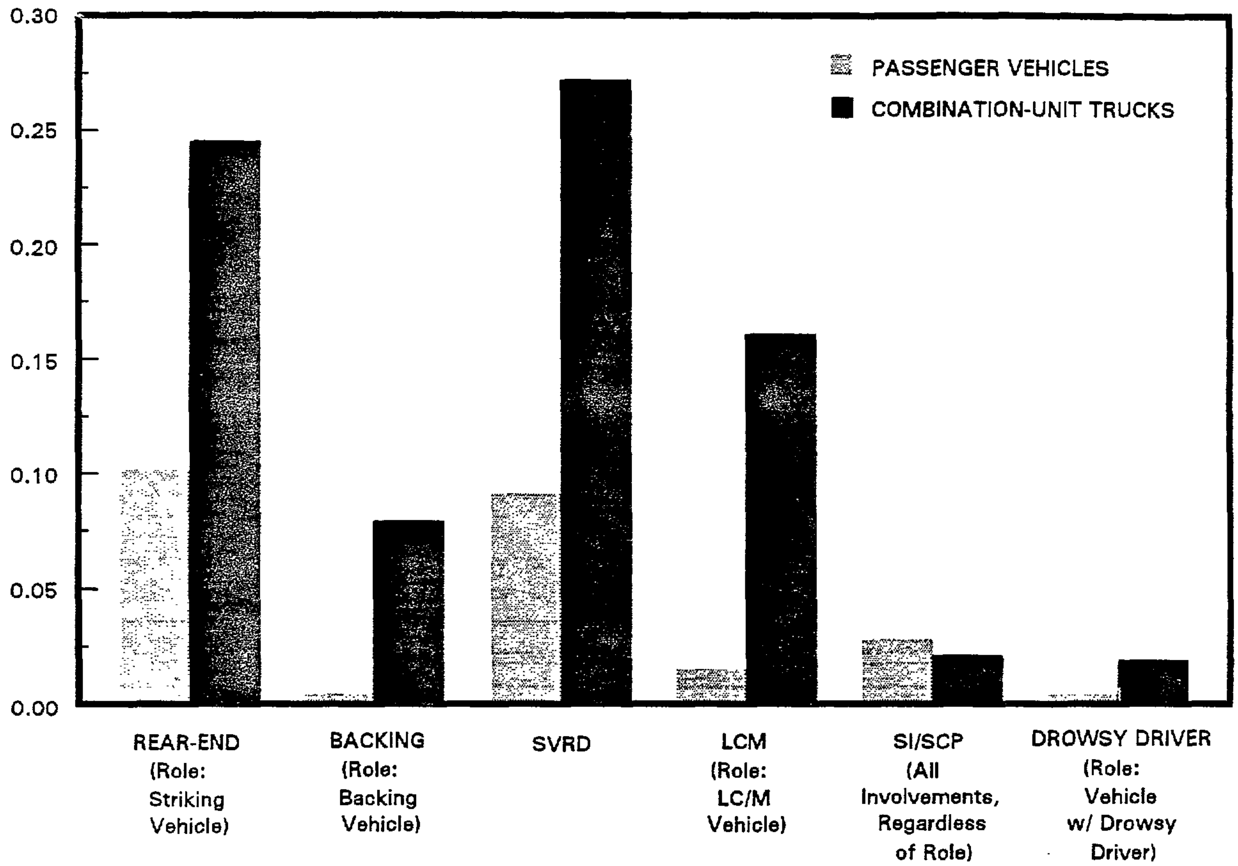


Figure 2 shows that SVRD and rear-end crashes have the highest I_{LIFE} values of these six crash types and that, for most crash types, combination-unit trucks have far greater expected numbers of involvements than do passenger vehicles. The I_{LIFE} values, however, do not by themselves tell the "whole story" regarding potential countermeasure cost-benefits. For example, they incorporate neither crash severity considerations nor a consideration of the likely *preventability* of the crash types, which will be addressed in the following sections.

REAR-END CRASHES

The rear-end crash type was the first addressed under this program and was the prototype for the process to be followed in the other analyses. Leasure (3) described the overall analytical process. Knipling *et al* (4) describes specifics of the rear-end crash analysis.

Scenarios, Causes, and Applicable Countermeasures

The initial steps of front-end analysis include analysis of statistical crash characteristics (e.g., per GES and FARS) as well as a more in-depth review of individual target crash cases, principally from the National Accident Sampling System (NASS) Crashworthiness Data

System (CDS). The level of detail available in individual NASS CDS case files allows an assessment of major crash causal factors, the first step in defining countermeasure concepts and functional requirements.

The analysis of rear-end crashes revealed two major subtypes. About 70 percent of rear-end crashes involve a stationary lead (struck) vehicle at the time of impact, whereas about 30 percent involve a moving lead-vehicle (5). That is, most rear-end crashes do not involve "coupled" vehicles that collide due to a sudden deceleration by the lead vehicle. Rather, in most rear-end crashes a moving vehicle collides with a stopped vehicle in its forward travel path. The most common contributing causal factor associated with rear-end crashes is driver ***inattention*** to the driving task. A second, and overlapping, major causal factor is following too closely. One or both of these factors are present in approximately 90 percent of rear-end crashes (4). Based on this causal factor assessment, one applicable countermeasure concept appears ***to*** be ***headway detection*** (HD). HD systems monitor the separation and closing rate between equipped vehicles and other vehicles (or objects) in their forward paths of travel.

Countermeasure Technologies

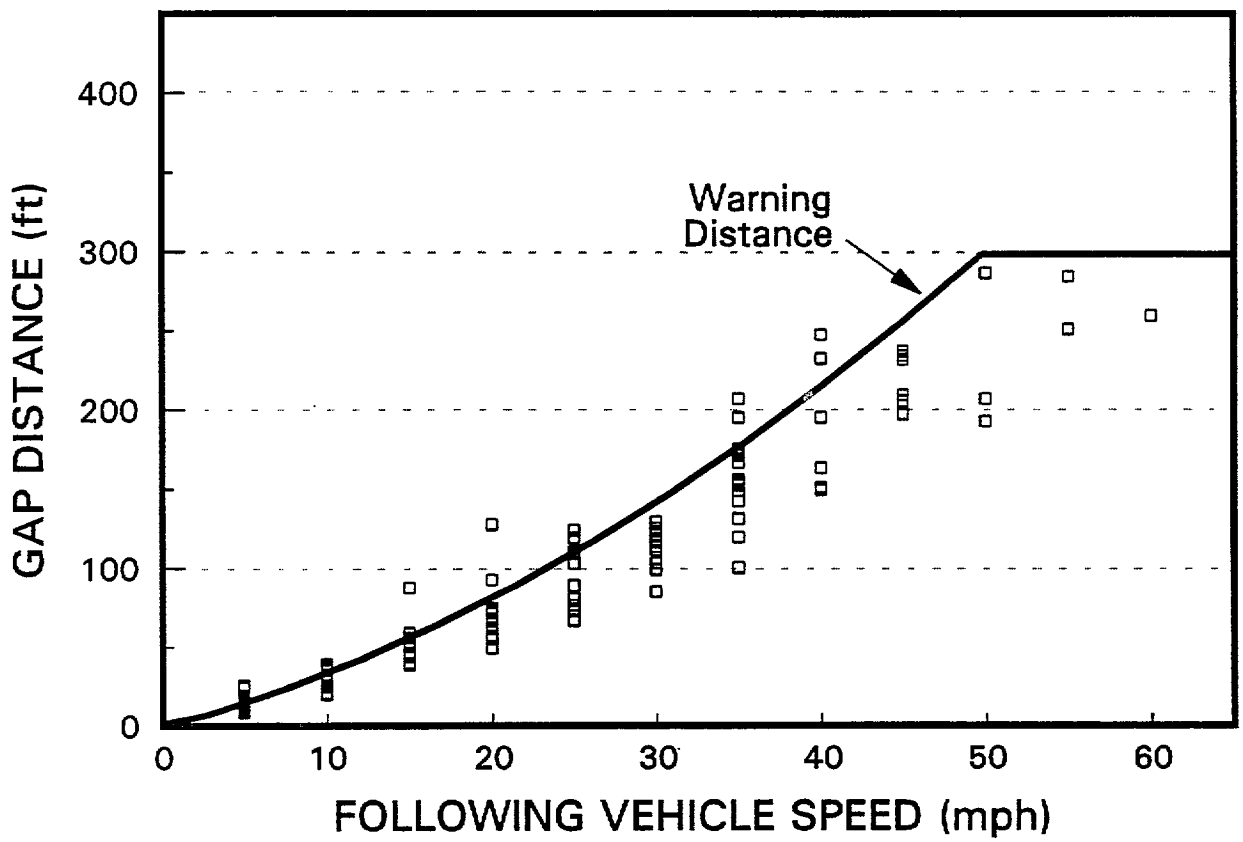
Among the technology options for fulfilling basic HD system requirements are microwave/ millimeter wave radar and laser (infrared band) radar. Such systems typically include a transmitter on the following vehicle that emits electromagnetic energy in the direction of the lead vehicle. A portion of this energy is reflected from the lead vehicle and intercepted by a receiver on the following vehicle. The receiver measures both the two-way transit time between vehicles to determine the range and the frequency shift (i.e., Doppler shift) in the reflected beam to determine the relative velocity between vehicles. Prototype HD systems exist and are commercially available; e.g., the microwave radar system produced by VORAD Safety Systems, Inc. that is being installed on the entire fleet of Greyhound buses.

Modeling

Countermeasure modeling attempts to predict system effectiveness in preventing crashes, to identify principal countermeasure functional requirements, and to identify major factors (e.g., roadway configuration, weather) that are likely to influence countermeasure effectiveness. Countermeasure modeling involves postulating realistic design functional parameters for the system, and then predicting how "real" drivers and vehicles would perform to avoid crashes given the aid of the system. The realism and meaningfulness of modeling results are entirely dependent on the realism of the values used for countermeasure system and driver/vehicle performance parameters. Several diverse approaches to modeling have been employed, depending on the information available about countermeasure and driver/vehicle performance parameters.

Figure 3 illustrates graphically a small portion of the countermeasure modeling for rear-end lead-vehicle stationary (RE-LVS) crashes and a headway detection (HD) system with a maximum range of 300 feet. The partial modeling sample shown consists of 100 GES cases (1990-91) arrayed by the proportion of coded pre-crash following vehicle speeds. The line in Figure 3 represents one possible design system algorithm for warning distance at different vehicle speeds. Each of the 100 sample points represents a modeling "event"; i.e., a hypothetical driver/vehicle confronted with the crash situation while aided by the HD system. Each hypothetical driver/vehicle has been assigned a braking reaction time (RT) and deceleration rate per a Monte Carlo simulation designed to approximate the actual population of drivers and vehicles. Points below the line represent crashes prevented by the countermeasure under these assumptions; those above the line represent crashes not prevented. The full Monte Carlo simulation for this case (4) generated approximately one-half million "events" and yielded an effectiveness estimate of 77 percent.

Figure 3
Illustration of 100 Sample Data Points from the HD System Modeling For Rear-End, Lead-Vehicle Stationary Crashes



Across a *variety* of modeling parameters (i.e., crash subtype, modeling sample, HD system parameters, and other modeling assumptions), the headway detection countermeasure modeling yielded theoretical effectiveness estimates between 40 and 80 percent for HD-system-applicable crashes (i.e., those involving driver inattention and/or following too closely as principal causes).

The modeling of the HD system effects on rear-end crashes was extended to address severity reduction of crashes *not prevented* by the countermeasure. Conceptually, crash avoidance countermeasures that improve the driver-vehicle response to crash threats are likely to affect *both* the occurrence and the severity (e.g., impact speeds and resulting injuries) of crashes. Earlier driver awareness, faster braking, and other such measures that enable drivers to avoid crashes are likely to also decrease the severity of crashes not actually prevented. **Figure 4** shows conceptually the simultaneous prevention and severity-reduction effects of crash avoidance countermeasures.

In an analytical test of the concept shown in Figure 4, the HD system counter-measure modeling was extended to include a preliminary examination of the level of crash and injury severity reduction that might be expected in RE-LVS crashes *not prevented* by HD systems. Crash impact severity was measured by Delta V (ΔV), the change in vehicle velocity that occurs during a collision. Injury severity was measured in terms of the Maximum Abbreviated Injury Severity (MAIS) Scale value. In the most simplistic analysis, reductions in ΔV were associated with reductions in the *probability* of a moderate (MAIS 2) or greater injury for crash-involved occupants. The probabilities of MAIS 2+ injury for different ΔV levels were determined based on 1982-86 National Accident Sampling System RE-LVS crash reconstructions. Then, HD system effects were modeled for a small sample of RE-LVS crashes. For each crash not prevented by the countermeasure, "before" (i.e., without countermeasure) and "after" (with countermeasure) ΔV levels were determined. These reductions in ΔV were associated with reductions in the probability of MAIS 2+ injury.

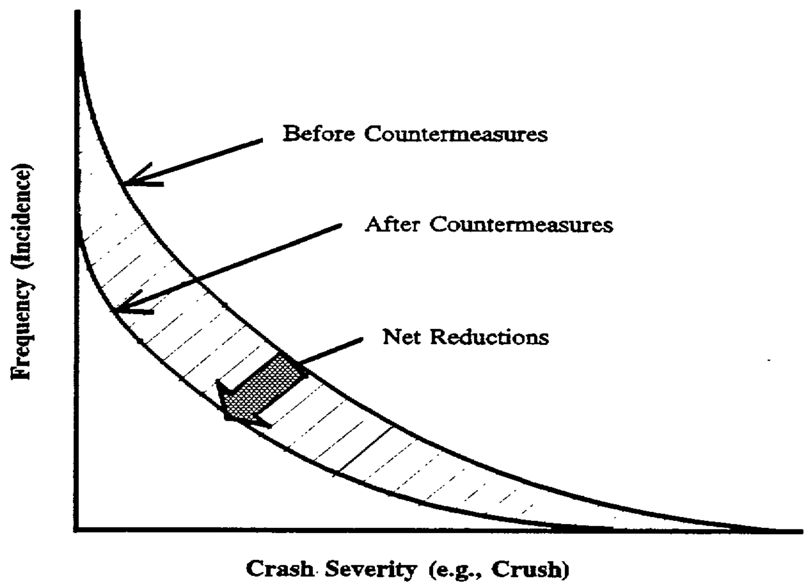


Figure 4: Conceptual Model of Countermeasure Payoffs; Decreases in Both Crash Frequency and Severity.

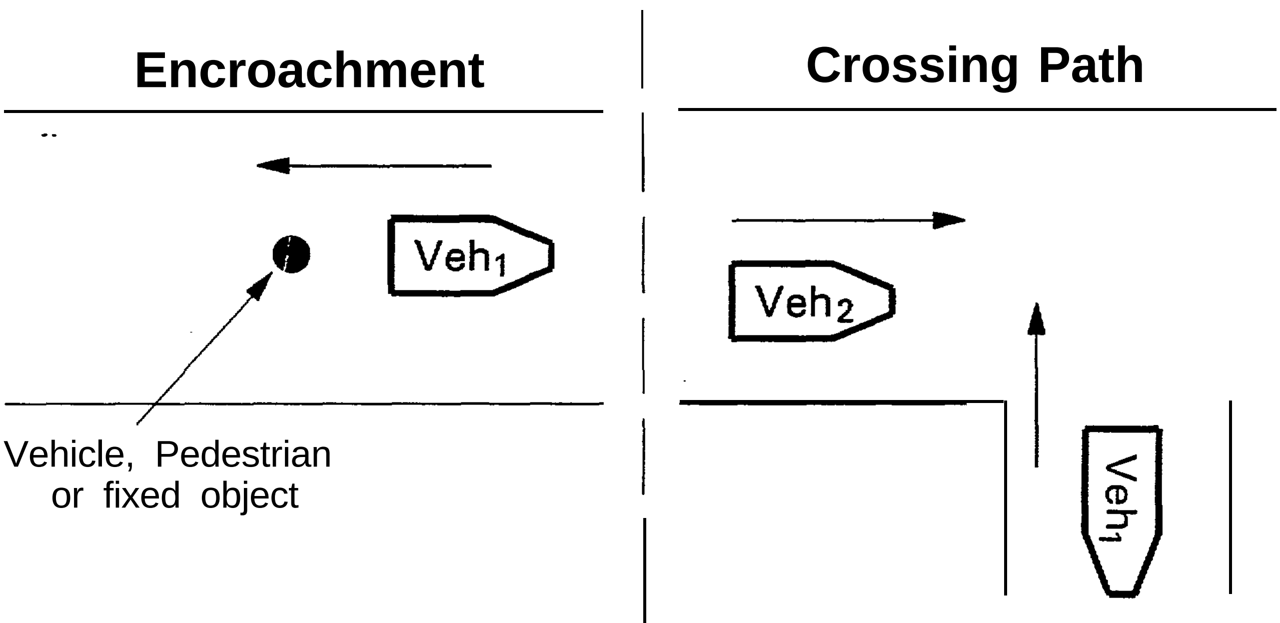
For example, for a 150-foot HD system, 12 crashes not prevented were associated with a 0.064 probability of MAIS 2+ injury for each occupant. With the aid of the HD system, the expected ΔVs of these crashes were reduced sufficiently to reduce the MAIS 2+ injury probability to 0.037, a 42 percent reduction. The significance of this finding is not in the exact percentage reduction derived but rather in the analytical demonstration of the potential severity reduction benefits of the countermeasure for crashes not prevented.

BACKING CRASHES

Scenarios, Causes, and Applicable Countermeasures

Analysis of backing crash scenarios (6,7) reveals two distinct subtypes: "encroachment" and "crossing path" crashes. ***Encroachment*** backing crashes involve slow closing speeds and a stationary (or slowly moving) struck pedestrian, object, or vehicle. In contrast, in ***crossing path*** backing crashes the backing vehicle collides with a moving vehicle. For example, a vehicle backs out f a driveway and strikes (or is struck by) another vehicle moving "at speed" on the roadway. Obviously, crossing path backing crashes generally involve higher closing speeds. **Figure** 5 illustrates these two backing crash scenarios. Approximately 43 percent of all backing crashes are encroachment crashes; the remaining 57 percent are crossing path crashes. One possible approach to addressing the encroachment subtype is the proximity detection countermeasure concept; e.g., a sensor detects nearby objects in the backing path of the vehicle and warns the driver of its presence. The applicability of this countermeasure concept to backing crashes is corroborated by an analysis showing that approximately 90 percent of drivers involved in backing crashes (as the driver of the backing vehicle) are unaware of the presence of what they hit (6).

Figure 5
Two Major Categories of Backing Crash Scenarios



- Backing vehicle strikes other vehicle, pedestrian, or fixed object
- Backing path may be straight or curved (e.g., out of driveway)

- Veh, traveling on roadway
- Veh_1 strikes or is struck by Veh_2

Crossing path backing crashes may prove difficult to address with vehicle-based countermeasures in the backing vehicle. Detection of the crossing-path vehicle would require more sophisticated sensors and data processing, and would involve more complex driver human factors issues. For this reason, the current analysis addresses ***only encroachment*** backing crash countermeasures.

Countermeasure Technologies

Ultrasound and radar are two sensor technologies that have been utilized for rear-blind zone warning systems. Ultrasonic sensors transmit acoustic waves toward a target and receive the echo reflection from it. The distance between the sensor and the target is determined by comparing the time shift between the triggered pulse and the received pulse of the echo. Several commercially-available ultrasonic rear-blind-zone detection systems are available; product names include SCAN II™ and PROTEX™. Most operate in the 40 to 50 KHz frequency range. A typical range for existing systems is 15 feet, although the effective range is less for relatively small and irregularly-shaped targets (e.g., people, as opposed to vehicles) (6).

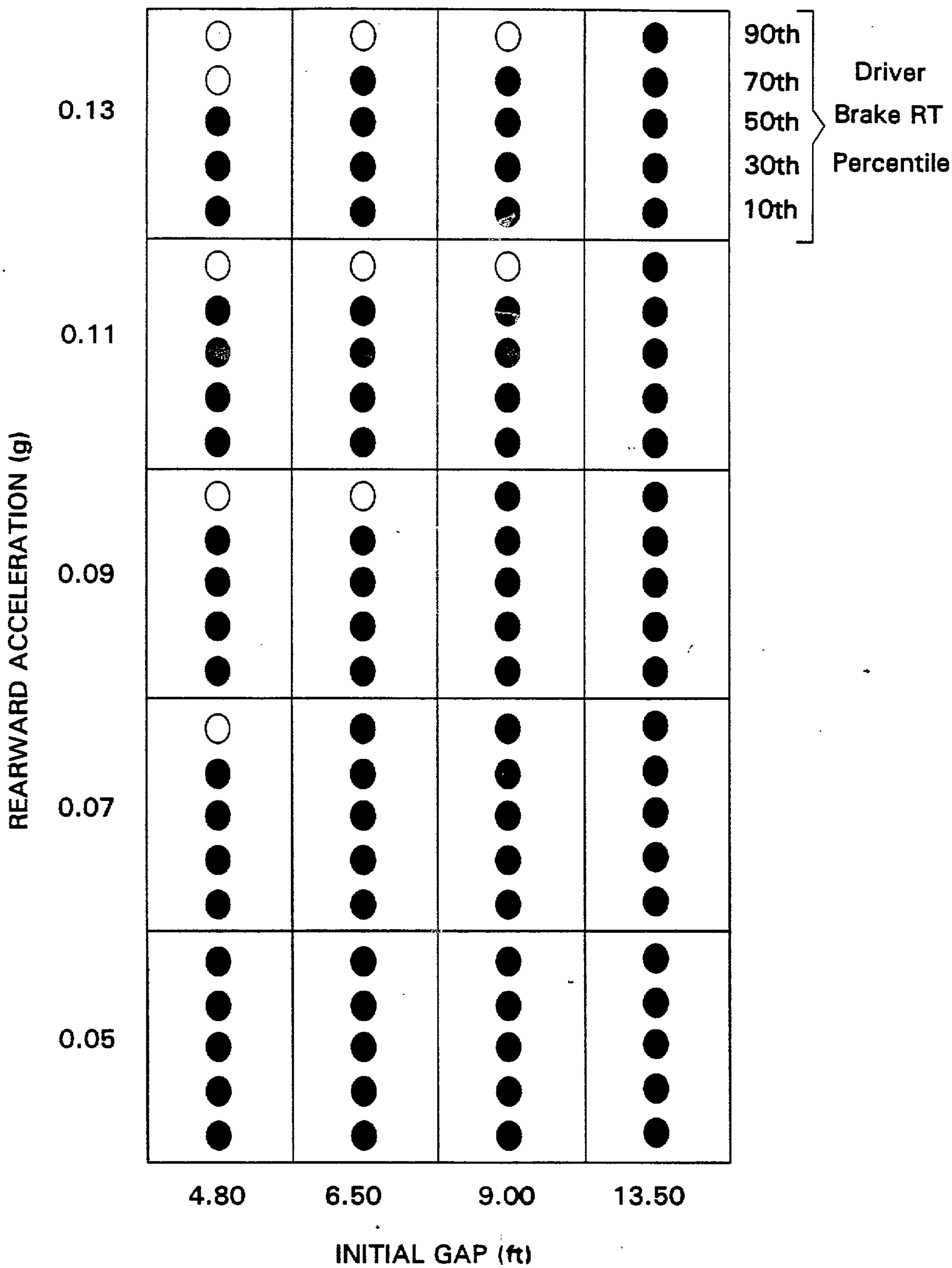
Radar sensor systems may be microwave (less than 30 GHz) or millimeter wave (30 to 300 GHz). A radar transceiver propagates electromagnetic pulses and then uses the speed of propagation and two-way signal transit time to calculate distance to target. AM Sensors and ***Safety First*** are two companies marketing such systems. These systems have operational ranges of 10 to 20 feet with range resolution of less than one foot (0.3 meters). Greater ranges are possible, but at the cost of a higher false or "nuisance" alarm rate (6).

Modeling

Effectiveness modeling of rear-blind-zone object detection systems was applied to several subcategories of ***encroachment*** backing crashes. The assumed causal factor was driver perceptual failure (i.e., "did not **see"). System effectiveness** depends on many different variables; e.g., system parameters (e.g., range), vehicle rearward speed/acceleration, initial distance between sensor and target, driver RT, and braking efficiency.

Figure 6, reproduced from the project backing crash analysis report by Tijerina et ***al (6)*** presents a portion of the results -- a "factorial" model of a hypothetical rear-blind zone detection system applied to 100 hypothetical crashes of one encroachment backing crash subtype. This subtype is vehicle-into-vehicle "parallel path" backing crashes; i.e., a vehicle backs directly into another vehicle in the same lane behind it. The 100 hypothetical cases in Figure 6 were generatedusing a factorial matrix of five rearward acceleration values, four initial gaps, and five driver RTs (5 X 4 X 5 = 100). The five braking RTs used were 0.57, 0.83, 1.07, 1.39, and 2.01 seconds, which represent, respectively, the 10th, 30th, 50th, 70th, and 90th percentile braking reactions times according to an analysis by Taoka (8). These five percentile values were selected because they represent the mid-points of five "quintiles" of the RT distribution. In 90 of the 100 hypothetical cases in Figure 6, the crash would have been avoided through the use of this hypothetical rear-blind zone countermeasure. Note here that higher percentiles are associated with ***longer*** RTs and thus lower prospects for crash avoidance.

Figure 6
Matrix Chart of Parallel Path Encroachment Backing Crash Modeling Results (6)



Somewhat lower effectiveness estimates were derived for two other encroachment subtypes, vehicle-to-vehicle "curved-path" crashes (e.g., vehicle backs out of driveway and strikes parked car on street) and for pedestrian backing crashes. The lower effectiveness estimates for pedestrian backing crashes resulted from the assumption of a shorter system range for human targets than for vehicle targets. Overall, across several different encroachment crash subtypes and two different assumptions about backing vehicle motion (e.g., constant speed versus accelerating), effectiveness estimates ranged from a high of 90 percent (i.e., the modeling data shown in Figure **6)** to a low of 26 percent.

SINGLEVEHICLE ROADWAY DEPARTURE (SVRD) CRASHES

Scenarios, Causes, and Applicable Countermeasures

SVRD crashes are a "mixed bag." Based on a review of 100 SVRD crashes by Hendricks et al (9), a number of distinct contributory/causal factors are apparent:

- 20% Slippery road (snow or ice)
- 20% Excessive speed/reckless maneuver
- 15 % Driver inattentive/distracted (includes evasive maneuver to avoid rear-end crash)
- 14% Evasive maneuver to external crash threat (e.g., animal, other vehicle encroaching in lane)
- 12 % Drowsy driver (fell asleep at wheel)
- 10 % Gross driver intoxication (often including excessive speed, **reckless** maneuver, etc.)
- 8 % Other (vehicle failure, driver illness).

With so many diverse crash causes, no single countermeasure concept emerges for these crashes. One potential countermeasure concept is road edge detection. Such a system would monitor the vehicle's lateral position within the travel lane and detect imminent roadway departures. The system could activate a warning to the driver or automatic vehicle control (i.e., corrective steering).

Other countermeasure concepts are applicable to portions of the SVRD problem. For example, the headway detection concept discussed under rear-end crashes would be applicable to SVRD crashes resulting from an evasive maneuver to avoid a rear-end crash. Drowsy driver countermeasures (discussed later in this paper) are applicable to drowsy driver SVRD crashes. Infrastructure-based warning or advisory systems may be applicable to crashes on slippery roads and/or involving excessive speeds, especially at hazardous locations such as curves.

Countermeasure Technologies and Modeling

Road edge detection can be accomplished by either vehicle-based lane position monitors or infrastructure-based systems. Such systems provide data which allows determination of a vehicle's lateral position in the lane. Examples of applicable vehicle-based technologies include video image processing and infrared laser scanning. Cooperative (vehicle-infrastructure) technologies could include two-frequency radar (which tracks a vehicle's lateral position with respect to reflectors mounted along the road edge) or "magnetic following" systems that track a vehicle's lateral position in relation to magnets or a wire surrounded by an electromagnetic field **located** in the center of the lane. Of course, having a reliable lateral ***detection*** does not in itself ensure a viable lane drift countermeasure. Research will be required to "calibrate" driver lane keeping to develop algorithms that reliably distinguish "pre-crash" lane deviations from "normal" lane deviations. Moreover, this calibration may be dramatically different for different drivers.

Countermeasure effectiveness modeling results are not yet available for SVRD crashes. Road edge detection modeling employs such crash parameters as travel speed, departure angle, distance to point-of-impact, and required steering correction. Both warning systems and automatic steering systems are under consideration in the modeling.

LANE CHANGE/MERGE CRASHES

Scenarios, Causes, and Applicable Countermeasures

Approximately 95 percent of lane change/merge crashes are angle or sideswipe collisions. The remaining 5 percent are rear-end crashes where the lane-changing vehicle is struck in the rear immediately following the lane change or merge (10). These two crash subtypes may require different countermeasures. In this preliminary analysis, only the angle/sideswipe subtype is considered.'

Most lane change/merge crashes occur during dry, clear, daylight conditions. Just over half (55 percent) occur on divided highways. Causal factor assessments performed under the Indiana Tri-Level study (11) and as part of the current program (12) indicate that approximately three-quarters (or more) of these crashes involve a recognition failure by the lane changing/merging driver. **In other words,** the driver "did not **see"** the **other vehicle** until the crash was unavoidable.

A potential vehicle-based countermeasure to these crashes is a proximity or "lateral encroachment" warning system (or, possibly, automatic control system) that would detect vehicles adjacent to the equipped vehicle, especially in the area of the driver's lateral "blind zone" **(see Figure** 7; only left-side scanning zone is shown).

Countermeasure Technologies and Modeling

The technology issues and options relevant to lateral proximity detection systems are substantially the same as for backing crashes. However, the required coverage area is likely to be considerably larger than that for backing crash prevention. The system may need to extend its beam laterally 8 to 12 feet into the adjoining travel lane and rearward (adjacent to the vehicle) 20 to 30 feet to detect vehicles located in the portion of the lateral blind zone that is just behind the equipped vehicle.

Although common technologies (i.e., sensor types) may be applied to the backing and lane/change merge crash problems, the required driver interfaces may be different. The nature of the driver interface for lane change/merge crash warning systems may be more problematic since the driver's steering maneuver to avoid the lane change crash may be less reliable (and thus more hazardous) than a braking response in a backing situation.

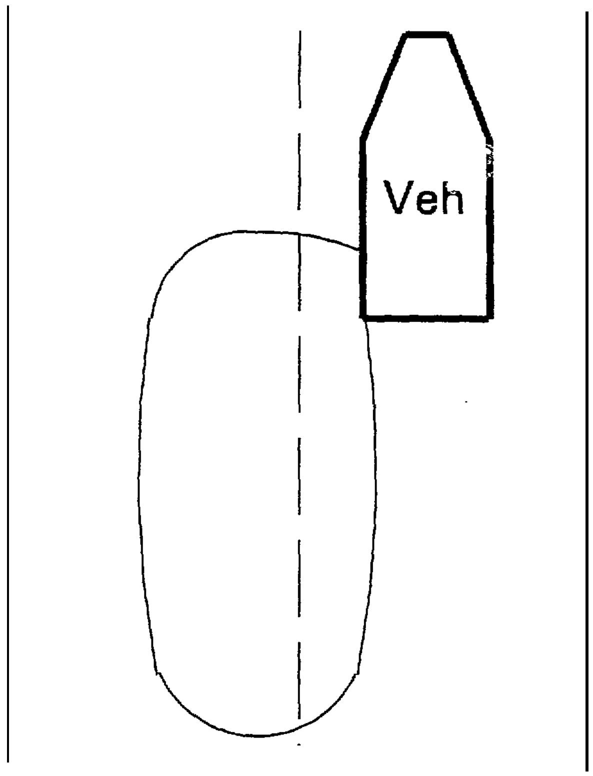


Figure 7
'Schematic of Lateral Proximity Detection System (Left Side Scanning Zone)

Countermeasure modeling for lane change/merge crashes is currently being performed under the VNTSC contract with Battelle by Tijerina ***et al (12).*** Results are not yet final. Modeling parameters include:

- Vehicle speed
- Lateral separation between vehicles at initiation of the lane change maneuver
- Lateral speed and acceleration pattern of maneuver
- Driver steering RT following warning
- Vehicle response time to steering correction.

A key issue being addressed in the modeling relates to the close lateral proximity of vehicles in lane change situations. Typically, two vehicles in adjacent highway lanes are only about six feet apart laterally. Therefore, to be useful, a system would need to provide the information before the initiation **of** the lane change maneuver or early enough in the maneuver to permit successful evasive steering.

SIGNALIZED **INTERSECTION/CROSSING PATH CRASHES**

Scenarios, Causes, and Applicable Countermeasures

By definition, this crash type represents a very specific crash scenario. Virtually all of these crashes involve a signal violation by one vehicle. A causal factor analysis of 50 NASS cases by Tijerina ***et al*** (13) indicates the following percentage breakdown of principal causes:

- Deliberately ran signal (39 percent)
  - Ran red light (23 percent)
  - Tried to beat signal change (16 percent)
- Inattentive driver ("did not see" signal) (36 percent)
- Driver intoxicated (13 percent)
- Vision obstruction (e.g., frost on windshield) (4 percent)
- Other (e.g., collision with ambulance) (8 percent).

One countermeasure concept for these crashes is a system that warns a driver that another vehicle, approaching an intersection in a crossing path, is not decelerating and thus may violate the signal. Another countermeasure concept, applicable to a portion of the above crashes, is one that warns drivers of an approaching red signal light. To reduce nuisance alarms, the system may be programmed to activate a warning only if there are indications (based on vehicle location and motion) that the driver may run the light.

Technology assessment and countermeasure modeling for SI/SCP crashes are currently underway.. Results will be reported upon completion of **the** analysis.

DROWSY DRIVER CRASHES

Scenarios, Causes, and Applicable Countermeasures

As noted earlier, the drowsy driver crash type overlaps with several other types, most notably SVRD. "Drowsy driver" is itself a crash ***cause,*** not a crash configuration. It is not being addressed as a specific **crash** problem assessment topic, but rather under a cooperative agreement for development of measurement protocols and processing algorithms for in-vehicle drowsy driver detection (Wierwille ***et al, 14).***

GES statistics indicate that drowsy driver crashes peak between midnight and dawn, with a second smaller peak in the afternoon. Most occur in non-urban areas, generally on roadways with 55-65 mph speed limits. More than 80 percent are SVRD crashes.

Numerous countermeasures to drowsy driver crashes have been proposed (l5, l6). These include "alertness maintainers" (e.g., coffee and loud music), operational rules (e.g., hours of service regulations for commercial drivers), pre-driving fitness-for-duty tests, and continuous driver status/performance monitoring during driving. NHTSA is supporting research on the continuous monitoring approach, based on the following rationale:

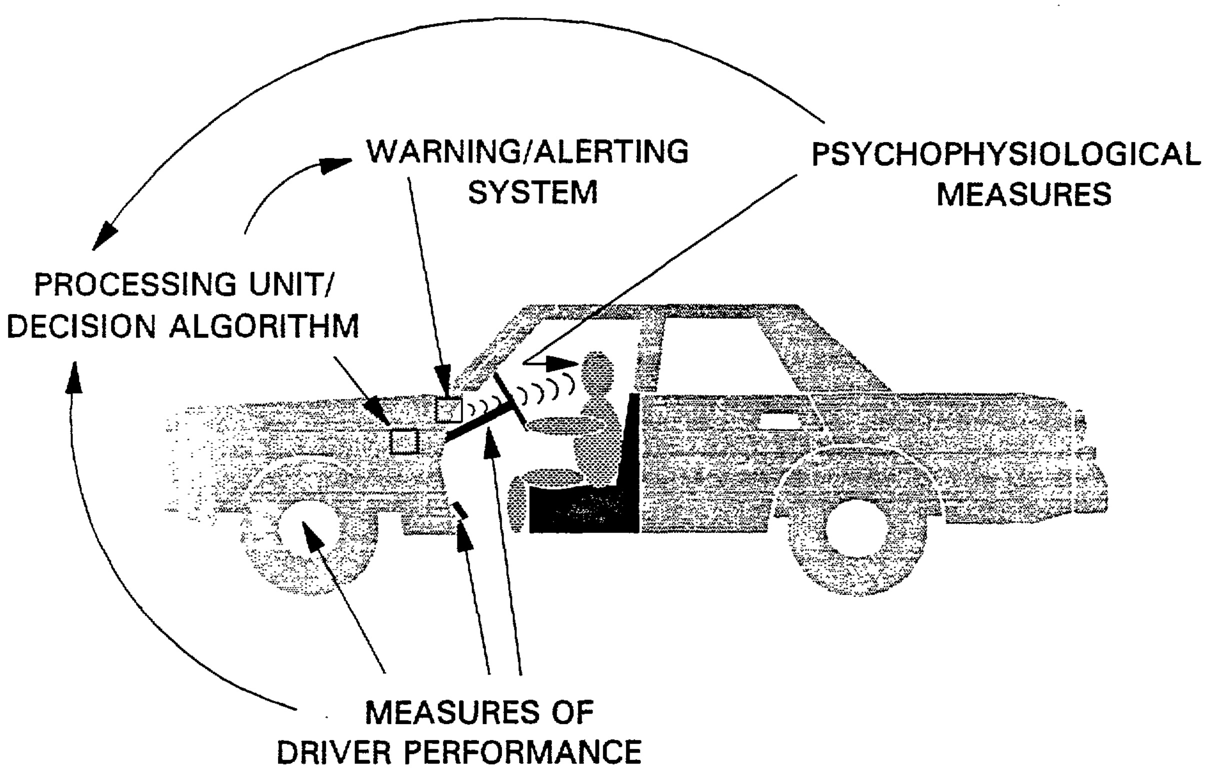
- Drivers typically do not "drop off" instantaneously. Usually, there is a preceding condition in which performance deteriorates and telltale psychophysiological changes are measurable (14).

- Drowsiness can be detected with relatively high probability using such performance measures as vehicle lateral lane position, steering movements, and driver seat movements. For example, drowsy drivers tend to exhibit a distinctive "drift-and-jerk" pattern of steering (14).

- Direct, unobtrusive psychophysiological measures of driver status, such as detection of "slow" eye closures associated with loss of alertness, could potentially enhance drowsiness detection and reduce false alarm rate significantly.

The NHTSA-supported research is addressing the concept of a vehicle-based device to unobtrusively monitor driver performance and, potentially, psychophysiological status. The device would require a processing unit to "decide" whether the driver was drowsy and, if so, issue an appropriate warning signal to the driver. **Figure 8** is a schematic of the prospective countermeasure system. Such a system appears feasible, particularly on rural or other "open" roadways. It would likely not be effective in "busy" driving situations such as those involving high traffic density or a lot of turning maneuvers (e.g., a "cross town" trip). The conceptualized system would detect subtle driver performance changes (e.g., "drift-and-jerk" steering) that would likely be "washed out" by the high number and magnitude of driver control inputs required in heavy traffic or "cross town" driving. However, accident data indicate that few drowsy driver crashes occur under "busy" traffic conditions.

Figure 8
Schematic of Prospective Vehicle-Based Drowsy Driver Detection System



Countermeasure Technologies

Measurement of driver control inputs (i.e., steering, accelerator, brakes) and other behavior (e.g., seat movements) would employ readily-available technologies. Several technology options for lateral lane position monitoring (probably an essential component of driver performance monitoring) have already been described.

Potential psychophysiological measures of driver alertness include measures of heart rate variability, electroencephalograms (EEGs), electrooculograms (EOGs), and measures of eyelid activity (especially "slow closure"). The R&D challenge here is to develop ***unobtrusive*** or "minimally-obtrusive" devices that drivers are willing and able to use regularly, and which do not interfere with **normal** driving performance.

Modeling

Only a limited amount of countermeasure modeling has been done relating to drowsy driver detection. However, driving simulation studies (e.g., 17) indicate that drowsiness detection accuracies of approximately 75 percent with false alarm rates of approximately 3 percent are feasible using currently-known algorithms. Although this performance level appears impressive, a cursory analysis of likely false alarms versus "hits" (correct detections of drowsiness} indicates that this system accuracy level would probably not be acceptable for a deployed countermeasure. In **Table 1,** the assumption is made that drivers are dangerously drowsy during 1 percent of driving time periods or "epochs." . (Such epochs would probably be short time periods -- e.g., one minute -- over which a system would measure performance and/or psychophysiology and "decide" whether the driver is drowsy.) Based on these three parameters (75 percent rate, 3 percent false alarm rate, driver drowsy 1 percent of the time), Table 1 shows that false alarms would still outnumber "hits" by 4:l. If the drowsiness rate were less than 1 percent (e.g., 0.1 percent), the ratio of false alarms to "hits" would be higher (e.g., 40: 1).

This analysis demonstrates the critical research need to reduce the false alarm rate of these systems. Current research (e.g., l4) is directed toward this goal. One potential method to dramatically reduce the false alarm rate is to incorporate two qualitatively-different measures of driver status: i.e., performance measures ***and*** simultaneous psychophysiological measures. False alarms would be reduced since it is unlikely that a driver could exhibit both performance characteristics (e.g., "drift and jerk" steering) ***and*** psychophysiological characteristics (e.g., slow eye closure) without actually being drowsy. Given the same assumptions shown in Table **1,** a **90** percent reduction of the false alarm rate (to **0.3** percent) without any change in detection rate would reduce the false alarm: hit ratio to 1: 2.5 **--** obviously a more acceptable ratio.

Table 1
Illustration of the False Alarm Problem in Drowsy Driver Detection

- **HYPOTHETICAL ASSUMPTIONS:**
  - **75% DETECTION RATE, 3% FALSE ALARM RATE**
  - **DRIVER DROWSY 1% OF THE TIME (10 of 1,000 "EPOCHS")**

- **RESULTING SYSTEM PERFORMANCE:**

System Decision/Response: Actual Driver Status:	Activate Alarm	No Alarm
Drowsy	"Hit": 7.5 epochs	"Miss": 2.5 epochs
Alert	False Alarm: 29.7 epochs	Correct Rejection: 960.3 epochs

- **RESULTING FALSE ALARM:HIT RATIO = 29.7/7.5 = ~4:1**

RESEARCH NEEDS

Front-end analysis of crash types and countermeasures by its very nature represents a "first-cut" analysis attempt based on a limited set of existing data. The process is ***heuristic;*** it identifies numerous data needs which must **be** addressed if the functional concepts of countermeasure action and associated effectiveness modeling are to be refined. Broadly, across all six crash subtypes discussed here, the following research data needs are salient:

- **Further elucidation of driver human error is** required to determine the probable applicability of countermeasure concepts to specific crash types and subtypes. For example, research on left-turn-across-path maneuvers and driver errors will likely need to distinguish perception errors ("looked but didn't see") from decision errors (saw vehicle but misjudged time/distance available for maneuver) since these two types of errors may imply different countermeasure requirements. Furthermore, within each error category, the likelihood of the error in relation to dynamic parameters of the crash scenario needs to be determined. For example, data on the effects of approaching vehicle characteristics (e.g., speed, location, size, conspicuity, proximity to other vehicles) on driver gap acceptance for a turning maneuver may help identify and specify situations where technology could best aid the driver.

- **Driver reaction time** (for braking or steering) is a major driver performance parameter affecting the outcome of countermeasure modeling. A positively-skewed driver RT distribution (8) is assumed for most of **the** modeling conducted under this program, although no attempt is made to factor in degradations due to such factors as alcohol impairment. In addition, no attempt has been made to account for the probability that driver RT correlates significantly with other driver behaviors; e.g., travel speed, following distance, gap acceptance, and braking deceleration rate. Since human RT is a function of the number of response choices available (i.e., Hicks Law; 18), different types of warning systems for different crash situations may result in vastly different average RTs. Indeed, the phrase "perception-decision-response time" may be more appropriate than "reaction time" for the more complex crash/warning situations (6).

- **Older driver errors and crash avoidance performance are** specific areas where more data are needed. For example, older driver perception/decision errors at intersections and their responses to intersection crash countermeasures will be particular areas of research focus in **future** NHTSA-sponsored research.

- **A knowledge base on vehicle location and motion** is needed to better understand the "normal" and "hazardous" motions of vehicles in relation to roadway markings and to each other. NHTSA has addressed this research need by initiating a program to develop a specialized measurement system to quantify the "vehicle motion environment". Once a roadside imaging device has been developed and validated, it will be used to quantify vehicle location and motion variables for a variety of traffic/ crash threat situations.

- **Data on roadway geometry** relevant to specific countermeasure concepts will help to define performance requirements and assess countermeasure applicability to various roadways. For example, the applicability of line-of-sight sensor systems will in part be a function of roadway features such as curves and hillcrests. Thus, data on "headway geometry" in typical crash situations are needed to refine assessments of countermeasure feasibility and models of countermeasure functioning.

Countermeasure modeling demonstrates the potential effectiveness and benefits of countermeasure interventions into the chains of driver error and other events that result in these crashes. However, further basic research on driver performance, vehicle performance, and the traffic environment (vehicle motion and roadway characteristics) is needed to refine assessments of what countermeasures can be and what they must be to be effective.

Theoretical IVHS countermeasure modeling reveals promising safety opportunities. The challenge to product designers is to match the characteristics of their system to the capabilities and limitations of drivers in order to actually achieve the theoretically-projected benefits.

Future Performance Specification Research

Future research undertaken by NHTSA and other researchers will address these ergonomic, operational, and technological issues in order to transform the formulations of front-end -analysis into countermeasure ***performance specifications*** i.e., recommended functional guidelines for optimal countermeasure performance and effectiveness. These performance specifications will be intended to facilitate industry efforts to develop practical, driver-friendly, and commercially-viable countermeasure systems. Specific NHTSA countermeasure performance specification projects ongoing or planned include the following, most of which were addressed in this paper:

- Rear-end crash countermeasures
- Lane change/merge/backing crash countermeasures
- Single vehicle roadway departure crash countermeasures
- Intersection crash countermeasures
- Vehicle-based drowsy driver detection
- Vision enhancement systems
- Emergency. medical service collision notification systems.

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