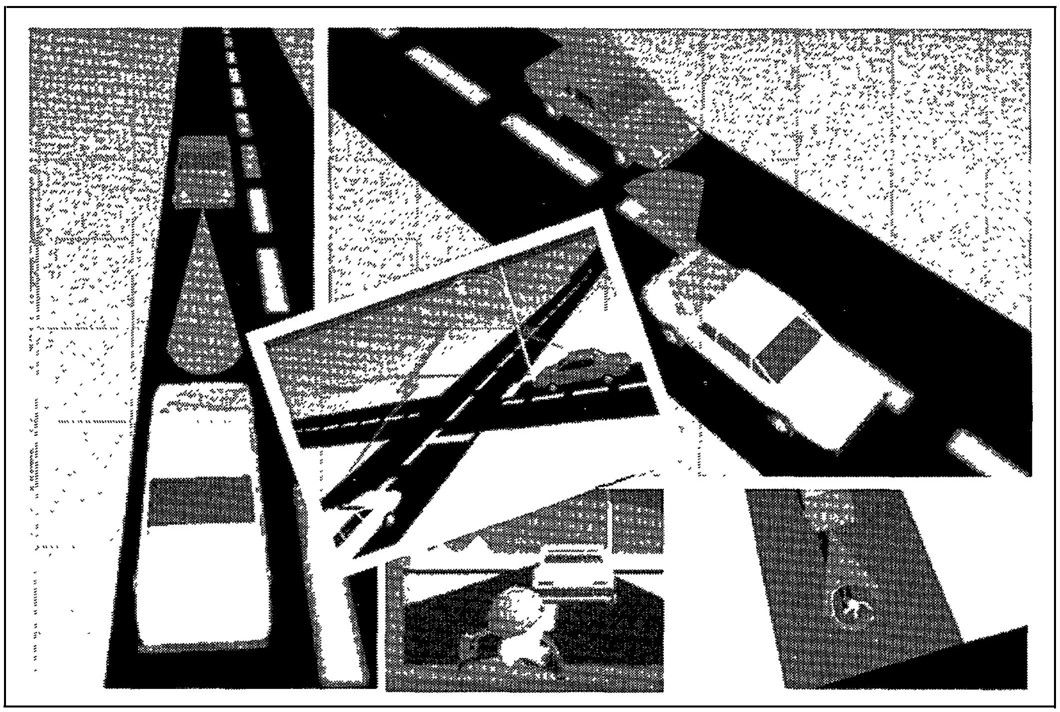
U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures

DOT HS 808 263
DOT-VNTSC-NHTSA-95-4

Final Report
June 1995



U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1995	3. REPORT TYPE AND DATES COVERED September 1994 - April 1995

4. TITLE AND SUBTITLE Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures	**5.** FUNDING NUMBERS HS521/S5007
6. AUTHOR(S) Wassim Najm,* Mark Mironer,* Joseph Koziol, Jr.,* Jing-Shiarn Wang,** Ronald R. Knipling***	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Special Programs Administration John A. Volpe National Transportation Systems Center Cambridge, MA 02142	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NHTSA-95-4
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation National Highway Traffic Safety Administration Office of Crash Avoidance Research 400 7th Street, SW Washington, DC 20590	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER** DOT HS 808 263

11. SUPPLEMENTARY NOTES
*Volpe Center
**Information Management Consultants
***NHTSA OCAR

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
This document is available to the public through the National Technical Information Service, Springfield, VA 22161	

13. ABSTRACT (Maximum 200 words)

This report synthesizes the results of a preliminary analysis of nine major target crashes: (1) rear-end, (2) backing, (3) lane change and merge, (4) single vehicle roadway departure, (5) opposite direction, (6) signalized intersection, straight crossing path, (7) unsignalized intersection, straight crossing path, (8) left turn across path, and (9) reduced visibility. This report provides statistical descriptions of target crash sizes and characteristics, identifies crash subtypes and causal factors, defines Intelligent Transportation System (ITS) Collision Avoidance System (CAS) concepts, and includes a sample of kinematic models representing crash avoidance actions. A case-by-case examination of a sample of 1,183 crashes identified 18 crash subtypes and showed that driver recognition and driver decision errors were the primary causes of 44% and 23% of target crashes, respectively. The CAS concepts discussed in this report provide mechanisms of intervention in three basic categories: advisory, warning, and automatic control intervention. Crash avoidance actions are kinematically modeled as applied to target crash subtypes in terms of braking, steering, and holding course actions. This report concludes by highlighting key results of the analysis.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Vehicle crash analysis, crash characteristics and circumstances, crash types, crash causes, crash countermeasures, ITS, crash avoidance, kinematic models	64
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

PREFACE

The National Highway Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research (OCAR), in conjunction with the Research and Special Programs Administration (RSPA) Volpe National Transportation Systems Center (Volpe Center), has undertaken a 3-year, multidisciplinary project to identify crash causal factors and applicable Intelligent Transportation System (ITS) Collision Avoidance System (CAS) concepts; model crash scenarios and avoidance maneuvers; provide preliminary estimates of CAS effectiveness when appropriate; and identify research and data needs. This project was conducted with contract support from Battelle Memorial Institute and its subcontractor ARVIN/Calspan.

Under this project, nine target crash types were examined, including the following:

- Rear-End
- Backing
- Single Vehicle Roadway Departure
- Lane Change/Merge
- Signalized Intersection, Straight Crossing Path
- Unsignalized Intersection, Straight Crossing Path
- Intersection, Left Turn Across Path
- Reduced Visibility (Night/Inclement Weather)
- Opposite Direction

This report synthesizes the results of this project. The results are based on the analysis of 1,183 crash cases that were selected from the 1991-1993 General Estimates System (GES) and Crashworthiness Data System (CDS) within the National Accident Sampling System (NASS). The crashes analyzed in this project were weighted for severity so that they might more closely approximate the national profile.

The authors of this report are Wassim G. Najm, Mark Mironer, and Joseph S. Koziol, Jr., of the Volpe Center; Jing-Shiam Wang of Information Management Consultants, Inc.; and Ronald R. Knipling of NHTSA OCAR.

John Hitz of the Volpe Center and William A. Leasure, Jr., August L. Burgett, and Robert M. Clarke of NHTSA OCAR provided technical guidance and reviewed this report. Eve C. Rutyna of Camber Corporation served as editor.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)

1 foot (ft) = 30 centimeters (cm)

1 yard (yd ❑ 0.9 meter (m)

1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)

1 square foot (sq ft, ft^2 = 0.09 square meter (m^2)

1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)

1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)

1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)

1 pound (lb) = .45 kilogram (kg)

1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)

1 tablespoon (tbsp ❑ 15 milliliters (ml)

1 fluid ounce (fl oz) = 30 milliliters (ml)

1 cup (c) = 0.24 liter (l)

1 pint (pt) = 0.47 liter (l)

1 quart (qt) = 0.96 liter (l)

1 gallon (gal) = 3.8 liters (l)

1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)

1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F ❑ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)

1 centimeter (cm) = 0.4 inch (in)

1 meter (m) = 3.3 feet (ft)

1 meter (m) = 1.1 yards (yd)

1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)

1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)

1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)

1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)

1 kilogram (kg) = 2.2 pounds (lb)

1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) ❑ 0.03 fluid ounce (fl oz)

1 liter (1) = 2.1 pints (pt)

1 liter (l) = 1.06 quarts (qt)

1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)

1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C ❑ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^{o}F	-40°	-22^o	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. Cl3 10286.

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ABBREVIATIONS AND ACRONYMS

BK	Backing
CAS	Collision Avoidance System
CDS	Crashworthiness Data System
CSM	Component Status Monitor
DVM	Driver Vigilance Monitor
FARS	Fatal Accident Reporting System
GAA	Gap Acceptance Aid
GES	General Estimates System
HD	Headway Detection
ICP	Intersection Crossing Path
IDM	Intoxicated Driver Monitor
ITS	Intelligent Transportation System
IVS	In-Vehicle Signing
LCM	Lane Change/Merge
LPM	Lane Position Monitor
LTAP	Left Turn Across Path
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stationary
NASS	National Accident Sampling System
NHTSA	National Highway Traffic Safety Administration
OCAR	Office of Crash Avoidance Research
OD	Opposite Direction
PAR	Police Accident Report
PCM	Pavement Condition Monitor
PD	Proximity Detection
POV	Principal Other Vehicle
RE	Rear-End
RV	Reduced Visibility
SI/SCP	Signalized Intersection, Straight Crossing Path
s v	Subject Vehicle
SVRD	Single Vehicle Roadway Departure
UI/SCP	Unsignalized Intersection, Straight Crossing Path
VES	Vision Enhancement System

1. INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) of the United States Department of Transportation has undertaken major research programs to facilitate and stimulate industry efforts which result in the deployment and commercialization of cost- and safety-effective ***Intelligent Transportation System*** (ITS) products. These research programs follow a five-thrust ITS strategic plan [l] that was devised by NHTSA to:

1. Build research tools and compile knowledge bases;
2. Identify promising crash avoidance opportunities;
3. Demonstrate proof of concepts for crash avoidance;
4. Facilitate development of crash avoidance products toward commercialization; and
5. Assess the safety of other ITS systems (e.g., mobility and productivity enhancement systems).

Thrust 2 of NHTSA's ITS strategic plan identifies promising opportunities for the application of advanced technologies for improving the crash avoidance capabilities of the driver-vehicle system. Recent advances in sensors, communications, processors, controllers, and driver/system interfaces can now allow for the design of collision avoidance systems with increased sophistication, reduced cost, and high reliability. However, there is a weak link in the logic chain between available technologies and the prevention of crashes [2]. The mechanisms of intervention of high-technology devices in crash scenarios are not well understood. A key element to defining crash avoidance opportunities is the problem definition and analysis of target crashes and ITS/countermeasure actions. By analyzing candidate technological solutions in relation to the parameters of target crash scenarios and the capabilities and limitations of drivers, countermeasure functions can be identified which, in turn, can lead to assessments of the most promising applications of technology and associated R&D needs.

The preliminary stage of problem definition and analysis of target crashes and ITS/countermeasure actions was performed, in a three-year project, by the Research and Special Programs Administration's Volpe National Transportation Systems Center in conjunction with NHTSA's Office of Crash Avoidance Research, with contract support from Battelle Memorial Institute and its subcontractor ARVlN/Calspan. This project has developed and applied a seven-element methodology to describe target crash characteristics, identify causal factors and crash subtypes, devise applicable ITS countermeasure concepts, model crash scenarios and avoidance maneuvers, develop sensitivity curves, provide preliminary estimates of countermeasure effectiveness when appropriate, and identify research and data needs. The purpose of this study is to help guide R&D on high-technology crash countermeasures. Specifically, results of these analyses support NHTSA-sponsored research to develop performance specifications for advanced collision avoidance systems.

This report summarizes and synthesizes results of this study, especially target crash causes and subtypes, countermeasure concepts, and kinematic models of avoidance maneuvers.

1.1 TARGET CRASHES

Seven major crash types are defined below, which were targeted for ITS technology applications:

1. Rear-End (RE): The front of a subject vehicle (SV) strikes the rear of a leading principal other vehicle (POV), both traveling in the same lane.

2. Backing (BK): The SV strikes, or is struck by, an obstacle while moving backwards. The obstacle can be another vehicle, or an object, animal, or pedestrian.

3. Lane Change/Merge (LCM): The SV driver attempts to change lanes and strikes, or is struck by, a vehicle in the adjacent lane.

4. Single Vehicle Roadwav Departure (SVRD): The SV leaves the roadway as a first harmful event. This crash type does not include roadway departures resulting from a collision with another vehicle.

5. Opposite Direction (OD): The SV collides with a POV traveling in the opposite direction. This crash type results in a frontal impact or a sideswipe.

6. Intersection Crossing Path (ICP): Three types of ICP crashes were identified and analyzed:

   i. Signalized Intersection, Straight Crossing Path (SI/SCP): The SV without a right-of-way strikes, or is struck by, a POV with a right-of-way, both traveling through a signalized intersection in straight paths perpendicular to each other.

   ii. Unsignalized Intersection, Straight Crossing Path (UI/SCP): The SV without a right-of-way strikes, or is struck by, a POV with a right-of-way, while both are attempting to pass in perpendicular directions straight through an unsignalized intersection (generally controlled by stop signs).

   iii. Left Turn Across Path (LTAP): The SV attempts to turn left at an intersection and strikes, or is struck by, a POV traveling in the opposing traffic lanes.

7. Reduced Visibility (RV): This crash ***circumstance*** encompasses all crash types occurring in reduced visibility conditions that include non-daylight (dark, dark but lighted, dawn, or dusk) or bad weather (rain, sleet, snow, fog, or smog) conditions.

Eight individual reports on the analysis of target crashes have been published and are available from the National Technical Information Service [3-6] [8-11]. The results of the OD crash analysis are not published in a separate report, but rather are incorporated into this summary report.

1.2 METHODOLOGY FOR CRASH PROBLEM ANALYSIS

The methodology employed in target crash analyses, shown in Figure l-l, emphasizes the analysis of target crash scenarios and applicable avoidance maneuvers and the development of functional countermeasure concepts. Specific elements of this methodology included the following:

- Baseline crash problem sizes were quantified and crash characteristics were described from NHTSA's General Estimates System (GES) and Fatal Accident Reporting System (FARS) crash databases.

- Target crash subtypes and causal factors were identified by an assessment of individual crash investigation case files.

- ITS countermeasure concepts, and their basic functional requirements which depend largely on the crash scenario itself, were devised based on crash subtypes and causal factors.

- First-level kinematic models were derived which describe the crash subtypes and possible evasive actions of the driver-vehicle system needed to avoid the crash (i.e., braking or steering). These models provide a means for analyzing the time available to take evasive action and the intensity of action needed to avoid the crash, as illustrated in Figure 1-2.

- Sensitivity curves were developed based on the above kinematic equations which show either the time or distance available for the driver-vehicle-countermeasure system to avoid the crash in terms of other crash avoidance parameters.

- Parameters of the kinematic models were matched with the functional requirements of each applicable countermeasure concept in order to derive effectiveness estimates. Current data were then assessed in terms of availability and suitability so as to determine whether reliable countermeasure effectiveness estimates could be computed.

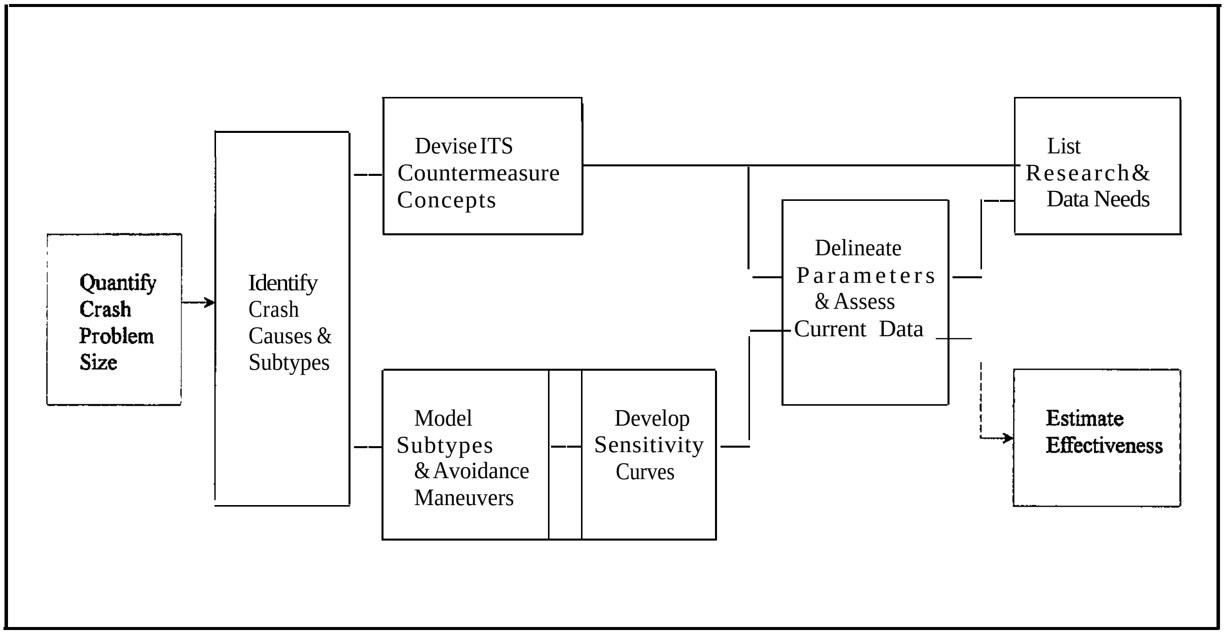

Figure l-l. Block Diagram of Crash Problem Analysis Methodology

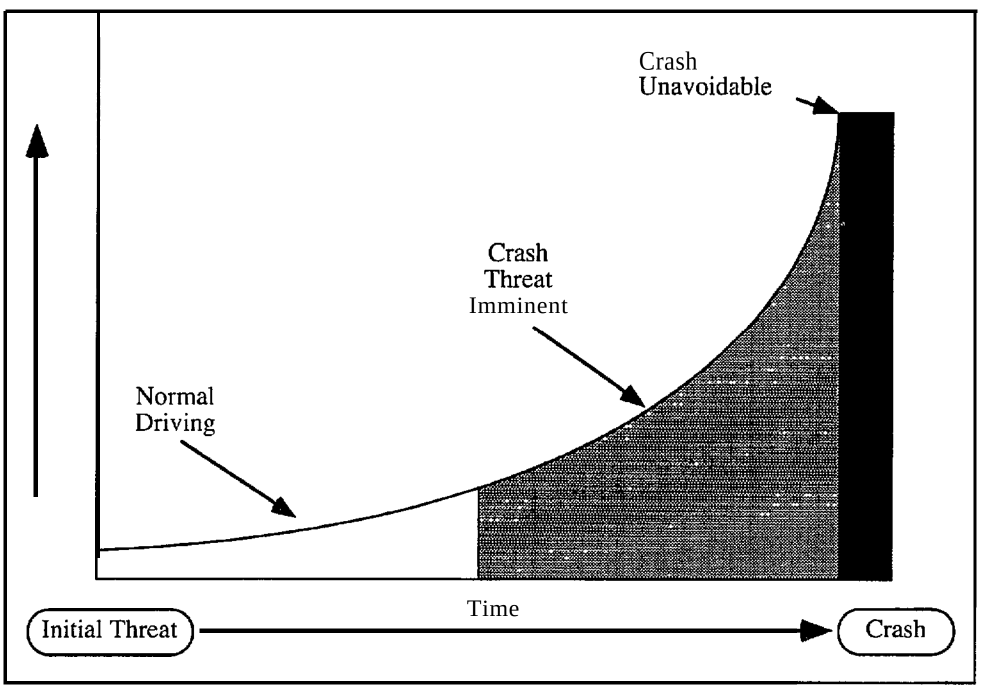

Figure l-2. Time-Intensity Curve of Crash Avoidance Requirements

Finally, research and data needs were identified which may enhance the analysis of baseline target crash problems, countermeasure interventions, and human factors, and guide the development of proposed countermeasure concepts.

The effectiveness of rear-end and backing crash countermeasures was predicted by means of countermeasure intervention models and available data on countermeasure technology, driver behavior, and vehicle performance. Assumptions were made to substitute for unavailable data which dealt with warning logic criteria and probability distribution function of driver reaction time to warning signals. For the remaining crash types, effectiveness estimates were not derived due to a lack of situation-specific data on driver and vehicle crash avoidance system capabilities. Instead, the analysis concluded with modeling of basic relationships among key pre-crash parameters such as separation distance, closing speed, and driver response capabilities.

1.3 REPORT OUTLINE

This introduction is followed by five chapters:

- Chapter 2 provides statistical descriptions of target crash sizes and characteristics, using 1993 GES data.
- Chapter 3 presents target crash subtypes and causal factors identified by detailed analysis of individual crash cases from GES Police Accident Reports (PARs) and NHTSA's Crashworthiness Data System (CDS) case files.
- Chapter 4 delineates ITS collision avoidance concepts which were devised based on crash subtypes and causes.
- Chapter 5 covers the kinematic models derived to represent crash subtype scenarios and applicable evasive maneuvers.
- Chapter 6 concludes this report by highlighting key results of this project.

2. TARGET CRASH PROBLEM SIZE AND CHARACTERISTICS

This chapter presents statistics on target crash problem size and crash characteristics, based principally on 1993 General Estimates System (GES) data. GES statistics are used because the GES provides data on all crashes, as opposed to just fatal crashes, and it-contains all the variables needed to define the various target crash types. More detailed statistical information may be found both in the individual countermeasure assessment reports produced under this program [3-11] and also in the series of crash data reports published in support of the program [12-16]. These detailed crash data reports present data from the latest year available at the time of the analysis, mainly 1990 and 1991. Statistics from 1993 are cited here for consistency and currentness.

Defining crash types and subtypes is itself an iterative and heuristic process based on the detailed analysis of findings about the salient characteristics of target crash scenarios. Appendix A provides the detailed GES definitions of the target crash types and subtypes. The reduced visibility crash is not included in Appendix A because this is a crash ***circumstance,*** not a crash type. Reduced visibility crashes are defined by their conditions of occurrence and principal cause, as opposed to pre-crash vehicle movement. Thus, these crashes may include any of the crash types/subtypes discussed here, and are not mutually exclusive with any crash type. According to 1993 GES statistics, approximately 43% of all crashes occurred in non-daylight (dark, dark but lighted, dawn, or dusk) or in bad weather (rain, sleet, snow, fog, or smog) conditions. For simplicity, this chapter presents only target crash types and subtypes which are mutually-exclusive from other types.

All statistics in this chapter represent the aggregate of all vehicle types. Different vehicle types, such as combination-unit trucks, may have significantly different crash profiles than the statistics presented here for all vehicle types combined. The individual crash data reports [12-16] include such data on specific vehicle types.

2.1 TARGET CRASH PROBLEM SIZE

Table 2-l and Figure 2-1 present 1993 GES statistics on target crash problem size. Statistics are presented for the major crash types and subtypes examined under the program. The following comments are applicable to the definitions of the various crash types and subtypes in the taxonomy:

1. Rear-End Crash:

   The rear-end crash breakout of lead vehicle stationary (LVS) versus lead vehicle moving (LVM) is, like all GES data, based upon information contained in the Police Accident Report (PAR). Given the limitations of PAR data, the coded crash subtype may not always capture the exact dynamic scenario of the crash. For example, one difficult-to-classify dynamic situation is when a rapidly-decelerating vehicle stops and then is quickly struck by a following vehicle.

Table 2-1. Crash Size by Target Crash Types

Accident Type	# of Crashes (% of All Crashes)	
Rear-Ehd	1,537,000 (25.2%)	
Rear-End, Lead Vehicle Stationary (LVS)		979,000 (16.1%)
*Rear-End, Lead Vehicle Moved (LVM)		558,000 (9.2%)
Backing	177,000 (2.9%)	
Encroachment Backing		82,000 (1.3%)
Crossing Path Backing		95,000 (1.6%)
Lane Change/Merge (LCM)	237,000 (3.9%)	
Angle/Side-swipe Lane Change/Merge (AS LCM)		226,000 (3.7%)
Rear-End lane Change/Merge		11,000 (0.2%)
Single Vehicle Roadway Departure (SVRD)	1,241,000 (20.4%)	
Intersection Crossing Path (ICP)	1,805,000 (29.6%)	
Signalized Intersection Straight Crossing Path (SI/SCP)		204,000 (3.3%)
Unsignalized Intersection Straight Crossing Path (UI/SCP)		359,000 (5.9%)
Left Two Across Path (LTAP)		405,000 (6.6%)
Other ICP		837,000 (13.7%)
Opposite Direction (OD)	169,000 (2.8%)	
All Crashes	6,093,000 (100.0%)	

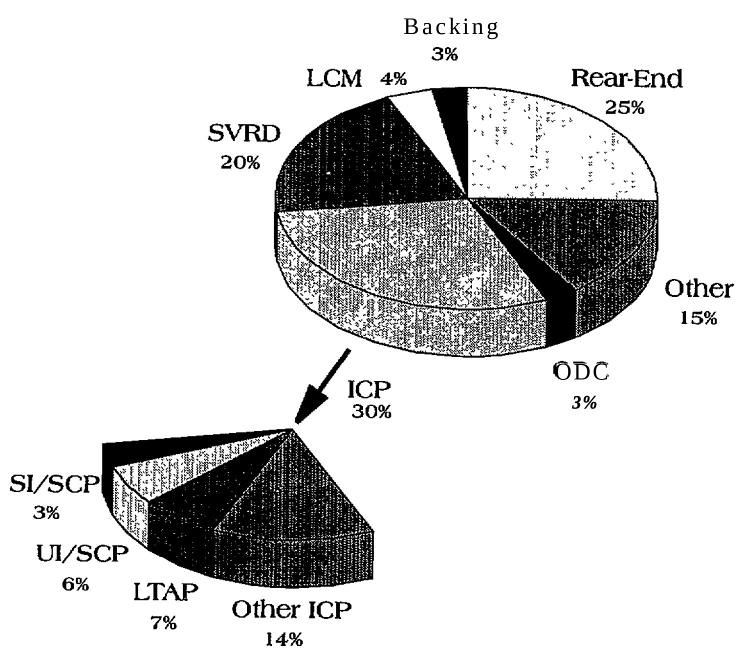

Figure 2-1. Target Crash Problem Size, 1993 GES Data

2. Backing Crash:

- Backing crashes include two distinct subtypes (see Figure 2-2): *encroachment* crashes involving slow closing speeds and a stationary (or slowly moving) struck pedestrian, object, or vehicle; and *crossing path* crashes where a backing vehicle (e.g., out of a driveway) collides with a moving vehicle (e.g., traveling "at speed" on a street).

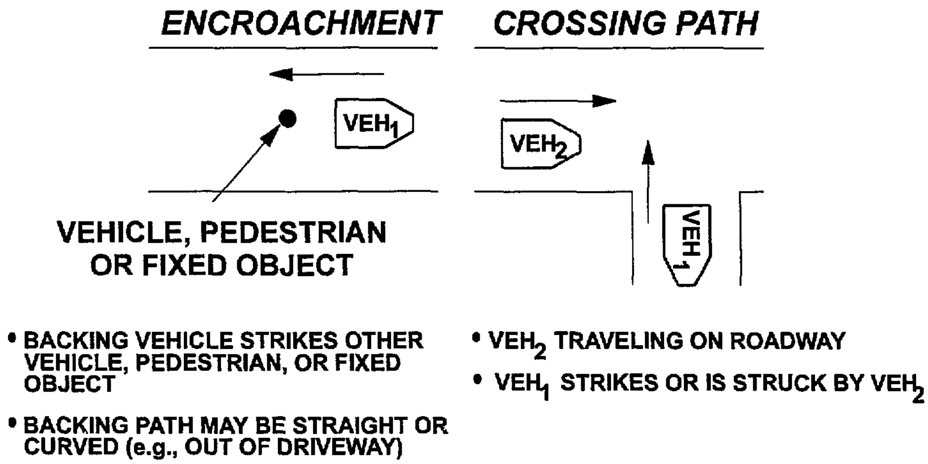

Figure 2-2. Backing Crash Subtypes

- Backing crashes occurring on private property (e.g., driveways and parking lots) are generally not police-reportable as traffic crashes and thus are not captured by these data. These private property crashes involve a significant number of serious injuries and fatalities - often involving young children.

3. Lane Change/Merge Crash:

- Lane change/merge crashes include primarily angle/sideswipe impacts (95.3%) but also a small number of crashes where the lane changing/merging vehicle is rear-ended after the lane change/merge maneuver (4.7%). LCM crashes can also be subdivided by maneuver; i.e., lane change versus merge. Of the 237,000 LCM crashes, 215,000 (90.6%) involved lane change maneuvers whereas 22,000 (9.4%) involved merge maneuvers.

4. Single Vehicle Roadway Departure Crash:

- Single vehicle roadway departure (SVRD) crashes include impacts with parked vehicles, but do not include road departures resulting from on-road crashes.

5. Opposite Direction Crash:

Opposite Direction (OD) crashes are defined by their crash scenario, not their configuration at impact. Common defining features of these crashes include a 180” approach angle between the two vehicles and the encroachment of one vehicle into the travel lane or path of another oncoming vehicle. Manners of collision (i.e., configurations at impact) include head-on, angle, and opposite-direction sideswipe.

6. Intersection/Crossing, Path Crash:

Intersection/Crossing Path (ICP) crashes include three distinct subtypes (see Figure 2-3):

- Signalized intersection straight crossing path (SI/SCP) crashes.
- Unsignalized intersection straight crossing path (UI/SCP) crashes.
- Left Turn Across Path (LTAP) crashes (initial opposite direction).

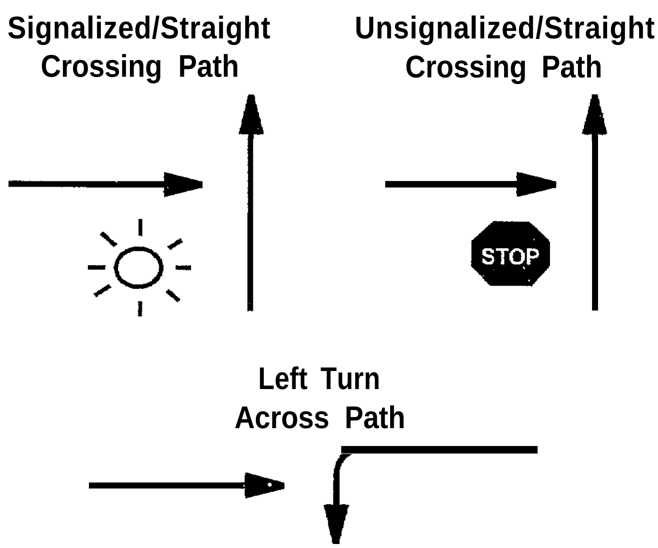

Figure 2-3. Intersection/Crossing Path Crashes - Three Major Subtypes

The remaining ICP crashes include two subtypes (see Figure 2-4) that are similar to SI/SCP and UI/SCP crashes, respectively:

- Signalized intersection/left turn across path/initial perpendicular direction (61,000 crashes).
- Unsignalized intersection/left turn across path/initial perpendicular direction (275,000 crashes).

Although not addressed explicitly in the countermeasure assessments, the dynamics of these crash subtypes are regarded as similar to the SI/SCP and UI/SCP crash subtypes, respectively.

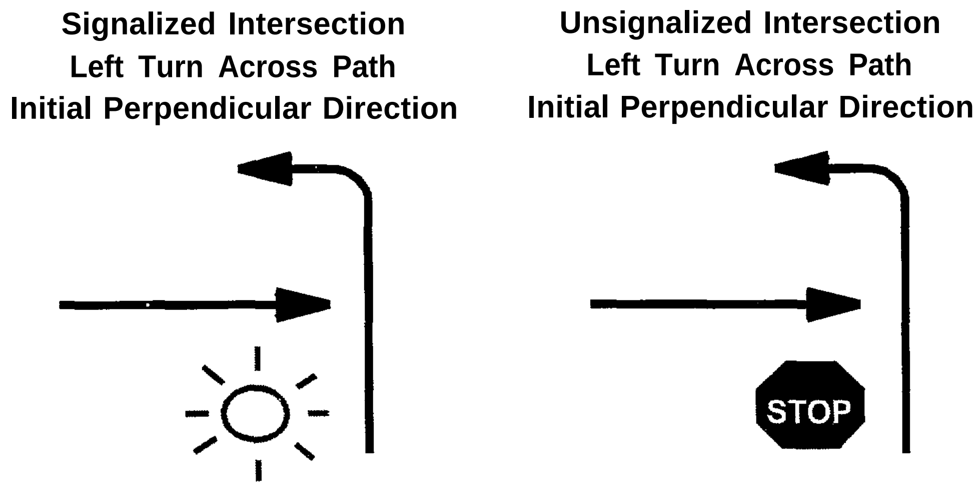

Figure 2-4. Intersection Left Turn Across Path/Initial Perpendicular Direction

LTAP crashes include both those at signalized and unsignalized intersections, since the dynamics of the two situations are generally similar. However, of the 405,000 LTAP crashes, 53.1% (215,000) occurred at signalized intersections while 46.9% (190,000) occurred at unsignalized intersections; i.e., those controlled by signs or with no controls. A “no controls” intersection could be the intersection of a roadway with a driveway or alley, or it could represent the situation where the involved vehicles were under no traffic control; e.g., two vehicles both traveling on a roadway with the right-of-way at an intersection with stop signs controlling traffic from the side streets.

2.2 STATISTICAL CHARACTERISTICS

Table 2-2 presents statistical data on the conditions of occurrence and other characteristics of target crash types. Comparable statistics are presented for all crashes in Table 2-2. The statistical variables presented are:

- Time-of-day (in five time blocks)
- Light condition
- Atmospheric condition
- Roadway surface condition
- Roadway alignment

- Roadway profile
- Speed limit (Note: for intersection or other crashes involving vehicles on two different roadways, the higher-classification roadway -- i.e., the larger roadway -- is coded).
- Relation to junction
- Alcohol involvement (any driver or pedestrian involved in the crash)
- Maximum severity (police-reported severity of most severely injured person).

Note that the statistics for LCM crashes include only the angle/sideswipe subtype.

A detailed discussion of statistical differences among the target crash types is beyond the scope of this report. However, a few notable comparative findings evident from the tables include the following:

Compared to other crash types, rear-end crashes are the most likely to occur during rush hours (morning and evening).

Compared to other crash types, backing crashes are the most likely to occur on low-speed roadways and are least likely to be severe in injury consequences. (However, recall the caveat that the present statistics generally do not include off-roadway crashes such as driveway backing crashes involving small children).

Backing crashes, followed by LCM crashes, are the least likely crash type to occur under adverse weather or roadway surface conditions.

SVRD crashes are the most likely crash type to occur at night, to occur on high-speed roadways, and to involve alcohol. Next to OD crashes, SVRD crashes are most likely to be fatal.

OD crashes are most likely to involve adverse weather/slippery road conditions. Compared to other crash types, OD crashes are the most likely crash to occur on curves. They are also most likely to be fatal. Next to SVRD crashes, OD crashes are the most likely to involve alcohol.

By definition, ICP crashes occur at intersections. Among the other crash types, backing crashes and rear-end crashes are the most likely crash types to occur at an intersection or be intersection-related.

Table 2-2. Crash Characteristics by Crash Types

Characteristics	Percent of Occurrence by Crash Type											
	All Crashes	Rear-End Crashes			Backing	ASLCM	SVRD	ICP Crashes				OD
		All RE	LVS	LVM				All ICP	SI/SCP	UI/SCP	LTAP	
Time-of-Day												
24:00 - 6:00	8.8%	3.5%	2.6%	4.9%	3.5%	5.7%	22.8%	3.5%	9.2%	2.6%	2.5%	6.6%
6:00 - 9:30	13.5%	14.3%	13.8%	15.3%	12.4%	13.4%	13.0%	13.4%	14.2%	13.6%	12.5%	14.5%
9:31 - 15:30	34.7%	38.7%	40.1%	36.5%	46.4%	41.0%	25.0%	40.2%	38.8%	41.4%	36.4%	32.3%
15:31 - 18:30	23.7%	28.6%	29.8%	26.6%	24.6%	23.3%	15.0%	26.1%	19.1%	27.0%	28.2%	24.5%
18:31 - 23:59	19.4%	14.9%	13.7%	16.8%	13.2%	16.6%	24.2%	16.8%	18.6%	15.4%	20.5%	22.1%
Light condition												
Daylight	68.5%	78.0%	80.1%	75.2%	81.9%	75.8%	50.0%	77.4%	72.4%	81.0%	73.3%	65.9%
Dark	11.4%	4.6%	3.4%	6.2%	3.6%	5.5%	23.6%	3.6%	3.4%	3.2%	3.9%	14.8%
Dark but Lighted	16.6%	14.1%	13.0%	15.7%	11.2%	15.5%	22.8%	16.0%	21.9%	12.2%	19.4%	14.1%
Dawn/Dusk	3.5%	3.3%	3.5%	2.9%	3.3%	3.2%	3.6%	3.1%	2.3%	3.6%	3.4%	5.2%
Atmosphere Condition												
No Adverse	81.0%	80.2%	80.0%	79.9%	91.0%	85.4%	75.3%	83.8%	83.5%	83.2%	85.3%	64.3%
Rain	13.8%	16.4%	16.8%	16.8%	6.9%	11.8%	15.0%	13.0%	13.8%	14.0%	11.8%	22.4%
Sleet/Snow/Fog/Otber	5.2%	3.4%	3.2%	3.3%	2.1%	2.8%	9.7%	3.2%	2.7%	2.8%	2.9%	133%
Roadway Surface Condition												
Dry	72.7%	72.9%	72.6%	72.6%	81.6%	79.7%	63.8%	76.2%	77.7%	73.8%	78.6%	49.5%
Wet	20.5%	23.4%	23.8%	23.7%	13.6%	17.9%	21.5%	20.2%	20.2%	20.8%	19.3%	31.2%
Snow/Ice/Sand/Other	6.8%	3.7%	3.6%	3.7%	4.8%	2.4%	14.7%	3.6%	2.1%	5.4%	2.1%	19.3%
Roadway Alignment												
Straight	89.5%	94.2%	94.4%	93.6%	96.6%	95.4%	75.0%	96.1%	98.8%	96.4%	97.1%	59.9%
Curve	10.5%	5.8%	5.6%	6.4%	3.4%	4.6%	25.0%	3.9%	1.2%	3.6%	2.9%	40.1%
Roadway Profile												
Level	74.6%	74.9%	75.2%	74.4%	80.0%	75.6%	68.0%	79.5%	81.0%	793%	78.9%	63.2%
Grade	23.1%	22.6%	22.1%	23.4%	18.7%	22.2%	29.6%	18.5%	16.9%	18.2%	19.1%	33.3%
Hillcrest	1.9%	2.2%	2.4%	1.9%	0.8%	2.3%	1.9%	1.8%	1.5%	2.3%	1.9%	3.0%
Other	0.3%	0.3%	0.4%	0.3%	0.5%	0.0%	0.6%	0.2%	0.6%	0.2%	0.1%	0.5%

Table 2-2. Crash Characteristics by Crash Types (Cont.)

Characteristics	Percent of Occurrence by Crash Type											
		Rear-End Crashes						ICP Crashes				
	All Crashes	All RE	LVS	LVM	Backing	AS LCM	SVRD	All ICP	SI/SCP	UI/SCP	LTAP	OD
Speed Limit												
20 mph and less	**2.0%**	**1.4%**	**1.1%**	**1.3%**	**6.4%**	**1.4%**	**2.1%**	**1.9%**	**0.9%**	**2.5%**	**1.3%**	**3.9%**
25 mph	**18.5%**	**12.1%**	**11.6%**	**10.7%**	**42.0%**	**12.0%**	**21.8%**	**20.0%**	**14.8%**	**32.5%**	**12.4%**	**19.4%**
30 mph	**11.2%**	**9.8%**	**10.3%**	**8.9%**	**14.4%**	**7.6%**	**9.0%**	**14.8%**	**16.8%**	**18.2%**	**12.2%**	**10.7%**
35 mph	22.3%	25.1%	27.0%	23.0%	19.7%	24.4%	14.8%	29.5%	38.4%	20.6%	32.0%	18.3%
40 mph	8.1%	10.8%	11.9%	9.3%	3.8%	9.3%	4.9%	10.2%	11.5%	4.6%	15.6%	6.6%
45 mph	12.5%	17.1%	18.9%	15.0%	4.1%	12.1%	9.3%	13.1%	11.5%	9.0%	17.7%	11.6%
SO mph	4.0%	5.8%	6.1%	5.4%	1.0%	5.6%	3.2%	3.2%	2.8%	2.8%	3.4%	2.9%
SS mph	19.1%	16.7%	12.5%	24.2%	8.3%	23.8%	30.2%	7.3%	3.3%	9.8%	5.5%	25.6%
60 mph and above	2.1%	1.2%	05%	2.2%	0.2%	3.8%	4.6%	0.0%	0.0%	0.0%	0.0%	1.0%
Relation to Junction												
Non Junction	**46.6%**	**46.8%**	**41.0%**	**56.9%**	**34.2%**	**71.9%**	**85.9%**					**81.2%**
Intersection/Intersection Related	**50.8%**	**49.0%**	**54.6%**	**38.8%**	**64.3%**	**22.6%**	**11.4%**	100.0%	100.0%	100.0%	100.0%	**17.5%**
Interchange Area	**1.7%**	**2.6%**	**2.6%**	**2.7%**	**0.8%**	**4.9%**	**1.9%**					**0.6%**
Other	**0.9%**	**1.6%**	**1.8%**	**1.6%**	**0.7%**	**0.6%**	**0.8%**					**0.7%**
Alcohol Involvement												
Yes, Alcohol Involved	6.4%	4.3%	3.8%	5.3%	3.3%	3.0%	15.2%	3.2%	4.7%	3.5%	2.8%	11.4%
No AIcohol Involved	93.6%	95.7%	96.2%	94.7%	96.7%	97.0%	84.8%	96.8%	95.3%	965%	97.2%	88.6%
Maximum Severity												
No Injury	66.7%	65.2%	63.8%	65.0%	87.9%	84.9%	66.2%	64.6%	51.0%	60.8%	56.2%	56.6%
Possible Injury	18.0%	25.9%	27.4%	25.2%	8.9%	10.2%	11.9%	19.8%	27.3%	20.7%	23.8%	15.4%
Non-Incapacitating	9.7%	5.9%	5.8%	6.5%	2.5%	3.3%	13.7%	10.0%	13.5%	12.0%	12.9%	13.9%
Incapacitating	5.1%	2.9%	2.9%	3.2%	0.8%	1.6%	7.5%	5.4%	8.0%	6.0%	6.9%	11.4%
Fatal	0.4%	0.1%	0.1%	0.1%	0.0%	0.1%	0.7%	0.2%	0.3%	0.4%	0.2%	2.8%

3. CRASH SUBTYPES AND CAUSAL FACTORS

A detailed analysis of individual cases of target crashes was conducted to identify crash subtypes and causal factors. The analysis approach adopted in this study entailed subjective assessment by an expert analyst, which involved content analysis of narrative statements and kinematic assessment to cross-check narratives. The analyst developed an impression of the crash subtypes or causal factors from the reviews. Error sources in this analysis process might include limited sample size, incomplete case files, and analyst decision processes that are subject to cognitive heuristics and biases in judgement. Despite these error sources, the detailed analysis of case files represented an invaluable aid to understanding the nature of crashes. In addition, this analysis opened up data sources (e.g., additional uncoded information in Police Accident Reports [PARs]) that were otherwise unavailable. Next, the case sample is described, followed by subtypes and causes of target crashes, and synthesis of causal factors.

3.1 CASE SAMPLE DESCRIPTION

A total of 1,183 cases were subjected to a detailed analysis, which were mostly selected from the 1991-1993 General Estimates System (GES) and Crashworthiness Data System (CDS) within the National Accident Sampling System (NASS). Table 3-1 provides the case sample size, source, and year selected for each target crash type. The case sample consisted of 257 GES PARs, 877 CDS case files, and 49 cases from the "old" NASS (i.e., before GES and CDS were established as separate systems). CDS cases were primarily selected for this analysis. GES PARs were picked to supplement the case sample if an insufficient number of CDS cases were available for a particular crash type. In case of

Table 3-l. Case Sample Characteristics

Crash Type	No. of Cases	Data Source	Year
Rear-End	77	CDS	1991
Backing	100 49	GES "old" NASS	1991-92 1986
Lane Change/Merge	144 16	GES CDS	1991 1992
SVRD	100	CDS	1991
SI/SCP	37 13	CDS GES	1992 1991
UI/SCP	100	CDS	1992
LTAP	184	CDS	1992
Opposite Direction	113	CDS	1993
Reduced Visibility	250	CDS	1993

backing crashes, a representative sample was selected from the 1986 “old!’ NASS because the CDS did not contain any backing crash cases at the time of this study. GES crash descriptions, while useful for national accident profiles, are highly coded and are limited to information provided on the PARs. On the other hand, CDS cases were used in this analysis which provide sufficient, detailed information to successfully determine crash subtypes and causal factors. The CDS investigates a nationally-representative sample of about 5,000 Police-Reported (PR) crashes annually, involving at least one towed passenger car, light truck, van, or utility vehicle. It should be noted that both CDS and GES have added new variables on pre-crash events beginning with the 1992 data collection year, including (1) attempted avoidance maneuver, (2) pre-event movement (prior to recognition of critical event), (3) critical pre-crash event, (4) pre-crash stability after avoidance maneuver, and (5) pre-crash directional consequences of avoidance maneuver.

Although the CDS was designed primarily for crashworthiness/occupant protection research, CDS files typically provide a rich body of data including:

- PARs;
- Driver statements;
- Witness statements;
- Scaled schematic diagrams depicting crash events and physical evidence generated during the crash sequence; and
- Case slides documenting vehicles, damage sustained, and other physical evidence.

A representative check performed subsequent to the detailed analysis of crash cases indicated that the crash and injury severity profile of the case sample was more severe than the GES profile. In order to correct for this bias and to characterize the results statistically, the CDS data were weighted based on the distribution of four crash severity levels in the GES for each crash type. The last row of Table 2-2 indicates the GES distribution of severity levels by crash type. Note that “incapacitating” and “fatal” severity levels were combined in the weighting scheme because of the small number of fatal crashes. All percentages cited in this report are severity-weighted.

Although severity-weighting of sample cases was necessary to correct for differential sampling of crashes of different severities in the original GES and CDS sampling, it resulted in analysis samples consisting of cases of unequal weights. One or two heavily-weighted cases could greatly affect the profile of crash causes for a given sample. For example, one heavily-weighted case in which the driver became ill represented a ***weighted*** percentage of nearly 10% of the 74 cases in the rear-end (RE) crash sample. Thus, although the case weighting scheme was necessary, it admittedly resulted in some anomalous findings.

3.2 TARGET CRASH SUBTYPES

The examination of individual cases identified a sample of 595 cases suitable for determining subtypes of target crashes, excluding backing (BK) and reduced visibility crashes. The case sample comprised 516 CDS files and 79 GES PARs. The subtypes of backing crashes were identified by a code search of the 1990 GES database. Table 3-2 identifies and

Table 3-2. Target Crash Subtypes (Percent of Target Crash Samples)

Type	Crash Subtypes	%
Rear-End 74 Cases	**Lead Vehicle Stationary:** POV decelerates to a stop and is then struck by SV.	74.8
	Lead Vehicle Moving: POV is decelerating and is struck before coming to a stop, or is traveling at a constant speed when struck.	25.2
Backing 1990 GES	**Parallel Path:** SV stops at an intersection, reverses direction and backs into a following vehicle, either stationary or very slow-moving.	24.0
	Curved Path: SV strikes a stationary vehicle or object while backing out of a parking space or private driveway along a curved travel path.	17.0
	Pedestrian/Pedalcyclist: SV hits pedestrian or pedalcyclist while backing on roadway or in off-roadway locations.	2.0
	Straight Crossing Path: SV backs out of a parking space or driveway onto a road and strikes or is struck by a crossing, fast-moving vehicle.	57.0
LCM 66 Cases	**Proximity:** There is little or no longitudinal gap and small speed differential between the SV and the POV. It may involve a POV location to the rear (*Forward Overlap*: 31.7%), middle (*Side-by-Side*: 26%), or front lateral area beside the SV (*Rearward Overlap*: 35%)	92.7
	Fast Approach: There is a longitudinal gap and a substantial velocity differential between the SV and POV prior to the start of the lane change maneuver. It may involve a POV that is fast approaching as the SV changes lanes (*Forward*: 4.6%) or an SV that is fast approaching and changes lanes (*Rearward*: 2.7%). A vehicle is struck on either the rear or the side.	7.3
SVRD 100 Cases	**Lane Keeping Failure:** SV driver failed to keep vehicle in lane and ran off the road unintentionally.	79.3
	Evasive Maneuver: SV driver steered off roadway in an evasive maneuver to avoid hitting another vehicle, animal, or pedestrian.	20.7
OD 98 Cases	**Lane Keeping Failure:** SV driver failed to keep vehicle in lane and encroached onto opposing lane unintentionally.	80.3
	Evasive Maneuver: SV driver steered onto opposing lane in an evasive maneuver to avoid hitting another vehicle, animal, or pedestrian.	18.6
	Passing: SV attempted to pass another vehicle and strikes POV in opposing lane.	1.1
SI/SCP 50 Cases	**Ran Red Light:** SV driver ran red light and strikes or is struck by POV.	100.0
UI/SCP 100 Cases	**Ran Stop Sign:** SV driver ran stop sign and strikes or is struck by POV.	42.3
	Proceeded against Cross Traffic: SV driver first stopped at the stop sign, then proceeded against cross traffic and strikes or is struck by POV.	57.6
LTAP 107 Cases	**Did Not Stop before Turn:** SV slows down, but does not stop, begins the left turn and strikes or is struck by oncoming POV.	71.5
	Stopped and then Turned: SV stops, then proceeds with the left turn, and strikes or is struck by POV.	28.5

defines the subtypes of each target crash type and lists their respective sample size and percent distributions. Note that the subject vehicle (SV) refers to the one that initiated the hazardous maneuver (e.g., changed lane) and collided with another vehicle, referred to as the principal other vehicle (POV). Of backing crashes, parallel path, curved path, and pedestrian/pedalcyclist crash subtypes are encompassed under one slow-closing-speed ***encroachment*** subtype. As indicated in Table 3-2, the encroachment crash subtype constitutes 43% of all backing crashes. Based on the detailed analysis of individual crash cases, the following observations are made:

- The majority of lane change/merge (LCM) crashes are ***proximity*** crashes that involve two vehicles traveling at almost similar velocities and small longitudinal gaps. Moreover, many proximity crashes involve POVs located outside the SV blind zone prior to the start of the lane change maneuver (i.e., side-by-side and rearward overlap proximity crash subtypes).

- About 67% of the ***lane keeping failure*** crash subtypes of single vehicle roadway departure (SVRD) occurred on curves. Conversely, 62% of the ***evasive maneuver*** crash subtypes occur on straight roads.

- Only 1.1% of opposite direction (OD) crashes were attributed to ***passing*** maneuvers. The remaining 98.9% of OD crashes resemble SVRD crash subtypes (i.e., lane keeping failure and evasive maneuver).

33 TARGET CRASH CAUSES

The causal factors of target crashes were determined by an in-depth review of 554 CDS files and 133 GES PARs, excluding reduced visibility crashes. Note that a larger sample of 927 crash cases was initially examined. However, a number of cases were discounted because they lacked sufficient information to identify a dominant cause. Some collisions were attributed to a combination of causes and contributing circumstances; but, one dominant cause was assigned based on the expert analyst's subjective assessment. Table 3-3 shows the distribution of causal factors for each target crash type. The causal factor distributions within each target crash subtypes were also determined [3-11]. Additional results of the causal factor analysis are revealed below.

- A combination of ***tailgating*** (following too closely) and driver ***inattention*** contributed to 19.4% of rear-end crashes. By subjective judgement, tailgating was noted as the primary cause.

- 2.2% of LCM crashes were due to ***excessive speed*** combined with ***bad roadway surface conditions.*** In these cases, excessive speed was judged to be the primary cause.

- 3.9% of SVRD crashes that were primarily caused by ***excessive speed*** involved ***drunk*** drivers.

Table 33. Target Crash Causes (Percent of Target Crash Samples)

Causal Factor	RE	BK	LCM	SVRD	OD	SI/SCP	UI/SCP	LTAP
Inattention	56.7	0.0	3.8	15.5	17.8	36.4	22.6	1.4
Looked-Did Not See	0.0	60.8	61.2	0.0	0.0	0.0	36.7	23.2
Obstructed Vision	0.0	0.0	0.0	0.0	0.0	4.3	14.3	24.4
Tailgating/ Unsafe Passing	26.5	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Misjudged Gap/Velocity	0.4	0.0	29.9	0.0	5.9	0.0	12.2	30.0
Excessive Speed	0.0	26.6	2.2	17.8	0.0	0.0	0.0	0.0
Tried to Beat Signal/POV	0.0	0.0	0.0	0.0	0.0	16.2	0.0	11.2
Failure to Control Vehicle	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Evasive Maneuver	0.0	0.0	2.6	13.7	18.6	0.0	0.0	0.0
Violation of Signal/Sign	0.0	0.0	0.0	0.0	0.0	23.2	3.4	7.4
Deliberate Unsafe Driving Act	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
Miscellaneous	1.1	0.1	0.0	0.0	1.0	5.9	0.0	1.7
Drunk	2.1	3.0	0.0	10.1	31.7	12.6	2.7	0.4
Asleep	0.0	1.9	0.0	11.8	0.0	0.0	0.0	0.0
Ill	9.6	0.0	0.0	3.5	1.1	0.0	0.0	0.0
Vehicle Defects	1.2	5.7	03	53	4.5	1.6	0.0	0.0
Bad Roadway Surface Conditions	2.3	0.0	0.0	20.2	18.3	0.0	7.0	0.0
Reduced Visibility/ Glare	0.1	0.0	0.0	0.0	0.0	0.0	1.1	0.1
Total %	100.0	100.0	100.0	100.1’	100.0	100.2’	100.0	99.8’
No. of Cases	74	74	46	100	98	50	91	154

* Rounding error

- The SV drifted out of its travel lane due to driver ***inattention*** and resulted in 3.8% of LCM crashes, 6.8% of SVRD crashes, and 17.8% of OD crashes.

- 13.7% of SVRD crashes were the result of an ***evasive maneuver*** by the SV to avoid crossing pedestrians or animals (5.8%), OD collisions with other vehicles in its travel path (6.5%), and LCM crashes initiated by other vehicles (1.4%).

- 7.0% of SVRD crashes caused by driver ***inattention*** resulted from an evasive action to avoid a rear-end crash with a lead vehicle.

- 11.8% of OD crashes were the result of an ***evasive maneuver*** by the SV to avoid a rear-end crash with a lead vehicle in its travel path.

- A driver's ***vision*** was obstructed by intervening vehicles in 0.8%, 10.3%, and 22.3% of signalized intersection, straight crossing path (SI/SCP), unsignalized intersection, straight crossing path (UI/SCP), and left turn across path (LTAP) crashes, respectively. In addition, roadway appurtenances obstructed the driver's vision in 3.5% and 0.8% of SI/SCP and UI/SCP crashes, respectively. Moreover, vision obstructed by road geometry caused 3.2% and 2.1% of UI/SCP and LTAP, respectively.

- SV drivers committed all the ***signal/sign violations*** in SI/SCP and UI/SCP crashes while, in contrast, POV drivers were cited for such violations in 7.1% of LTAP crashes compared to only 0.3% for SV drivers. Both SV and POV tried concurrently to beat the amber light at signalized intersections in 3.5% of LTAP crashes. Solely, SV and POV tried to beat the amber light in 1.7% and 2.8% of LTAP crashes, respectively.

- Finally, the OD crash sample included a number of cases listed under driver ***inattention*** that could not be specifically determined (distraction, daydreaming, or other). Thus, driver drowsiness might have been a factor.

To assess the direct impact of reduced visibility conditions on crashes, 250 CDS cases were selected for analysis based on accident time-of-day (between 21:00 and 06:00 hours) or adverse weather conditions (rain, snow, or fog) [11]. Of the 250 cases, 153 were'eliminated due to the lack of driver comments that might indicate an inability to see, insufficient time to respond, drowsiness, etc. A case was classified as ***possible*** if it occurred under night or adverse weather conditions and it did not involve driving under the influence of alcohol or drug, fatigue, or other extraneous factors. A case was classified as ***probable*** if, in addition to meeting the criteria for a ***possible*** case, the driver also stated an inability to observe, or had insufficient time to respond to, an object or event. The analysis yielded 17 cases as ***possible*** and 36 cases as ***probable.*** Of the reduced visibility ***probable*** cases, SVRD crashes were the largest category at 29.5%, followed by rear-end crashes at 18.4%.

3.4 SYNTHESIS OF CAUSAL FACTORS

The causal factors of target crash types are synthesized in five major categories employing the taxonomy shown in Figure 3-1. These categories include driving task errors, driver physiological impairment, vehicle defects, low-friction roadway surface, and reduced visibility. This particular classification will facilitate the development of Intelligent Transportation System (ITS) collision avoidance concepts, discussed in the following chapter. Table 3-4 shows the causal factor distribution across target crashes in terms of percentage of occurrence, weighted by the 1993 GES relative problem sizes shown in Table 2-1. According to GES estimates, target crash types addressed in this program (i.e., rear-end, backing, LCM, SVRD, SI/SCP, UI/SCP, LTAP, and OD crashes) accounted for about 71% of all 1993 crashes. Driver recognition errors were the leading cause of crashes investigated (44%), followed by driver decision errors (23%). These figures are supported by the following two previous studies.

The Indiana Tri-Level study has conducted an in-depth examination of 420 crash reports to identify causes in three major categories: human, vehicular, and environmental factors [17]. Collisions on freeways and crashes involving heavy trucks or motorcycles were excluded, as were most pedestrians and cyclists. Human error was implicated in 71% - 93% of the crashes. Of human direct causes, recognition and decision errors predominated. The results showed that recognition and decision errors ***definitely*** caused about 41.4% and 28.6% of all crashes, respectively.

Another study has analyzed 3,179 crashes drawn from the 1989 INRETS l/50 database, located in France, involving drivers and pedestrians [18]. A breakdown of essential driver safety needs was provided for all road users (i.e., drivers, cyclists, and pedestrians) involved in both urban and rural area crashes. It was determined that the timely detection of hazards was needed for 45.4% of road users. Also, estimation of distance and speed and prediction of other's intentions were needed for 23.6% of road users. However, no need was found for 19.7% of users.

Next, ITS collision avoidance concepts are devised based on crash subtypes and associated causal factors.

Table 3-4. Causal Factor Distribution of Target Crashes

Crash Type	Driving Task Errors			Driver Physiological State			Vehicle	Road	Atmosp.	Total
	Rec. Er.	Dec. Er.	Err.Ac.	Drunk	Asleep	ILL	Defects	Surface	Visib.	
RE	56.7	26.9	1.1	2.1	0.0	9.6	1.2	2.3	0.1	100.0
BK	60.8	26.6	2.0	3.0	1.9	0.0	5.7	0.0	0.0	100.0
LCM	65.0	32.1	2.6	0.0	0.0	0.0	0.3	0.0	0.0	100.0
SVRD	15.5	17.8	15.9	10.1	11.8	3.5	5.3	20.2	0.0	100.1^
OD	17.8	7.0	19.6	31.7	0.0	1.1	4.5	18.3	0.0	100.0
SI/SCP	40.7	16.2	29.1	12.6	0.0	0.0	1.6	0.0	0.0	100.2^
UI/SCP	73.6	12.2	3.4	2.7	0.0	0.0	0.0	7.0	1.1	100.0
LTAP	49.0	41.2	9.1	0.4	0.0	0.0	0.0	0.0	0.1	99.8^
%*	43.6	23.3	8.5	6.0	3.5	4.5	2.5	8.0	0.1	100.0

* Percentage of all target crashes (71% of 1993 GES)

^ Rounding error

- **Driving Task Errors** →
  - *Recognition Errors* →
    - Inattention
    - Looked - Did Not See
    - Obstructed Vision
      - Intervening Vehicles
      - Road Geometry
      - Road Appurtenances
  - *Decision Errors* →
    - Tailgating/Unsafe Passing
    - Misjudged Gap/Velocity
    - Excessive Speed
    - Tried to Beat Signal/Other Vehicle
  - *Erratic Actions* →
    - Failure to Control Vehicle
    - Evasive Maneuver
    - Violation of Signal/Sign
    - Deliberate Unsafe Driving Act
    - Miscellaneous
- **Driver Physiological Impairment** →
  - Drunk
  - Asleep
  - Ill
- **Vehicle Defects** →
  - Tires
  - Engine
  - Steering
  - Brakes
- **Low-Friction Road Surface** →
  - Wet
  - Snow
  - Ice
- **Reduced Visibility** →
  - Atmosphere
  - Glare

Figure 3-1. Causal Factor Taxonomy

4. ITS COLLISION AVOIDANCE CONCEPTS

Functional countermeasure concepts that address a particular target crash subtype may ideally be devised based on its dynamic situation and concomitant causes, contributing circumstances, and pre-crash time line of events. These concepts may provide mechanisms of intervention in three basic categories, as illustrated in Figure 4-1 [19]. The first category addresses ***advisory*** means which apply to potential collision situations; vehicle(s) not on a collision course, where urgent crash avoidance action is not necessary. The second category incorporates ***warning*** systems which apply to imminent collision situations; vehicle(s) on a collision course, where immediate driver action is needed. The third category provides ***automatic control intervention*** needed to avoid an imminent collision; vehicle(s) on a collision course, where driver intervention alone is not sufficient (e.g., automatic soft braking, emergency braking, and automatic steering). In addition, hybrid concepts may be suggested which employ concepts of the three previous categories and provide timely transitions among them.

In this study, the time line of pre-crash events in most cases was not established by the crash analyst due to a lack of details in the crash file. Consequently, various countermeasure concepts were developed and assigned to each of the three categories based on the target crash dynamic situation and associated causal factors. For instance, a driver advisory of a vehicle approaching the intersection would be applicable to an unsignalized intersection, straight crossing path (UI/SCP) crash (proceeded against cross traffic crash subtype) caused by subject vehicle (SV) drivers who were ***unaware*** of the approaching vehicle. However, this particular countermeasure concept would not help drivers who saw the other vehicle and ***misjudged its gap/velocity.*** A gap acceptance aid that warns the driver when it is unsafe to cross the intersection would most likely aid the latter drivers. In order to meet the time-intensity criteria of the three categories, these concepts need to be developed into crash avoidance systems that provide the driver with the appropriate reaction time and intensity of action needed.

Most crashes caused by driving task errors (i.e., driver recognition and decision errors and erratic actions) are amenable to countermeasures that depend on the specific crash scenario and relative dynamics. On the other hand, crashes caused by driver physiological impairment, vehicle defects, low-friction roadway surface, and reduced visibility may be alleviated by crash type-independent countermeasures which would intervene in the “normal driving” region at the left end of the spectrum of systems in Figure 4-1. For example, brake failure may contribute to multiple crash types and its countermeasure does not depend on a particular crash type etiology. This chapter defines Intelligent Transportation System (ITS) collision avoidance concepts which are either crash-scenario independent or crash-scenario specific. Also, the percent applicability of the various concepts to each crash type and to all target crashes is presented based on correlation between the weighted percentage of crash occurrence and causal factors. It is noteworthy that the percent applicability numbers should not be viewed as effectiveness estimates of these countermeasure concepts, but rather the percentages of crashes that might be targeted by such countermeasures. The evaluation of countermeasure technologies in actual driving situations may provide reasonable estimates of

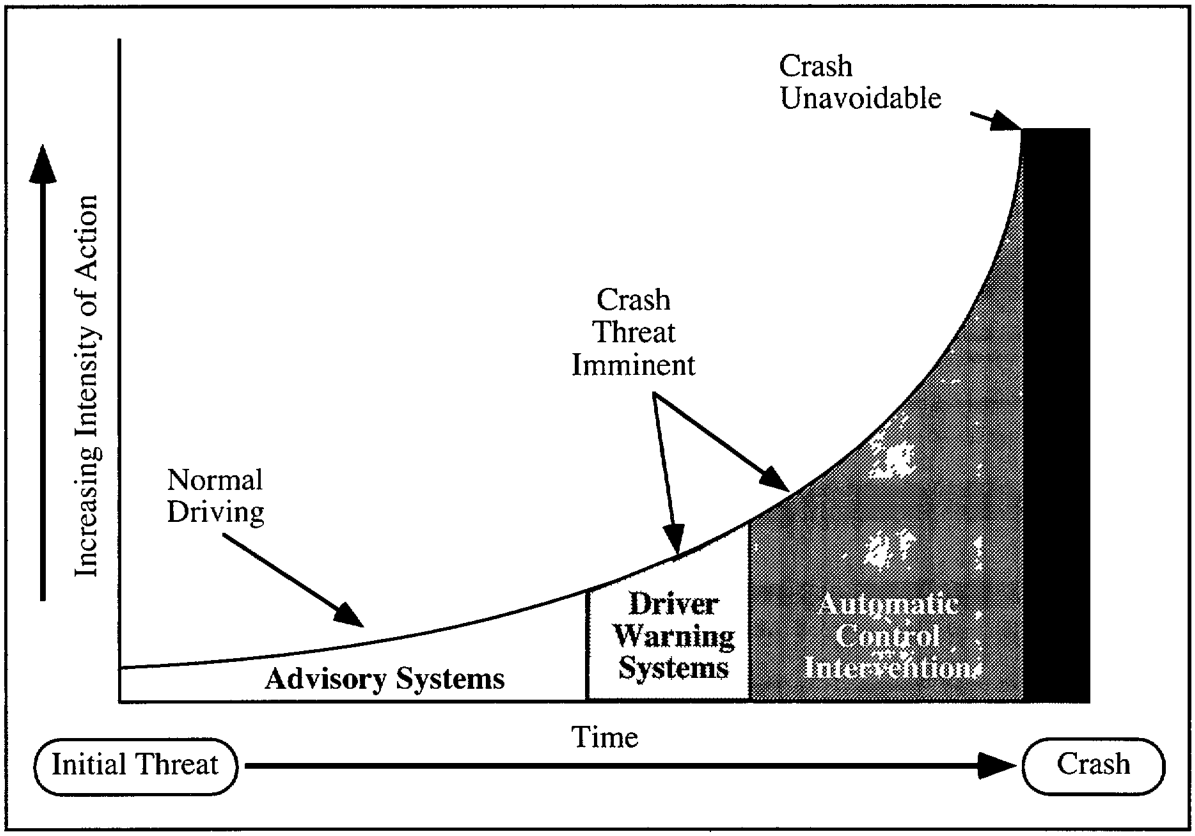

Figure 4-1. Crash Avoidance System Categories

their effectiveness, which is greatly influenced by the driving environment including the driver, vehicle, traffic, roadway, and atmosphere [20]. Next, crash-scenario-independent countermeasures are described, followed by crash-scenario-specific countermeasures and the synthesis of specific countermeasure concepts.

4.1 CRASH-SCENARIO-INDEPENDENT COUNTERMEASURE CONCEPTS

Crashes caused by driver physiological impairment, vehicle defects, low-friction roadway surface, and reduced visibility are addressed by ITS collision avoidance concepts independent of target crash dynamic situations. Five such concepts are defined below.

1. Driver Vigilance Monitor (DVM): advises drivers of physiological conditions (i.e., drowsiness and illness) that reduce their alertness and their ability to control the vehicle safely, before a hazardous event develops. Such a concept would address crashes caused by sleepy and ill drivers and by inattention/drift conditions.

2. Intoxicated Driver Monitor (IDM): prevents vehicle operation if drivers were under the influence of alcohol or drugs.

3. Component Status Monitor (CSM): advises drivers of impending failure of critical vehicle components, which may include brakes, tires, steering, and engine.

4. Pavement Condition Monitor (PCM): advises drivers of upcoming low-friction roadway surface due to precipitation effects (e.g., ice, snow, and water).

5. Vision Enhancement System (VES): presents drivers with a clear image of the environment ahead during reduced visibility conditions (e.g., night/inclement weather and glare).

Table 4-1 shows the percent applicability of ITS crash-scenario-independent countermeasures to each target crash type using causal factor distribution percentages in Table 3.3. These percentages indicate the potential applicability of the countermeasures based on both primary and secondary causes as discussed in Section 3.3. In addition, the last row of Table 4-1 indicates the percent of all target crashes that might be targeted by each of these countermeasures. The entries in the last row of Table 4-1 were determined by weighted averaging using the relative target crash sizes in Table 2-1 as weighting coefficients. From Table 4-1, about 29% of all target crashes might be targeted for crash-scenario-independent ITS countermeasure applications. Moreover, a DVM would be the most applicable countermeasure (~11%), followed by a PCM (~8%). Note that other crash countermeasures, such as anti-lock brakes, would also be applicable to some crashes caused primarily by low-friction roadway surface conditions.

In addition to the vision enhancement system concept defined above, the reduced visibility problem study identified two more candidate functional crash countermeasure concepts: in-vehicle warning and roadway information [11]. In-vehicle warning systems warn the driver in response to the detection of a possible roadway deviation or other crash hazard (i.e., ITS crash-scenario-specific countermeasures). Roadway information systems

Table 4-1. Percent Applicability of ITS Crash-Scenario-Independent Countermeasures

Crash Type	DVM	IDM	CSM	PCM	VES
% RE	9.6	2.1	1.2	2.3	0.1
% BK	1.9	3.0	5.7	0.0	0.0
% LCM	3.8	0.0	0.3	2.2	0.0
% SVRD	22.1	14.0	5.3	20.2	0.0
% OD	18.9	31.7	4.5	18.3	0.0
% SI/SCP	0.0	12.6	1.6	0.0	0.0
% UI/SCP	0.0	2.7	0.0	7.0	1.1
% LTAP	0.0	0.4	0.0	0.0	0.1
% Target Crashes*	**10.9**	**7.1**	**2.5**	**8.1**	**0.1**

* Target Crashes accounted for 71% of all crashes according to 1993 GES.

include in-vehicle display of traffic advisories (i.e., ITS crash-scenario-specific countermeasure), variable message roadside signs, and road shoulder rumble strips.

4.2 CRASH-SCENARIO-SPECIFIC COUNTERMEASURE CONCEPTS

ITS crash-scenario-specific collision avoidance concepts were devised to alleviate crash types or subtypes caused by driving task errors, as defined in Figure 3-1. These concepts were arranged in either driver advisory, driver warning, or control intervention categories based respectively on driver recognition errors, decision errors, or erratic actions. This arrangement might be appropriate for the system categorization illustrated in Figure 4-1 since the time line of events to avoid a road hazard starts with detection and recognition of a hazard, follows with decision-making for an appropriate control action, and ends with control action and vehicle response.

Table 4-2 defines these various countermeasure concepts for each crash type, within each of the three categories. It is assumed that driver recognition errors might be remedied by in-vehicle advisory systems which simply indicate the presence of potential hazards via proximal-traffic situation or traffic-control advisory displays. Driver warning concepts would incorporate a decision-making capability to compensate for driver decision errors and warn drivers of immediate hazardous situations. Erratic actions might be addressed by control intervention systems that would augment the capabilities of driver warning systems. For instance, crashes caused by unlawful drivers or attributed to unsafe driving acts or vehicle control failure might be mitigated by fully automatic control systems. On the other hand, some crashes might just be unavoidable due to misleading driver's intent, such as improper signalling cases by POV drivers in LTAP crashes.

4.2.1 Driver Advisory Systems

In-vehicle driver advisory systems present design challenges in order to be effective. They must inform the driver of crucial information at critical times, yet not be perceived as a nuisance or be an in-vehicle distraction.

Presence indicators would inform drivers of the presence of proximal vehicles in adjacent lanes or of vehicles/pedestrians/objects located in the rear, by means of a simple visual or auditory display. Such systems might continuously sense for proximal obstacles or be only activated by vehicle signals (e.g., turn or backing signals). Activation of a certain signal limits the system to cover a specific area for the time duration of signal activation. This scheme could reduce the risk of nuisance alarms by sensing only where a maneuver is to be initiated. In case of turn signals, signal-activated presence indicators might not be as effective since drivers do not always use turn signals when changing lanes. It is possible, however, that the availability of such ITS technologies would promote greater use of turn signals.

Situation displays are more sophisticated than presence indicators, which would render the driver's own vehicle as well as surrounding vehicles within a range. Such displays would, in principle, provide drivers with situation awareness information to guide judgements

Table 4-2. ITS Crash-Scenario-Specific Countermeasure Concepts

Crash Type	Driver Advisory	Driver Warning	Control Intervention
Rear-End	• Provide SV drivers with headway information to moving vehicles ahead via headway display.	• Warn SV drivers of imminent crash with lead vehicle cruising, stopping, or stopped by means of headway detection. • Lane change crash warning to POV drivers.	• Augment warning with soft, moderate, or hard braking w/o driver intervention. • POV automatic controls.
Backing	• Advise SV drivers of presence of cars/ objects/pedestrians behind the vehicle or of presence and approach direction of crossing vehicles.	• Warn SV drivers to stop when backing up if cars/objects/pedestrians are present behind the vehicle or if crossing vehicles pose a hazard.	• Augment warning with soft, moderate, or hard braking to stop w/o driver intervention.
LCM	• Advise SV drivers of presence of proximal vehicles in adjacent lanes via presence indicator, for proximity crash subtype. Detection coverage over the full length of SV may be needed, on both sides. • Provide SV drivers with situation awareness information via situation display, by showing both SV and surrounding vehicles within a range, for proximity and fast-approach crash subtypes.	• Warn SV drivers when it is unsafe to change lanes via overt/intrusive display. The warning could be directed to SV drivers to hold course or steer away and to SV and POV drivers to slow down, for proximity and fast-approach crash subtypes. • Warn SV drivers to reduce speed, if excessive. • Lane drift warning.	• Augment warning with soft, moderate, or hard braking to stop w/o driver intervention, for fast-approach crash subtype. • Augment warning with variable resistance steering or automatic steering w/o driver intervention, for proximity crash subtype.
SVRD	• Recommend to SV drivers a safe speed limit consistent with prevailing driving conditions. • Provide SV drivers with posted speed limit and curve ahead information.	• Warn SV drivers to reduce speed, if excessive. • Warn SV drivers to avoid rear-end crashes or to avoid crossing pedestrians/ animals via headway detection. • Warn SV drivers to keep vehicle within its lane boundaries. • Opposite-direction crash warning to POV drivers. • Lane change crash warning to POV drivers.	• Automatic speed control using brakes or throttle control. • Automatic soft, moderate, or hard braking to a stop to avoid stopped cars or pedestrians/animals. • Automatic lateral control to keep SVs within lane boundaries. • POV automatic controls. • Automatic headway control to keep SVs at safe distance with lead vehicle moving.

Table 4-2. ITS Crash-Scenario-Specific Countermeasure Concepts (Cont.)

Crash Type	Driver Advisory	Driver Warning	Control Intervention
OD	• Recommend to SV drivers a safe speed limit consistent with prevailing driving conditions.	• Warn SV drivers to reduce speed, if excessive. • Warn SV drivers to avoid rear-end crashes via headway detection. • Warn SV drivers to keep vehicle within its lane boundaries. • Warn SV drivers not to pass in hazardous driving situations due to oncoming vehicles or blind roads.	• Automatic speed control using brakes or throttle control. • Automatic soft, moderate, or hard braking to avoid rear-end crashes. • Automatic lateral control to keep SVs within lane boundaries. • Variable resistance steering to hold vehicle within lane to prevent unsafe passing.
SI/SCP	• Advise SV drivers of the presence. of a signalized intersection ahead and signal status.	• Graded warnings or constant warning times to prevent SV drivers from running the red light. System logic is tied to signal status and its time duration.	• Augment warning with soft, moderate, or hard braking to stop w/o driver intervention.
UI/SCP	• Advise SV drivers of the presence of intersection or stop sign ahead, for ran ***stop sign*** crash subtype. • Advise SV drivers of the presence and direction of vehicles approaching the intersection via situation display, for ***proceeded against cross traffic*** crash subtype.	• Graded warnings or constant warning times to SV drivers to stop at stop line, for ***ran stop sign*** crash subtype. • Warn SV drivers when it is unsafe to cross the intersection via gap acceptance aid, for ***proceeded against cross traffic*** crash subtype.	• Augment warning with soft, moderate, or hard braking to stop w/o driver intervention, for ***ran stop sign*** crash subtype. • Augment warning with automatic hard braking to hold SVs at stopped position, for ***proceeded against cross traffic*** crash subtype.
LTAP	• Advise SV drivers of the presence and direction of vehicles approaching the intersection via situation display.	• Warn SV drivers to brake or remain stopped when it is unsafe to turn left via gap acceptance aid. • Graded warnings or constant warning times to prevent SV and POV drivers from running the red light.	• Augment unsafe gap warning with soft or moderate braking w/o driver intervention when SV is moving and with hard braking when SV is stopped. • Augment warning with automatic braking to prevent SV and POV drivers from running the red light.

about when to and how to engage in various maneuvers. There are significant human factors issues associated with the design of such systems. These range from collecting and packaging key vehicle information to presenting it in a readily assimilated way. Situation displays must not impose undue workload on the driver, must be readily available to the driver and be easily checked prior to initiating new vehicle maneuvers.

Traffic control and road sign advisories would inform drivers of either posted or dynamic information provided by the traffic control infrastructure. For example, posted information may include a stop or curve ahead sign and dynamic information may contain light status at a signalized intersection or a variable speed limit. Posted sign advisories, in particular, must be effective at informing drivers with usually redundant information since drivers will be aware of upcoming roadside signs in most cases. In addition, these advisories should not be too intrusive because the advisory signals will be given frequently [5,9].

4.2.2 Driver Warning Systems

Driver warning systems would implement decision-making algorithms that imply some threshold conditions for alarm. The nuisance alarm issue becomes relevant to such systems, when an alarm is activated in situations that do not pose a true crash threat to the driver. Frequent nuisance alarms may prompt drivers to ignore system alarms or to defeat the system altogether. The apparent trade-off between nuisance alarm rate and crash avoidance performance is not well understood at present. Moreover, the tolerance of drivers to nuisance alarms is not known [3]. In any situation, nuisance and false alarm warnings will likely degrade crash avoidance system effectiveness. In addition, warnings will be ineffective if delivered too late to the driver. Warning thresholds are problematic to set and may require artificial intelligence methods to tailor warnings to individual types of drivers [8].

Warnings might produce several reactions in a driver, depending on circumstances. For example, a driver might react by steering or braking, or both, and might possibly do nothing. Driver warning systems might issue directive warnings so as to tell drivers how to react. In this case, warnings should not induce drivers to make maneuvers that prompt another crash with a third vehicle. As time-to-crash runs out, an ITS collision avoidance system might first offer nondirective alarms, followed by directive warnings if time is too short. Also, driver warning systems might incorporate a graded warning scheme with increased levels of intensity, depending on the time-to-crash and the intensity of action exhibited by the driver.

A single driver warning concept may address a number of crashes of different types which can result from a common pre-crash scenario. For instance, headway detection is devised to address primarily rear-end crashes. As indicated in Table 4-2, this collision avoidance concept may also apply to a number of SVRD and OD crashes which resulted from an initial avoidance maneuver to a potential rear-end crash scenario.

4.23 Control Intervention Systems

Control intervention systems, either partial or fully automatic, are an alternative or possibly a supplement to collision warning systems and would be activated beyond the point where driver warning alone is likely to be effective. Partial control intervention systems provide some vehicle deceleration or variable resistance to a heading change in the face of a crash hazard, provide additional cues to the driver for crash avoidance, and allow the driver to play a hand in the crash avoidance maneuver. Examples of such systems might be soft braking or variable resistance steering. Fully automatic control systems are applicable if the time available to avoid a crash dictates that driver time delays must be near zero. Concepts of these would involve full automatic braking, automatic steering, and perhaps automatic throttle control.

Automatic control intervention systems must be carefully designed to minimize or eliminate adverse secondary consequences on highway safety. Negative consequences might involve anything from precipitating a rear-end collision by abrupt hard braking to roadway departure due to a faulty automatic steering system. Control intervention systems will have to be extremely reliable and easily disengaged by the driver in the event of a false alarm. Driver acceptance of automatic controls is a major issue. In addition, the interaction of drivers with automatic vehicle control systems, such as the transition from driver control to automatic control and back to the driver, is poorly understood.

4.3 SYNTHESIS OF CRASH-SCENARIO-SPECIFIC COUNTERMEASURE CONCEPTS

This section defines five high-level, crash-scenario-specific collision avoidance concepts that integrate a number of functions specific to target crash types as defined in Table 4-2. These high-level concepts would first advise drivers to safety-critical driving situations, when feasible, and would later warn them if a preventive action were not taken. Control intervention functions are not included in these concepts but might be added to augment their crash avoidance capabilities. The definitions of the five high-level, crash-scenario-specific collision avoidance concepts are given below.

1. Headway Detection (HD): Such a system would provide drivers with advisory headway information about moving vehicles (i.e., traveling at a lower speed) ahead so as to keep a safe headway. In addition, such a system would warn drivers of an imminent collision with obstacles ahead in the vehicle's path. These obstacles might be lead vehicles either moving at a lower speed, stopping, or stopped; or crossing pedestrians/animals. This countermeasure concept would target SV drivers involved in some rear-end (caused by inattention, tailgating, and misjudged gap/velocity), fast-approach LCM subtype, OD (evasive maneuver to avoid a rear-end crash), and SVRD (evasive maneuver to avoid a rear-end crash and crossing pedestrians/animals) crashes. Moreover, POV drivers might also be targeted by such a countermeasure, especially those involved in the ***forward,*** fast-approach LCM crash subtype.

2. Proximity Detection (PD): Such a system would advise drivers of proximal vehicles in adjacent lanes or of other vehicles, pedestrians, or objects in the vehicle's path while backing up. The presence of obstacles would be indicated by presence indicators or situation displays. In addition, such a system would warn drivers when to stop while backing up or when it is unsafe to change lanes. This countermeasure concept would be applicable to SV drivers involved in many encroachment backing

(caused by looked-did not see and excessive speed) and proximity LCM (caused by inattention, looked-did not see, and misjudged gap/velocity) crashes. Moreover, few rear-end (POV cutting in SV's path) and SVRD crashes (evasive maneuver) might be targeted by such a countermeasure on-board the POVs.

3. Lane Position Monitor (LPM): Such a system would warn drivers if their vehicle was drifting out of its travel lane, so as to urge them to keep the vehicle within lane boundaries. This countermeasure concept would be applicable to some inattentive SV drivers whose vehicle drifted out of its travel lane and ended in LCM, SVRD, and OD crashes. Note that such a system might constitute a major component of the driver vigilance monitor as defined in Section 4.1.

4. In-Vehicle Signing (IVS): Such a system would convey to drivers static or dynamic information, usually provided by the traffic control infrastructure. Static information might include posted speed limit, upcoming curve information, intersection ahead, or stop signs. Dynamic information might contain variable speed limits, consistent with prevailing driving conditions, and signal status of signalized intersections. This countermeasure concept would advise drivers to the presence and content of safety-related roadside information. In addition, it would warn drivers either to stop in order to prevent running a stop sign or a red light, or to reduce speed to the recommended safe travel speed. Such a system would target a number of SV drivers involved in LCM, SVRD, OD, SI/SCP, UI/SCP, and LTAP crashes (caused by excessive speed, wet/icy pavement, inattention to/tried to beat sign/signal, and obstructed vision). Moreover, POV drivers might also be aided by such a system to prevent LTAP crashes caused by their running the red light.

5. Gap Acceptance Aid (GAA): Such a system would aid drivers to safely cross unsignalized intersections, turn left at intersections, or pass another vehicle in their path. It would advise drivers about the presence and direction of vehicles approaching the intersection. In addition, it would warn drivers when it is unsafe to cross or turn left at intersections, or to pass in hazardous situations. This countermeasure concept would target ***proceeded against cross traffic*** UI/SCP and most LTAP crashes (caused by looked-did not see, obstructed vision, and misjudged gap/velocity), and passing OD crashes.

Table 4-3 indicates the percent applicability of the five high-level concepts to each target crash type and to all target crashes. These values merely represent the relative population of target crashes that may be affected by the application and deployment of such systems. It is noteworthy that an overlap exists in the applicability of both types of countermeasures (i.e., percent applicability to target crashes in Tables 4-1 and 4-3 add up to over 100%) due to the definition of the DVM and to the consideration of primary and secondary (if identified) causes.

As seen in Table 4-3, a headway detection system would apply to approximately 35% of target crashes. An in-vehicle signing system would be the second most applicable countermeasure to about 18% of target crashes. Even though the lane position monitor would

only apply to about 3% of all target crashes, this particular system would be useful as a major component of driver vigilance monitoring systems and automated road vehicles.
Finally, the effectiveness of these five, high-level countermeasure concepts still needs to be determined.

Table 43. Percent Applicability of ITS Crash-Scenario-Specific, High-Level Countermeasures

Crash Type	HD	LPM	PD	IVS	GM
% RE	83.6	1.1	0.0	0.0	0.0
% BK	0.0	37.6	0.0	0.0	0.0
% LCM	7.3	88.0	3.8	2.2	0.0
% SVRD	12.8	1.4	6.8	38.0	0.0
% OD	11.8	0.0	17.8	18.3	1.1
% SI/SCP	0.0	0.0	0.0	56.9	0.0
% UI/SCP	0.0	0.0	0.0	28.9	56.6
% LTAP	0.0	0.0	0.0	8.0	82.3
% Target Crashes	34.6	6.7	2.9	17.7	12.0

^ Does not include possible applicability as a component in a DVM.
* Target Crashes accounted for 71% of all crashes according to 1993 GES.

5. KINEMATIC REPRESENTATION OF COUNTERMEASURE ACTIONS

Kinematic models were formulated to represent crash dynamic situations and effects of ITS countermeasure actions on crash avoidance. This modeling representation allows for estimation of crash avoidance requirements for the various crash subtypes identified in Table 3-2. Consequently, these models would be used, in part, to estimate the effectiveness of crash-scenario-specific ITS collision avoidance systems and to identify critical system functional requirements and data needs. As an example of crash avoidance requirements, the maximum available time (or distance) to enable the SV to avoid a collision with the POV was determined for different intensity levels of evasive actions. Note that the available time must accommodate both machine delays (i.e., ITS collision avoidance system and vehicle delays) and driver reaction times. For a certain machine delay, the available time can be used to estimate the proportion of drivers who might be able to respond within that time based on situation-specific driver reaction times. In addition, the available time can determine whether warning or control intervention systems may be required for successful evasive maneuvers, as illustrated in Figure 4-l. Note that negative values of available time indicate the case when a crash could not be avoided under any circumstances.

To avoid a crash, driver/collision avoidance system actions may include braking, steering, or holding course (maintaining the status quo). In some extreme cases, an acceleration action might prevent an incident, but these cases are rare and not considered in this study. In a braking maneuver, the brakes may be applied to either bring the vehicle to a complete stop or slow down to a speed more appropriate for the surrounding conditions. Steering maneuvers may be taken to either correct a deviation from the intended path or avoid a hazard in the roadway. In many situations, a crash may be avoided by simply continuing on the present course and not initiating a potentially hazardous maneuver. Next, kinematic models are discussed as applied to target crash subtypes in terms of braking, steering, and holding course actions, respectively.

5.1 BRAKING ACTIONS

Some crash scenarios can be evaded by braking actions to stop the vehicle or to slow down to a safe speed. This braking action may be initiated by either the SV or POV, depending on the crash situation. Braking to a stop was represented by kinematic equations that depend on the initial state of braking vehicle and on the type and state of the hazard. A common action across several crash subtypes is to stop to avoid a stationary obstacle or to stop at the stop line of an intersection, where the SV is initially traveling at constant speed. This crash avoidance action is applicable to (1) rear-end crash, lead vehicle stationary subtype; (2) UI/SCP crash, ran stop sign subtype; and (3) SVRD and opposite direction crashes, evasive maneuver subtype to avoid a rear-end crash with a stopped vehicle or crossing pedestrians/animals. This action is also applicable to SI/SCP crash and LTAP crash, did not stop before turn subtype under some conditions. In SI/SCP crashes, the avoidance maneuver of the SV is to stop if (1) the light status is red or (2) the time for the SV to clear the intersection is greater than the time remaining for the light to turn to red. In LTAP crashes, did not stop before turn subtype, the SV is to stop if (1) the time for the SV to slow down to turn is less than the time for the POV to clear the SV turning path or (2) the time for the SV to slow down to turn, to make the turn, and to clear the intersection is greater than the time for the POV to reach the SV turning path.

The maximum time delay available for driver and machine response, $t_{max\ available}$ (s), to avoid a crash is determined by:

$$t_{max\ available} = \frac{D_{Loc} - \left(\frac{V^2}{2a}\right)}{V}$$

where, D_{Loc} = Braking vehicle location from obstacle or stop line when countermeasure action is initiated, ft
V = Initial velocity of braking vehicle, ft/s
a = Deceleration level of braking vehicle, ft/s^2

Figure 5-1 illustrates the relationship between $t_{max\ available}$ and D_{Loc} for three levels of braking intensity and an initial speed of 35 mph. To determine the proportion of drivers who could brake as fast or faster than $t_{max\ available}$, subtract the machine time delay and look up the remaining value on a cumulative probability of a suitable, surprise brake reaction time. For example, Taoka models driver surprise braking reaction times as a log-normal distribution with a median of 1.07 s and a dispersion parameter of 0.49 s [21]. For a gap of 195 feet and a braking level of 16 ft/s^2, we find that $t_{max\ available}$ is 2.2 s. If the system delay is 0.2 seconds, then this leaves 2 seconds for the driver, accommodating about 90% of drivers. If the gap were only 145 feet and the other parameters were the same, there would only be 1 second left for the driver to react, which corresponds to about 45% of the population. In addition to SV

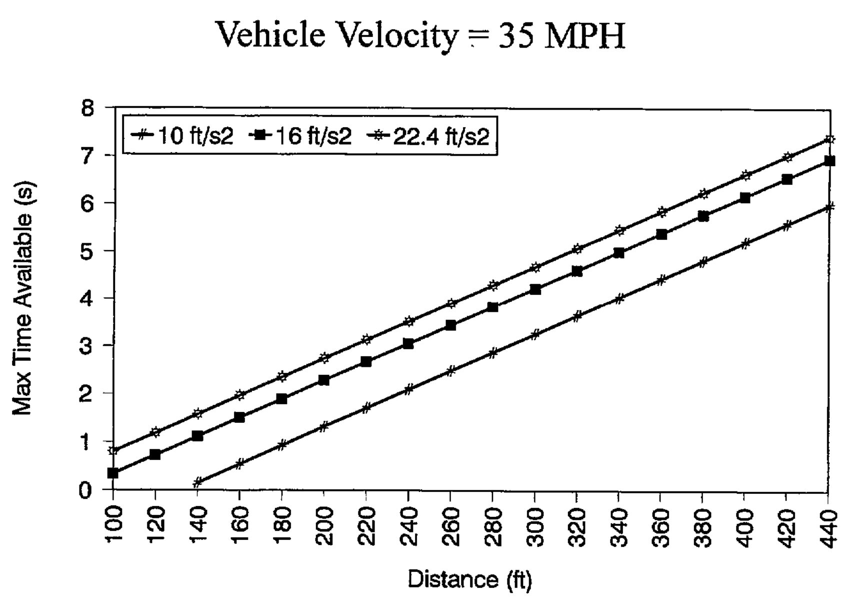

Figure 5-1. Time Available to Avoid a Stationary Hazard by Braking to a Stop

braking action, POV braking to a stop was also analyzed in this project, especially in intersection crashes, to assess the feasibility of a POV countermeasure action in case an approaching SV is not decelerating at certain levels as it should.

In the cases where there was a lead vehicle which was decelerating, rather than stopped, the analysis becomes more complex. Both the stopping characteristics of the subject vehicle, as shown above, and the deceleration of the lead vehicle must be accounted for. The maximum time delay available for driver and machine response is in this case determined by:

$$t_{\max\ available} = \frac{D_{gap} - \left(\frac{V_{FOL}^2}{2a_{FOL}}\right) + \left(\frac{V_{LEAD}^2}{2a_{LEAD}}\right)}{V_{FOL}}$$

where,
D_{gap} = Distance between vehicles when braking is initiated, ft
V_{FOL} = Initial velocity of following vehicle, ft/s
V_{LEAD} = Initial velocity of lead vehicle, ft/s
a_{FOL} = Acceleration of the following vehicle, ft/s^2
a_{LEAD} = Acceleration of the lead vehicle, ft/s^2

Another important variation to the braking equations applies in backing crashes, when the subject vehicle is accelerating, and continues to do so until braking is applied. The maximum available time is then given by:

$$t_{\max\ available} = \sqrt{\frac{2D_{Loc}}{a_{accel}} \times \frac{a_{brake}}{a_{brake} + a_{accel}}}$$

where,
D_{Loc} = Distance to obstacle, ft
a_{accel} = Acceleration from stop, ft/s^2
a_{decel} = Braking acceleration, ft/s^2

Finally, braking to a slower speed was suggested to avoid (1) rear-end crashes, lead vehicle moving (cruising) subtype, (2) SVRD and opposite-direction crashes, lane keeping failure subtype, especially those caused by excessive speed, and (3) LCM crashes, fast approach subtype (braking action is taken by the POV). For these cases, the equations take the form:

$$t_{\max\ available} = \frac{D_{Loc} - \left(\frac{1}{2a}\right)\left(V_{intial}^2 - V_{final}^2\right)}{V_{initial}}$$

where,
D_{Loc} = Distance at which new speed must be reached, ft
a = Braking level, ft/s^2

$V_{initial}$ = Velocity before countermeasure action is taken, ft/s
V_{final} = Final desired velocity, ft/s

5.2 STEERING ACTIONS

Crash avoidance maneuvers using steering actions were described either to avoid an obstacle or to correct a heading deviation error so as to maintain the vehicle in its travel lane. In lane change crashes, proximity subtype, a crash avoidance steering maneuver in the SV was suggested to avoid the POV in the adjacent lane after the SV initiated the lane change maneuver. Thus, a reverse steering action by the SV is required to end the normal lane change maneuver with a step input in steering away from the POV. As a first approximation, the normal lane change maneuver was modeled as a sine function of time for lateral acceleration. The crash avoidance steering action was described by a trapezoidal acceleration model with a maximum recovery acceleration value that the driver does not exceed. This acceleration, a, is defined as:

$$a = \begin{cases} a_0 - kt, & a < A_r \\ A_r, & \text{otherwise} \end{cases}$$

where, a_0 = lateral acceleration at the start of recovery maneuver, ft/s^2
k = rate of change in recovery acceleration buildup, ft/s^3
A_r = peak recovery acceleration, ft/s^2

Note that the lag between steering input and lateral acceleration is represented in k. As an example, Figure 5-2 indicates $t_{maxavailable}$ to enable the SV to avoid a collision with the

A_r = 0.4 g and k = 0.4 g/s

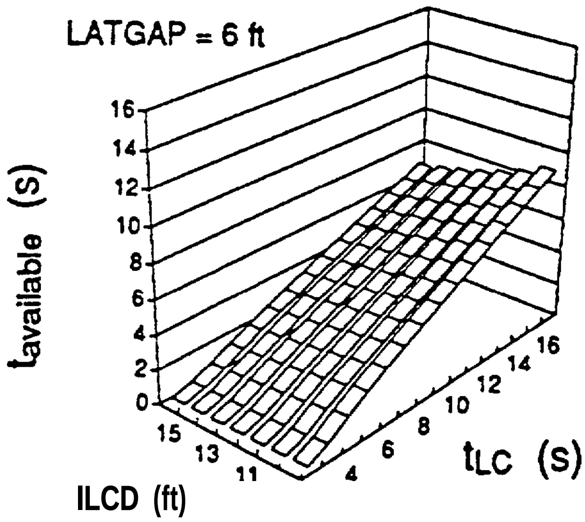

Figure 5-2. Time Available to Avoid a Proximity Lane Change Crash by Steering Action

POV by means of an evasive steering action. The graph shows $t_{max\ available}$ for every combination of the intended lane change distance (ILCD) between 9 ft and 15 ft, in 1 ft intervals, and the total time to complete the lane change (t_{LC}), ranging between 2 s and 16 s in 1 s interval. As with the braking actions, the success of a steering maneuver can be assessed by comparing the time to complete the lane change to the sum of the system delays and the driver reaction time. Malaterre, for example, found the reaction time for steering to avoid an unexpected hazard had a mean value of about 0.82 s with a standard deviation of 0.24 s [22]. The parameter, LATGAP, denotes the lateral gap between the SV and POV at the start of the lane change maneuver. The values of $t_{max\ available}$ were determined under two conditions: (1) SV lateral velocity= 0, and (2) total lateral distance traveled by the SV < LATGAP.

Steering action to correct a heading deviation error was the SV avoidance maneuver to many SVRD and opposite direction crashes, lane keeping failure subtype. The same corrective steering model as shown above was used, with an initial deviation angle assumed. Assessment of this model also required knowledge of the distance between the vehicle edge and the roadside hazard. Calculations were performed to determine the maximum speed at which a driver with quick reflexes who turned the wheel rapidly could return to the road before hitting a hazard. For a smaller departure angle, such as 5 degrees, with a relatively wide clear area on the side of the road, such as 12 feet, this highly capable driver could return to the road with a travel speed of 70 MPH. However, for a departure angle of 15 degrees with the same 12 feet, the maximum speed becomes only 24 MPH. And for a more typical driver, the speeds would be considerable lower. This illustrates how challenging it will be to return a vehicle safely to its lane in case of imminent roadway departure. In some SVRD crashes, the SV took an evasive maneuver to avoid a POV encroaching onto its travel lane from opposite direction. Thus, a steering action by the POV to stay in its travel lane was suggested.

5 3 **MOLDING COURSE**

Some crashes can be avoided by simply holding course and not attempting a hazardous maneuver (e.g., not changing lane if a collision threat exists with another vehicle in the adjacent lane). This action applies to (1) UI/SCP, proceeded against cross traffic subtype, (2) LTAP, stopped and then turned subtype, (3) LCM crashes, and (4) backing crashes. To avoid a crash, a Go/No Go decision needs to be made which depends on the time-gap between the SV and the POV. To illustrate, let’s consider an SV making a left turn from stop across the path of a POV. For any given POV speed, V_{POV}, there is a minimum distance of the POV from the SV turning path, D_{POV} , beyond which the SV can safely turn left and clear the intersection. If the POV is within this minimum distance, a NO GO decision should be made. Figure 5-3 illustrates such an example, given that it takes 4.25 s for the SV to turn left and clear the intersection from a stop.

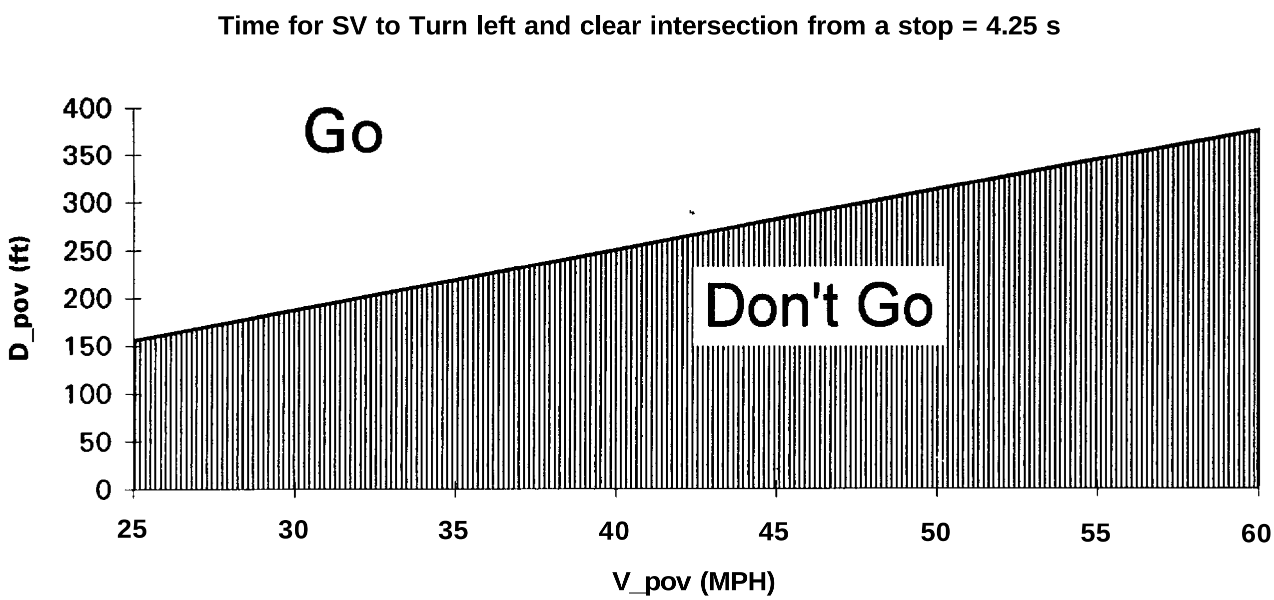

Figure 5-3. Envelope for Deciding to Turn Left at Intersections

6. SUMMARY OF MAJOR FINDINGS

This section summarizes the highlights, major findings, and conclusions of the three-year crash problem definition and analysis project. The reader is referred to the individual crash topic reports [3] - [16] for a complete description of the research and results.

6.1 CRASH PROBLEM SIZES

There were approximately 6 million crashes and 40,000 fatalities in 1993. The dominant target crash types are rear-end, single vehicle roadway departure (SVRD), and intersection/straight crossing path and left turn across path. These constitute about 61% of all crashes.

Other target crash types include lane change/merge, backing, and opposite direction. Although these are small percentagewise, they are still considered important because they are distinct collision types, they are amenable to ITS countermeasures, and they constitute a large number of crashes (about 200,000 per year, each).

In total, the target crashes comprise about 71% of all crashes. Crashes not covered include on-road rollovers, pedestrians and pedalcyclists (other than for backing), animals, motorcycles, other intersection crash types, non-lane change sideswipes, and non-intersection crossing paths.

6.2 CLINICAL ANALYSIS

It was found that the approach undertaken for this study, namely a clinical analysis (case-by-case) examination, was necessary in order to determine important crash subtypes, circumstances, the causes of the crashes, the crash mechanisms and crash parameters. The statistical databases such as the GES and the CDS simply do not contain enough information to allow researchers to reach meaningful conclusions on the nature of the crash scenario.

Information was evaluated against the physical evidence generated by the crash events in the context of the total crash environment based on police reports, driver statements, witness statements, schematics, scaled drawings, case slides and other physical evidence (i.e., skid marks). This added to the validity of the approach and findings. Our findings were consistent with other studies particularly with regard to major crash causes.

The studies were unique in their attempt to introduce crash scenario modeling in order to link major crash types and causes to potential ITS countermeasures and to provide an understanding of the interrelationships with crash scenario parameters. In certain cases, the modeling and linking led to estimates of potential effectiveness in terms of crashes that could be avoided. For other cases, specific data needs were identified that would allow these estimates to be made.

6.2.1 Crash Subtypes

The crash problem studies led to the identification of many crash subtypes that have major significance in defining crash scenarios and meaningful countermeasures. Some of the key crash subtypes are delineated below.

Rear-End: The dominant crash subtype (nearly 75% of rear-end crashes) was where the lead vehicle was stopped or coming to a stop. According to Table 2-2, about 55% of crashes of this subtype occurred at or close to intersections.

Backing: Most of the backing crashes (57%) occur where the subject vehicle backs out of a parking space or driveway onto a road and strikes or is struck by a crossing, fast moving vehicle. The kinematics of this crash subtype suggest that an autonomous, subject vehicle-based countermeasure would be inappropriate. About 2% of the backing crashes involve hitting a pedestrian or pedalcyclist. It should be noted that backing crashes occurring on private property (e.g., driveways and parking lots) are generally not police-reportable as traffic crashes and thus are not captured by these data. These private property crashes involve a significant number of serious injuries and fatalities - often involving young children.

Lane Change/Merge: Approximately 91% of lane change/merge crashes involve lane change maneuvers, as opposed to merge maneuvers. A surprisingly substantial amount (7%) of these crashes involve a fast approaching vehicle from the rear. Another surprising finding was the fact that a substantially large number (nearly one-third) of the lane change crashes involved a situation where the at-fault vehicle was changing lanes and hit another vehicle that was in front of it.

Single Vehicle Roadway Departure: About 21% of SVRD crashes involve evasive maneuvers to avoid another crash.

Opposite Direction: Very few opposite direction crashes involve a passing maneuver (1%). Most opposite direction crashes (78%) involve some form of lane keeping failure (i.e., the driver failed to keep the vehicle in lane and encroached onto opposing traffic unintentionally).

Intersection Crossing Path: Three different subtypes were examined: SI/SCP, UI/SCP, and LTAP. The crash mechanisms were sufficiently different to warrant this separation. For SI/SCP, all crashes involved the subject vehicle running the red light. For UI/SCP, there were two crash mechanisms: most crashes (57%) occurred after one vehicle stopped and then proceeded against the cross traffic; the other mechanism was where the subject vehicle ran the stop sign. For LTAP, a predominant number of crashes (about 72%) involved situations where the subject vehicle did not stop before turning.

Reduced Visibility: Although not strictly a crash type, reduced visibility may be considered a crash circumstance and is included since technologies are available to address this potential problem. By specifically addressing reduced visibility, the researchers were assured that this crash circumstance would not be omitted or overlooked in attempting to better understand the nature of all important crashes. In crashes that were considered probably or possibly caused by reduced visibility conditions, it was found that 62% of such cases did not involve an attempted avoidance maneuver: the driver either did not realize that a collision was impending or did not have enough time to respond once it was realized. One major category of reduced visibility crashes is vehicle departure from the roadway.

6.2.2 Causal Factors

In 89% of the target crashes, the primary causal factor was associated with the driver. The driver categories include driving task errors (i.e., recognition error, decision error and erratic actions) and driver physiological state. These findings were consistent with previous findings including the Indiana Tri-Level study [17] and the more recent French study [18]. Very few of the target crashes were associated with vehicle failures.

In terms of the causal factor distribution, recognition errors dominate for all crash types except SVRD and opposite direction, and even in these cases it is still an important factor. Decision errors play an important role for all crash types. Erratic actions showed up more for SVRD (evasive maneuver), opposite direction (evasive maneuver), SI/SCP and LTAP (failure to obey signal, improper signaling). Roadway factors showed up more for SVRD, opposite direction, and UI/SCP.

It is interesting to note that a number of common threads were found in certain pre-crash events and circumstances that eventually led to quite different crash types. For example, a driver inattentive to the driving situation when rapidly closing on a lead vehicle could lead to a rear-end, single vehicle roadway departure or an opposite direction crash depending on the type of last minute correction action (or lack of it) the driver might have undertaken. These findings indicate that a single countermeasure, such as a Headway Detection System, would be capable of preventing a number of different crash types.

6.3 ITS COUNTERMEASURES

Applicable countermeasures to the crash types, subtypes and causes were divided into two categories:

First, those that tended to align with particular crash types. These included a Headway Detection system for the subject vehicle in rear-end and SVRD crashes and the principal other vehicle in LCM-fast approach crashes; Gap Acceptance Aid system for the subject vehicle and principal other vehicle in ICP, lane change and OD (passing) crashes; Situation Display, providing information about surrounding and approaching vehicles for LCM, backing and some intersection crashes; In-Vehicle Signing for SVRD (roadside curve, speed) and ICP (stop ahead); and Lane Position Monitor for lane change, SVRD, and opposite direction.

The second category includes those crashes that are cross-cutting or independent of crash type: Vigilance Monitor for sleepy, ill, inattentive or drifting driver; Pavement Condition Monitor for wet, snowy or and icy roads; Vehicle Component Monitor for stalled engines, brake failure, steering failure or blowouts; and Vision Enhancement System for reduced visibility or glare.

For each of these countermeasures, the intensity of action required to prevent a collision in a particular situation will dictate the level of system needed (e.g., advisory, warning, semi-automatic control or full control). Additional studies are needed to determine the types and levels of systems that warrant implementation.

6.4 MODELING

Various models were introduced in the studies. These included kinematic, driver behavior, benefit estimation (Monte Carlo, Stochastic and Factorial), and reliability models. The kinematic models described point mass representations of the vehicle in various maneuvers. The driver behavior models described either how the driver would react in certain driving situations or how he/she would perform a certain function (e.g., lane change). Together, the kinematic and driver behavior models were useful for performing sensitivity analysis and examining the potential influence of parameters in crash and crash avoidance scenarios.

For certain crash types where sufficient data were available and assumptions were minimal, benefit estimation models were employed to determine the potential number of crashes that could have been avoided had an ITS countermeasure been present. The benefit estimation models were essentially statistical methods that allow the processing of large amounts of known or assumed data. The Monte Carlo method operated on complete data distributions. With the Factorial method, levels of one manipulated factor were systematically combined with all levels of another factor. With Stochastic modeling, a key crash parameter was varied to determine its effect on a variable of interest. Thus, the study was able to link the kinematic and driver behavior models, and the clinical analysis data with the benefit estimation models, for certain crash types, to produce a bottom line benefit estimate (i.e., the potential number of crashes that could be avoided). Furthermore, specific data needs were identified that would allow these methods to be expanded to other crash types.

Reliability models were also used in the study to introduce the concept of parallel or serial processing. With a driver in the loop responding to a crash avoidance system, the rate of successful outcomes depends on whether parallel or serial processing of the available information (i.e., warning signal from the collision avoidance system and environmental cues) is being employed. An analysis of a crash avoidance scenario showed the dramatic difference in results depending on whether serial or parallel processing was involved.

6.5 RESEARCH AND DATA NEEDS

Many research needs have been identified throughout the course of the current study. For each target crash topic, specific needs have been documented in the available reports. Some of the more important research and data needs are repeated here.

Human Factors: Perhaps the most important needs are those associated with the driver. These include determining driver acceptance of and response to various yet specific collision avoidance systems. There is a need to determine the extent to which risk compensation is present and will affect the outcome. There is also a need to determine how false or nuisance alarms will impact system effectiveness.

Crash/Crash Avoidance Scenario Data: Although much has been gleaned from available databases on crash circumstances, characteristics and causal factors, there is still a need for additional data related to both crash scenarios and normal driving. These data would be particularly useful for developing crash avoidance models and estimating the potential impact of countermeasures. The data needed include the relative positions and motions of vehicles and fixed objects under a variety of driving conditions, circumstances and situations. Furthermore, data on the joint distribution of key variables, such as headways and closing speeds of two vehicles traveling in close proximity on a high speed roadway, are also needed to enhance the modeling effort and predicted results. Finally, data are needed on the characteristics, performance, capabilities and limitations of existing and prototype technologies in order to study and promote promising, yet realistic countermeasures.

6.6 CONCLUSIONS AND NEXT STEPS

The results of the current study provided an in-depth and clear description of the relative magnitude of the vehicular crash problem, the contributing factors associated with various crash types, as well as the important issues associated with databases, modeling of the crash/crash avoidance scenario, and implementing effective countermeasures.

The purpose of this study was to help guide R&D on advanced-technology countermeasures. Specifically, this study (1) helped prioritize NHTSA's R&D program in this area, and (2) defined the problems for system designers and contractors to NHTSA's sponsored research to develop performance guidelines for advanced collision avoidance systems. NHTSA is taking a pro-active stance and working with industry to foster the development and deployment of crash avoidance technologies. Currently, NHTSA has several research efforts underway to establish functional and performance requirements of promising crash avoidance systems for LCM and backing crashes, rear-end crashes, SVRD crashes, and intersection crashes. Research activities are also underway to test, evaluate, and develop performance specifications for driver vision enhancement systems and drowsy driver detection/warning systems.

The next steps, as the performance specifications are being developed, will generate engineering data to better understand normal driving, the events that lead up to a crash, and the capabilities of potential countermeasures. To assist in these areas, data will be gathered from NHTSA's Vehicle Motion Environment Project, Pre-Crash Test Variables from the NASS databases, and the actual testing of available and prototype countermeasures with instrumentation support from NHTSA's DASCAR Project [2].

REFERENCES

[1] National Highway Traffic Safety Administration. ***NHTSA IVHS Plan.*** DOT HS 807 850, July 1992.

[2] Leasure, W.A., Jr., ***The NHTSA Collision Avoidance Program.*** Workshop on Collision Avoidance Systems, S&HF Committee, ITS America, March 1994.

[3] Knipling, R.R., Mironer, M., Hendricks, D.L., Tijerina, L., Everson, J., Allen, J.C., and C. Wilson. ***Assessment of IVHS Countermeasures for Collision Avoidance: Rear-End Crashes.*** DOT HS 807 995, May 1993.

[4] Tijerina, L., Hendricks, D.L., Pierowicz, J., Everson, J.H., and ***S.*** Kiger. ***Examination of Backing Crashes and Potential IVHS Countermeasures.*** DOT HS 808 016, August 1993.

[5] Chovan, J.D., Tijerina, L., Alexander, G., and D.L. Hendricks. ***Examination of Lane Change Crashes and Potential IVHS Countermeasures.*** DOT HS 808 071, March 1994.

[6] Mironer, M. and D.L. Hendricks. ***Examination of Single Vehicle Roadway Departure Crashes and Potential IVHS Countermeasures.*** DOT HS 808 144, August 1994.

[7] Chovan, J.D., Everson, J.H., Hendricks, D.L., and J. Pierowicz. ***Analysis of Opposite Direction Crashes.*** OMNI Task RA1039, Contr. No. DTRS-57-89-D-00086, USDoT, Volpe Center, June 1994.

[8] Tijerina, L., Chovan, J.D., Pierowicz, J., and D.L. Hendricks. ***Examination of Signalized Intersection, Straight Crossing Path Crashes and Potential IVHS Countermeasures.*** DOT HS 808 143, August 1994.

[9] Chovan, J.D., Tijerina, L, Pierowicz, J., and D.L. Hendricks. ***Examination of Unsignalized Intersection, Straight Crossing Path Crashes and Potential IVHS Countermeasures.*** DOT HS 808 152, August 1994.

[10] Chovan, J.D., Tijerina, L, Everson, J.H., Pierowicz, J., and D.L. Hendricks. ***Examination of Intersection, Left Turn Across Path Crashes and Potential IVHS Countermeasures.*** DOT HS 808 154, September 1994.

[1l] Tijerina, L., Browning, N., Mangold, S.J., Madigan, E.F., and J.A. Pierowicz. ***Analysis of Reduced Visibility Crashes.*** DOT HS 808 201, January 1995.

[12] Knipling, R.R., Wang, J.S., and H.M. Yin. ***Rear-End Crashes: Problem Size Assessment and Statistical Description.*** DOT HS 807 994, May 1993.

[13] Wang, J.S. and R.R. Knipling. ***Backing Crashes: Problem Size Assessment and Statistical Description.*** DOT HS 808 074, January 1994.

[14] Wang, J.S. and R.R. Knipling. ***Lane Change/Merge Crashes: Problem Size Assessment and Statistical Description.*** DOT HS 808 075, January 1994.

[15] Wang, J.S. and R.R. Knipling. ***Single Vehicle Roadway Departure Crashes: Problem Size Assessment and Statistical Description.*** DOT HS 808 113, March 1994.

[16] Wang, J.S. and R.R. Knipling. ***Intersection Crossing Path Crashes: Problem Size Assessment and Statistical Description.*** DOT HS 808 190, August 1994.

[17] Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R.L., and N.J. Castellan. ***Tri-Level Study of the Causes of Traffic Accidents - Executive Summary.*** DOT HS 805 099, May 1979.

[18] Malaterre, G. and H. Fontaine. ***An a Priori Evaluation of Electronic Driving Aids Using Accident Reports.*** PTRC 19th Ann. Mtg., England, September 1991.

[19] Burgett, A.L., ***Methodologies for Evaluating the Impact on Safety of Intelligent Vehicle Highway Systems.*** 14th Int. Tech. Conf. on Enhanced Safety of Vehicles, No. 94 S3 0 12, Munich, May 1994.

[20] Ervin, R.D., ***Evaluating Active Safety Technology for the Motor Vehicle.*** Workshop on Collision Avoidance Systems, S&HF Committee, ITS America, March 1994.

[21] Taoka, G.T., ***Brake Reaction Times of Unalerted Drivers.*** ITE Journal, March 1989.

[22] Malaterre, G. and D. Lechner. ***Emergency Maneuvers at Junctions Using a Driving Simulator.*** Transportation and Traffic Theory, pp. 213-232, 1990.

APPENDIX A. DATA SPECIFICATIONS

This appendix provides detailed data specifications of the target crash types and subtypes per the GES data files (Note: The reader is referred to the 1993 GES User's Manual for definition and explanation of the following data variables.)

A.1 Rear-End Crash Types/Subtypes

The rear-end crash data retrieval specification for the 1993 GES is provided below; see the GES User's Manual for a detailed description of variables. All rear-end crashes were defined as:

Imputed Manner of Collision (A071, MANCOL_I) = 1 (Rear-End)

Relation to Roadway (Al0, REL_RWY) = 1 (On-Roadway).

Two major subtypes of rear-end crashes were defined as follows:

1. **Rear-end, lead-vehicle stationary (LVS) Crashes**

Imputed Manner of Collision (A071, MANCOL_I) = 1 (Rear-End)

Relation to Roadway (Al0, REL_RWY) = 1 (On-Roadway)

Accident type (V23) of striking vehicle (vehicle with Imputed Vehicle Role = 1 [Striking]) = 20 (Lead Vehicle Stopped).

2. **Rear-end. lead-vehicle moving (LVM) crashes**

Imputed Manner of Collision (A071, MANCOL_I) = 1 (Rear-End)

Relation to Roadway (Al0, REL_RWY) = 1 (On-Roadway)

Accident type (V23) of striking vehicle (vehicle with Imputed Vehicle Role = 1 [Striking]) = 24, 28 (Lead Vehicle Moved).

A.2 Backing Crash Types/Subtypes

Backing crash types/subtypes were defined as follows in GES:

1. **Encroachment Backing Crashes**

Pedestrian/pedalcyclist

Crashes involving vehicle with Accident Type (V23, ACC_TYPE) 92 with criteria:

Imputed Vehicle Role (V22I, VROLEI) = 01 (Striking)

Hotdeck Imputed Vehicle Most Harmful Event (V20I, V_EVNT_H)
= 21 (Pedestrian)
= 22 (Pedalcyclist)

Parallel path, vehicle

Crashes involving Accident Type 92 and 93, where the vehicle with Accident Type 92 meets the following criteria:

Imputed Vehicle Role (V22I, VROLE_I) = 01 (Striking)

and, for the vehicle with Accident Type 93:

Vehicle Speed (V11, SPEED) $\leq$ 05 (Stopped or Slowly Moving)

Hotdeck Imputed Initial Point of Impact (V24I, IMPACT_H)
= 0 (No Damage)
= 1 (Front)

Curved path, stationary vehicle or object

Backing into stationary vehicle; crashes involving Accident Type 92 and 93, where vehicle with the Accident Type 92 meets the following criteria:

Imputed Vehicle Role (V22I, VROLE_I) = 01 (Striking)

and, for the struck vehicle with Accident Type 93:

Vehicle Speed (V11, SPEED) = 00 (Stopped)

Hotdeck Imputed Initial Point of Impact (V24I, IMPACT_H)
= 2 (Rightside)
= 3 (Leftside)
= 4 (Back)
= 7 (Comer)

Or: backing into fixed objects; crashes involving vehicles with Accident Type 92 meeting the following criteria:

Hotdeck Imputed Vehicle Most Harmful Event (V20I, V_EVNT_H)
= 31 - 49 (Collision with Fixed Object)

Imputed Vehicle Role (V22I, VROLE_I) = 01 (Striking)

2. Crossing Path Backing Crashes

Backing vehicle strikes front of a moving vehicle; i.e., crashes involving Accident Types 92 and 93 where the vehicle with Accident Type 92 meets the following criteria:

Imputed Vehicle Role (V22I, VROLE_I) = 01 (Striking)

and, for the vehicle with Accident Type 93:

Hotdeck Imputed Initial Point of Impact (V24I, IMPACT_H)
= 0 (No Damage)
= 1 (Front)

Vehicle Speed (Vll, SPEED) $\geq$ 06 (Moving; Includes Unknowns)

Or: backing vehicle strikes other part of moving vehicle; i.e., crashes involving Accident Types 92 and 93, where the vehicle with Accident Type 92 meets the following criteria:

Imputed Vehicle Role (V22I, VROLEI) = 01 (Striking)

and, for the vehicle with Accident Type 93:

Hotdeck Imputed Initial Point of Impact (V24I, IMPACT_H)
= 2 (Rightside)
= 3 (Leftside)
= 4 (Back), or
= 7 (Corner)

Vehicle Speed (Vll, SPEED) $\geq$ 01 (Moving; Includes Unknowns)

Or: backing vehicle is struck by moving vehicle; crashes involving Accident Types 92 and 93 where the vehicle with Accident Type 92 meets the following criteria:

Imputed Vehicle Role (V22I, VROLE_I)
= 02 (Struck)
= 03 (Both Striking and Struck)

and, for the vehicle with Accident Type 93:

Vehicle Speed (Vll, SPEED) $\geq$ 01 (Moving; Includes Unknowns)

A 3 Lane Change/Merge (LCM) Crash Types/Subtypes

1. Angle/sideswipe LCM crashes

Imputed Vehicle Maneuver (V21I, MANEUV_I)	=	14 (Changing Lanes or Merging)
Imputed Vehicle Role (V22I, VROLE_I)	=	1 (Striking) **2** (Struck) 3 (Both Striking and Struck)
Involved Vehicles per Crash (A3, VEH_INVL)	≥	2 (2 or More Vehicles per Crash)
Imputed Manner of Collision (A7I, MANCOL_I)	=	4 (Angle) 5 (Sideswipe, Same Direction)

2. Rear-end LCM crashes

Imputed Vehicle Maneuver (V21I, MANEUV_I)	=	14 (Changing Lanes or Merging)
Imputed Vehicle Role (V22I, VROLEI)	=	2 (Struck)
Involved Vehicles per Crash (A3, VEH_INVL)	≥	2 (2 or More Vehicles per Crash)
Imputed Manner of Collision (A7I, MANCOL_I)	=	1 (Rear-End)

A.4 Single Vehicle Roadway Departure (SVRD) Crashes

Number of Vehicles (A3, VEH_INVL)	=	1
Accident Type (V23, ACC_TYPE)	=	01 - 05 (Right Roadway Departure) 06 - 10 (Left Roadway Departure) 11 - 12, 14 - 16 (Forward Impact)
Relation to Roadway (Al0, REL_RWY)	=	2 (On Shoulder/Parking Lane) 3 (Off The Roadway/Shoulder/Parking Lane) 4 (On The Median)

A.5 Intersection Crossing Path (ICP) Crash Types/Subtypes

The ICP crash data retrieval specification for the 1993 GES is provided below; see the GES User's Manual for a detailed description of variables. All ICP crashes were defined as:

Vehicle Accident Type **(V23,** VEH_TYPE)	=	68/69 (Turn Across Path, Initial Opposite Direction) 70/71 (Turn Across Path to Right, Initial Same Direction) 72/73 (Turn Across Path to Left, Initial Same Direction) 76/77 (Turn Left into Same Direction) 78/79 (Turn Right into Same Direction) 80/81 (Turn Right Into Opposite Direction) 82/83 (Turn Left Into Opposite Direction) 86/87 (Straight Path, Striking Vehicle From 90^{o} Right) 88/89 (Straight Path, Striking Vehicle From 90^{o} Left) 90/91 (Straight Path, Vehicle Maneuver Unknown)
Imputed Relation to Junction (A9I, RELJCT_I)	=	1 (intersection) 2 (intersection-related) 4 (driveway/alley).

Three major ICP subtypes were defined as follows:

1. <u>Signalized Intersection Straight Crossing Path (SI/SCP) Crashes</u>

Vehicle Accident Type (V23, VEH_TYPE)	=	86/87 (Straight Path, Striking Vehicle From 90^{o} Right) 88/89 (Straight Path, Striking Vehicle From 90^{o} Left)
Imputed Relation to Junction (A9I, RELJCT_I)	=	1 (intersection) 2 (intersection-related) 4 (driveway/alley).
Imputed Traffic Control Device (V16I, TRFCON_I)	=	01 (Traffic Control Signal-on colors) 04 (Flashing Traffic Control Signal or Flashing Beacon) 08 (Other Traffic Signal) 09 (Unknown Traffic Signal)

2. <u>Unsignalized Intersection Straight Crossing Path (UI/SCP) Crashes</u>

Vehicle Accident Type (V23, VEH-TYPE)	=	86/87 (Straight Path, Striking Vehicle From 90^{o} Right) 88/89 (Straight Path, Striking Vehicle From 90^{o} Left)

Imputed Relation to Junction (A9I, RELJCT_I)	=	1 (intersection) 2 (intersection-related) 4 (driveway/alley).
Imputed Traffic Control Device (V16I, TRFCON_I)	≠	01 (Traffic Control Signal-on colors) 04 (Flashing Traffic Control Signal or Flashing Beacon) 08 (Other Traffic Signal) 09 (Unknown Traffic Signal) 61 (Active Devices at Railroad Crossing) 62 (Passive Devices at Railroad Crossing) 97 (Traffic Device - No Detail) 98 (Other Traffic Device)

3. Intersection Left Turn Across Path (LTAP) Crashes

Vehicle Accident Type (V23, VEH_TYPE)	=	68/69 (Turn Across Path, Initial Opposite Direction)
Imputed Relation to Junction (A9I, RELJCT_I)	=	1 (intersection) 2 (intersection-related) 4 (driveway/alley).

A.6 Opposite Direction Crashes (ODC)

Manner of Collision (A7I, MANCOL_I)	=	2 (Head-On) 4 (Angle) 6 (Sideswipe, Opposite Direction)
Number of Vehicles Involved (A3, VEH_INVL)	≥	1
Accident Type (V23, ACC_TYPE)	=	50 - 67 (Same Trafficway, Opposite Direction)