Examination of Backing Crashes and Potential IVHS Countermeasures

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**National Highway
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Administration**

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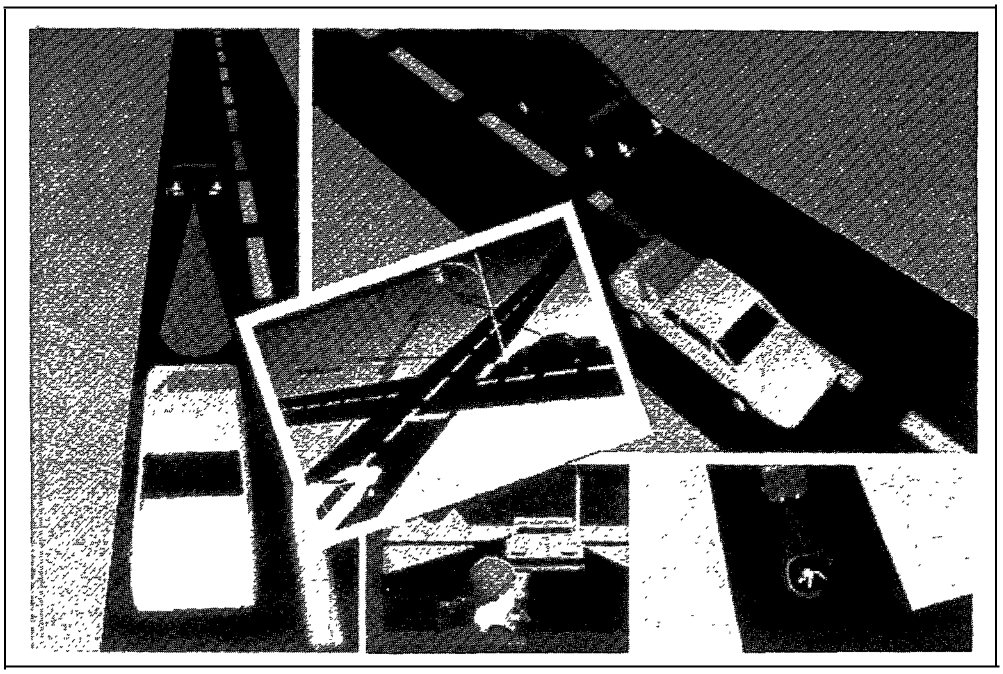

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This report examines the potential for Intelligent Vehicle Highway System (IVHS) technology to inprove the crash avoidance capability of drivers and vehicles for backing crashes. IVHS has the potential to greatly enhance highway traffic safety. This report attempts to determine the safety impications of IVHS by using analytical methods to model the backing crash type and potential IVHS crash avoidance countermeasures.

The causal assessments show that approximately 87.0 percent of the cases occurred because drivers were unaware of (did not see or did not check for the struck vehicle, object, or pedestrian. Of the causal factors which appear to be amenable to IVHS countermeasures in the near term, the main causal factor appeared to be that the backing vehicle's driver was unaware of an obstacle. This suggested that a vehicle-based IVHS countermeasure that warns drivers of obstacles in the backing path might be helpful. The suggested countermeasure was a rear-zone object detection system.

It is estimated that the functional rear-zone object detection system would be approximately 70 percent effective in avoiding the parallel path, curved path, and pedestrian/pedalcyclist crash subtypes. In terms of all backing crash subtypes, the system would be approximately 28 percent effective.

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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 (VNTSC), has underway a multi-disciplinary program to: identify crash causal factors and applicable countermeasure concepts, model target crash scenarios and Intelligent Vehicle Highway System (IVHS) technological interventions, provide preliminary device effectiveness estimates, and identify countermeasure research data needs.

Under this program major target crash types will be examined including the following:

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

This paper presents the results of the backing crash study. The results are based upon a detailed analysis of 100 1991 and 1992 General Estimates System (GES) police accident reports (PARS) and 49 case reports from the 1986 NASS data file. All percentages were weighted to reflect GES data in terms of accident severity since these data are assumed to be representative of the national population.

The authors of this report were: Louis Tijerina, Battelle; Donald Hendricks, CALSPAN; John Pierowicz, CALSPAN; Jeff Everson, Battelle; and Steve Kiger, R&R Research.

Other contributors included Terri Faciane (Castle Rock Consultants), Milton Seiler (Battelle), and John Chovan (Battelle). Joseph Koziol, Tony Passera, Wassim Najim, and Mark Mironer of the Volpe National Transportation Systems Center (VNTSC) provided technical guidance, as did Ronald Knipling of the National Highway Traffic Safety Administration, Office of Crash Avoidance Research (NHTSA OCAR). Jing-Shiam Wang of Information Management Consultants, Inc. accessed target crash problem size statistics. Laura K. Brendon (Battelle) served as technical 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°	-22^0	-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. C13 10286.

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EXECUTIVE SUMMARY

This report examines the potential for Intelligent Highway Vehicle System (IVHS) technology to improve the crash avoidance capability of drivers and vehicles for backing crashes. IVHS has the potential to greatly enhance highway traffic safety. This report attempts to determine the safety implications of IVHS by using analytical methods to model the backing crash type and potential IVHS crash avoidance countermeasures. The link between candidate technology solutions and backing crash scenarios may help identify the characteristics of the most promising technologies and research and development (R&D) needs to develop these technologies for the benefit of the driving population.

Backing Crash Problem Size

There were approximately 182,000 police-reported backing crashes in 1990 which represents about 2.8 percent of all police-reported crashes. There were 185 fatalities caused by backing crashes in 1990.

Analysis of Backing Crash Circumstances

The results of this study are based on a detailed analysis of 100 1991 and 1992 General Estimates System (GES) police accident reports (PARs) and 49 case reports from the 1986 NASS data file. Percentages were weighted to reflect the GES data in terms of accident severity since these data are considered representative of the national population. The causal assessments show that approximately 60.8 percent of the cases occurred because drivers did not see the struck vehicle, object, or pedestrian. Approximately 26.6 percent of the cases occurred because of “improper backing.” The remaining 12.6 percent were divided between crashes that were caused by vehicle defects (5.7 percent), intoxicated drivers (3.0 percent), or miscellaneous causes (3.9 percent).

The backing crash subtypes (and percentages from the 1990 GES file) are:

- Parallel path (23.1 percent) – the lead vehicle backs into a following vehicle, usually as the lead vehicle tries to back out of an intersection. Both vehicles were initially traveling in the same direction.

- Curved path (15.1 percent) – the subject vehicle backs out of a parking space or private driveway along a curved travel path and strikes a stationary vehicle or object.

- Pedestrian/pedalcyclist (1.4 percent) – the subject vehicle strikes a pedestrian or pedalcyclist while backing.

- Straight crossing path (53.4 percent) — two vehicles travel at right angles to each other; the subject vehicle backs and strikes, or is struck by, a passing vehicle traveling a perpendicular path.

- Miscellaneous (6.9 percent) — crashes caused by unusual circumstances such as: vehicle failure, unusual pedestrian/pedalcyclist activities, or absence of a vehicle operator.

Assessment of *Potential IVHS Countermeasures*

Of the casual factors which appear amenable to IVHS countermeasures in the near term, the main causal factor appeared to be that the backing vehicle's driver was unaware of an obstacle. This suggested that a vehicle-based IVHS countermeasure that warns drivers of obstacles in the backing path might be helpful. The suggested countermeasure was a rear-zone object detection system. The parameters used for modeling include an effective range of 15 ft, a minimum lateral coverage of 6 ft immediately behind the vehicle, and a maximum lateral coverage of 16.5 ft at 15 ft range.

Delineation of *Driver, Vehicle, and Environmental Factors Related to Proposed Countermeasures*

Driver, vehicle, and environmental factors of warning systems and image-based situation displays were delineated and are summarized as follows:

- Driver performance is a key factor in determining the potential effectiveness of a crash avoidance warning system. It includes driver brake reaction times (RTs), compliance probabilities, and error likelihoods. Driver RT was modeled using a log normal distribution but further research about driver perception, decision, and response times was recommended.

- A second class of driver factors relates to warning system interface design. Specifically, warning modality, information content and context with other warning systems that could also be in the vehicle need to be considered.

- Vehicle factors involve rearward travel velocities, accelerations, and braking levels. In addition, gap distances to the object were used.

- Potentially compromising environmental factors include temperature, wind and precipitation. Given that a majority of backing crashes occur under no adverse weather conditions, the environmental impact on overall effectiveness is expected to be minimal. Environmental factors were not specifically modeled.

Effectiveness Modeling of a Rear-Zone Object Detection System

This study employed a so-called ***factorial modeling*** method for estimating the effectiveness of the parallel path, curved path, and pedestrian/pedalcyclist crashes. Key factors were identified, specific levels or values of these factors were selected, and all combinations of all factors were evaluated. The term ***factorial*** thus means in this study that levels of one manipulated factor were systematically combined with all levels of another factor. For example, five levels of driver RT combined with four levels of backing acceleration and five vehicle-to-vehicle gap distances generated 5x4x5 = 100 combinations. A so-called ***stochastic*** modeling approach was also used in one instance. This approach examines the full range of pre-crash travel speeds and their impact on the proportion of drivers who could brake in time to avoid the crash.

It is estimated that the functional rear-zone object detection system would be approximately 70 percent effective in avoiding the parallel path, curved path, and pedestrian/pedalcyclist crash subtypes. In terms of all backing crash subtypes the system would be approximately 28 percent effective.

The straight crossing path backing crash subtype is qualitatively different from the other types. Modeling the rear-zone object detection system for the straight crossing path subtype yielded very minimal benefits and was not reported.

Research and Development Needs

The report discussed several R&D issues and needs associated with IVHS crash avoidance technology for backing crashes, including the four following key items:

- **Driver response to false or nuisance alarms:** Throughout the modeling effort, driver reaction to false or nuisance alarms was not considered due to lack of empirical data. Yet, this may be the single greatest threat to the success of an otherwise useful IVHS crash avoidance countermeasure. A better understanding and quantitative characterization is needed of what constitutes “high” false rates, what driver reactions are to false or nuisance alarms, what the situational variables are that affect driver reactions to false alarms, and what design features may enhance driver acceptance of a system.

- **Distribution of subject vehicle kinematic variables:** This report’s modeling effort required estimates about the distribution of key kinematic variables, such as travel velocity, rearward accelerations, and backing distances in the accident population. Covariation between such variables and driver performance was not addressed. It was suggested that such information be collected to support future effectiveness determination and the development of detection systems.

- **Appropriateness of existing backing sensors for passenger vehicles:** Backing sensors are currently used for commercial applications such as loading docks and construction sites. It is not known whether they are appropriate for passenger vehicle applications. It was suggested that these sensor systems be evaluated for non-commercial situations.

- **IVHS countermeasures for the straight crossing path backing crash:** Over one-half of the backing crashes reported in 1990 were straight crossing path crashes wherein a subject vehicle backs out of a parking space or driveway onto a roadway and strikes or is struck by a passing vehicle that is traveling at a higher travel velocity. A vehicle-based rear-zone object detection system such as the one considered in this study would be largely ineffective in such situations. There is a need to develop an alternative crash avoidance countermeasure for this crash type.

1.0 INTRODUCTION

The purpose of this report is to examine the potential for Intelligent Vehicle Highway System (IVHS) technology to improve the crash avoidance capability of drivers and vehicles for backing crashes. IVHS has the potential to greatly enhance highway traffic safety. This report attempts to determine the safety implications of IVHS by using analytical methods to model the backing crash type and potential IVHS crash avoidance countermeasures. The link between candidate technology solutions and backing crash scenarios will help identify the characteristics of the most promising technologies and R&D needs to develop these technologies for the benefit of the driving population.

The goals of this research are to:

- Define the backing crash problem, uncover the causes of a given crash type, and quantitatively describe backing crashes.
- Identify candidate IVHS countermeasures technologies and the key factors and parameters that contribute to or detract from likely effectiveness.
- Develop analytical models of selected countermeasure concepts and specific crash scenarios to estimate effectiveness and variations in effectiveness as a function of key variables or parameters.
- Identify research and development needs to resolve key technological, human factors, modeling, and other issues to ensure that the countermeasure's potential is reached.

This report focuses on backing crashes. A backing crash occurs when a vehicle that is moving backwards strikes, or is struck by, an obstacle. The obstacle can be another vehicle, or an object, animal, or person.

The backing crash type is of interest for several reasons. First, backing crashes often involve slow closing speeds and thus, may be preventable with IVHS crash avoidance countermeasures. Second, backing crashes, though usually minor in severity, may be particularly severe and tragic when they involve a vehicle backing over a child or other pedestrian. Third, rear-zone object detection systems, which may help prevent such crashes, are already on the market.

This report presents a preliminary effort to model the safety implications of a vehicle-based IVHS countermeasure for backing crashes. The modeling effort frequently involved many assumptions and engineering adjustments where empirical data did not exist. Alternative modeling schemes might be applied in place of the approaches chosen. The results obtained are, therefore, first approximations only. They estimate the crash avoidance potential and benefits of a rear-zone object detection system that is technically feasible in the near term (0 to 5 years). It is hoped that, as more becomes known about the distributions of critical crash parameters, covariation among sets of parameters, and driver pre-crash behaviors, future work will extend these results. Indeed, the presentation of countermeasure modeling and its parameters in this report is intended to be ***heuristic*** (i.e., supportive of future research) rather than definitive.

This report is organized into the following chapters:

- Chapter 2.0 presents the backing crash problem size.

- Chapter 3.0 identifies backing crash subtypes and causal factors derived from an assessment of a sample of crash cases.

- Chapter 4.0 discusses potential IVHS technologies to help prevent backing crashes.

- Chapter 5.0 examines driver, vehicle, and environmental considerations for the proposed countermeasures.

- Chapter 6.0 presents modeling results of the proposed countermeasure.

- Chapter 7.0 provides general estimates of countermeasure effectiveness.

- Chapter 8.0 indicates research and development issues and needs related to backing crash prevention using IVHS technology.

2.0 BACKING CRASH PROBLEM SIZE

This chapter presents statistics on the backing crash problem size, based primarily on National Highway Traffic Safety Administration (NHTSA) accident data systems. The information in this chapter is a summary of that presented in Wang and Knipling (1993).

Table 2-l indicates the following regarding the backing crash type:

- In 1990, there were approximately 182,000 police-reported (PR), target crashes (per General Estimates System (GES)) on roadways with 185 associated fatalities (per Fatal Accident Reporting System (FARS)).

- There were an estimated 22,000 associated injuries, mostly of relatively mild severity.

- Backing crashes constitute:
    - 2.81 percent of all PR crashes
    - 0.41 percent of all fatalities.

- During its operational life, a vehicle can be expected to be involved in 0.0123 PR backing crashes as the striking (backing) vehicle.

- There are roughly 300,000 non-police reported (NPR) backing crashes annually.

- Backing crashes account for a small percentage (roughly 0.88 percent) of all crash-caused delay.

Unless otherwise indicated, all of the GES and FARS statistics cited above and provided in Table 2-l relate to police-reported backing crashes. Off-roadway backing crashes (those occurring on parking lots, driveways, etc.) are generally not police-reported and, therefore, are not captured by GES and FARS.

Table 2-1. Problem Size Statistics for Backing Crashes
Involved Vehicle Types: All Vehicles

GES/FARS Based Statistics (1990)		All Backing Crashes
Annual # PR Crashes (GES)	Total:	181,500
	Injury:	16,500
	PDO:	165,000
Annual # Fatalities (FARS)		185
Ann. # Non-Fatal PR Injuries (GES)	Total:	22,000
	A:	1,500
	B:	5,500
	c:	15,000
Fatal Crash Equivalents		772
Percentage of All PR Crashes		2.81%
Percentage of All Fatalities		0.41%
Involvements as "Subieot (Backing) Vehicle:"		
Involvement Rate Per 100 Million VMT		8.4
Annual Involvements Per 1,000 Vehicles		0.94
Expected # Involvements During Vehicle Life		0.0123
Estimated Annual # NPR Crashes	Total:	298,000
	Injury:	35,000
	PDO:	263,000
Crash-Caused Congestion (Delay)	Veh-Hours:	4.3M
Percentage of All Crash-Caused Delav:		0.88%

Legend:

A	Incapacitating Injuries
B	Nonincapacitating Injuries
C	Possible Injuries
FARS	Fatal Accident Reporting System
GES	General Estimates System
M	Million
NPR	Non-Police Report
PDO	Property Damage Only
PR	Police Reported
VMT	Vehicle Miles Traveled

3.0 ANALYSIS OF BACKING CRASH CIRCUMSTANCES

Details about backing crash scenarios and causes are needed to identify relevant IVHS countermeasures. This chapter describes backing crashes in terms of subtypes and identifies causal factors that contribute to these crashes.

3.1 Data Sets

Two data sets were available for analysis:

- 100 hard copy police reports selected from the 1991 and 1992 data years of the GES within the National Accident Sampling System (NASS).
- 49 hard copy case reports selected from 1986 NASS data files.

Steps were taken to ensure that the selected case samples were representative of regional variations including the time of day and time of year when the crashes occurred.

The GES sample consisted of 100 unsanitized police accident reports (PARs). That is, these police reports included all of the information originally reported by the investigating officer. The NASS sample consisted of 49 hard copy sanitized case reports examined by National Highway Traffic Safety Administration Office of Crash Avoidance Research (NHTSA OCAR) personnel at the NASS storage facility in Washington, D.C. Case information used in these reports included copies of crash descriptions and scaled schematics prepared by the primary sampling unit (PSU) investigation teams.

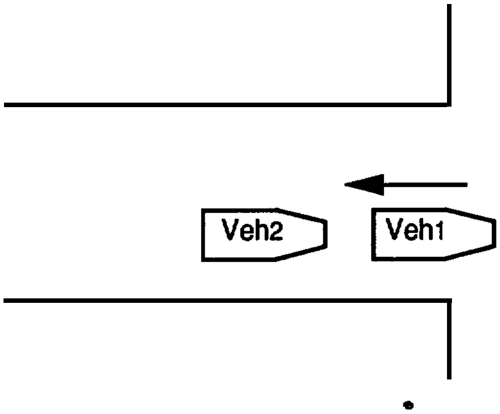
These two data sets did not provide sufficient information to support a definitive causal factor analysis. Case identifiers and driver and witness statements were deleted from the NASS case files. Police descriptions of crash events in these cases were also sanitized, creating gaps in available information. Crash descriptions contained in the GES PAR file were incomplete because they typically did not include driver assessments of pre-crash actions and crash events.

Although these limitations were significant, there was sufficient information in both data sets to determine general characteristics or subtypes of backing crashes. The GES data set also provided information sufficient for an overview of causal factors. These areas are discussed in the subsections which follow.

3.2 Backing Crash Subtypes

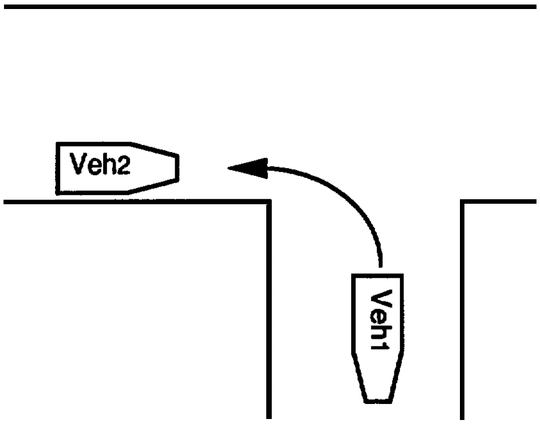
There are four major crash subtypes within the backing crash population; these are depicted in Figure 3-1. These subtypes may be categorized and described as follows:

Parallel Path



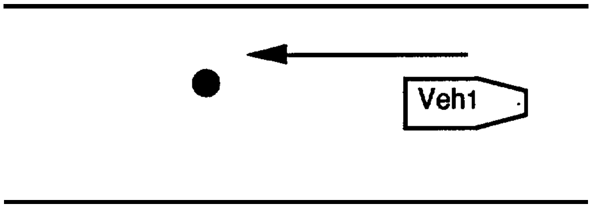
- Veh$_1$& Veh on roadway, traveling in same lane in same direction
- Veh$_1$ stops
- Veh$_1$ reverses direction 81 hits Veh$_2$

Curved Path



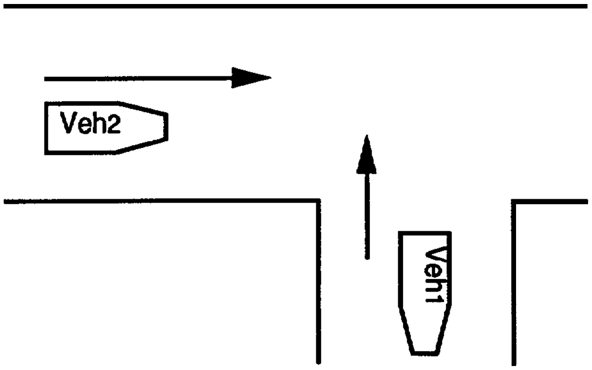
- Veh stationary
- Veh$_1$ backs into Veh$_2$

Pedestrian/Pedalcyclist



- Pedestrian or pecalcyclist behind Veh$_1$
- Veh$_1$ backs & hits pedestrian or pedalcyclist

Straight Crossing Path



- Veh traveling on roadway
- Veh$_1$ strikes or is struck by Veh

Figure 3-1. Backing Crash Subtypes

Parallel Path - This subtype involves two vehicles that are traveling in the same direction in the same travel lane. Typically, the two vehicles stop at an intersection. The lead vehicle reverses direction and backs into the following vehicle because the lead vehicle driver has stopped in the intersection and is trying to withdraw from it. Major characteristics of the parallel path subtype include low travel velocities for the backing vehicle and frontal damage to the struck vehicle. The following vehicle, which is struck, is usually stationary; 81.2 percent of the following vehicles in the clinical data set were stationary at the time of impact.

> EXAMPLE: NASS case number 55-151E. Prior to the crash, both vehicles were proceeding west on a two-lane roadway, approaching a T-intersection that was controlled by a stop sign. The lead vehicle stopped at the intersection and the following vehicle stopped behind the lead vehicle. The driver of the lead vehicle apparently realized that he had stopped with a portion of his vehicle protruding into the intersection. At that point, the driver of the lead vehicle reversed direction and backed into the following vehicle. Contact surfaces were limited to the rear plane of the lead vehicle and the frontal plane of the following vehicle.

Curved Path - This subtype involves a subject vehicle backing out of a parking space or private driveway along a curved travel path. The backing vehicle then strikes a stationary vehicle or object. These crashes are characterized by damage to the rear of the subject vehicle and damage to the corner areas or side structure of the struck vehicle or object. Backing velocities for the striking vehicle are typically low (i.e., 5 niph or less).

> EXAMPLE: NASS case number 02-044E. Prior to the crash, the struck vehicle was parked at the south curbline of an east/west roadway, facing toward the east. The driver of the subject vehicle backed from a private driveway located on the north side of the roadway and proceeded along a westward arc. The right corner of the rear bumper of the subject vehicle struck the left rear quarter panel of the struck vehicle.

Pedestrian/Pedalcyclist Crashes - This subtype includes all pedestrian/pedalcyclist crashes that occur while the subject vehicle is backing on the roadway or in off-roadway locations. Because of the severity of injuries sustained by the pedestrian/pedalcyclist, this crash type has the most severe injury consequences of the four identified crash subtypes.

> EXAMPLE: NASS case number 12-114C. Prior to the crash, the subject vehicle was parked in a parking lot, facing the northwest. The parking spaces in this row were designed for diagonal parking with vehicles facing to the northwest. The subject driver began backing straight out of the parking space toward the southeast. The pedestrian was crossing the parking lot, proceeding toward the southwest along a trajectory that was approximately perpendicular to the vehicle's backing trajectory. After backing a distance of approximately 12 ft, the subject vehicle's rear bumper struck the right side of the pedestrian.

Straight Crossing Path - This subtype typically involves two vehicles traveling at right angles to each other. For example, the subject vehicle backs out of a parking space or private driveway into the roadway and strikes or is struck by a passing vehicle. The travel velocity of the passing vehicle is higher than the travel velocity of the backing vehicle. This velocity differential often causes more serious crash consequences for this subtype than any other except for pedestrian/pedalcyclist fatalities. This velocity difference also makes this subtype qualitatively different from the other three.

> EXAMPLE: NASS case number 54-105E. Prior to the crash, the subject vehicle was backing eastward in a private driveway. The driver intended to back into a north/southbound roadway. The driver of the subject vehicle apparently did not see the struck vehicle approaching the crash site in the southbound travel lane. As the subject vehicle backed into the roadway, the left portion of its rear bumper struck the right side of the passenger compartment of the southbound vehicle.

Table 3-l shows the distribution of crash subtypes within the selected data sets. The parallel path crash subtype dominated the combined data set with a weighted proportion of 46.4 percent (see Appendix A for a description of the weighting scheme used). Crash location characteristics are also provided in Table 3-l. All of the parallel path crashes occurred on the roadway, with most of the crashes located at or near intersections. Crashes within the other subtypes occurred both on and off the roadway. The "miscellaneous"

Table 3-l. Distribution of Crash Subtypes Within the Selected Data Sets and Crash Location Characteristics by Crash Subtype

Crash Subtype	GES PARS	NASS	Total Cases	*Weighted %	Crash Location	Total Cases	*Weighted %
Parallel Path	47	18	65	46.4	On roadway:		
					Straight	23	15.0
					Curve	3	2.0
					Intersection	39	29.4
Curved Path	12	10	22	17.3	On roadway:		
					At driveway	13	10.8
					At intersection	4	2.7
					Parking lot	5	3.8
Pedestrian/ Pedalcyclist	6	5	11	1.9	On roadway:		
					At driveway	1	0.1
					At intersection	1	0.3
					Straight	4	0.5
					Parking lot	5	1.0
Straight Crossing Path	17	IO	27	18.4	On roadway:		
					At driveway	17	12.4
					At intersection	1	0.2
					Parking lot	9	5.8
Miscellaneous	18	6	24	16.0		24	16.0
Total	100	49	149	100.0		149	100.0

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* Weighting scheme is described in Appendix A.

category contains crashes that occurred under unusual circumstances for which IVHS countermeasures are difficult to envision. These included the following events or conditions:

- Crashes resulting from vehicle failure (primarily brake, throttle, and/or drivetrain failures).
- Crashes resulting from unusual pedestrian/pedalcyclist activities where the pedestrian/pedalcyclist was judged to be responsible for the crash.
- Crashes resulting from the lack of a vehicle operator, for example, if the operator placed the transmission selector lever in reverse and then fell or jumped from the vehicle.

3.3 Causal Factor Overview

Table 3-2 summarizes causal assessments contained in the narrative or coded portions of the GES PAR sample. In 26 of the 100 cases in the sample, no causal assessments were provided by the investigating officer. In 40 of the remaining 74 cases (weighted percentage = 60.76 percent) containing causal assessments, the investigating officer noted that the subject driver “did not see the struck vehicle/object/pedestrian.” The specific reasons why the driver did not see or was unaware of the impending danger could not be determined from data available in the reports. Probable scenarios include inattention to the driving task (cited in 6 of the 40 cases), driver distraction, failure to adequately check for obstacles prior to initiating the backing maneuver, and blindspots.

The second most frequently cited category involved the designation of “improper backing." This assessment was noted in 25 of the 74 cases (weighted percentage = 26.64 percent). Again, the specific reasons why the investigating officer assigned this designation could not be determined from available data. Probable scenarios include the failure to adequately check for obstacles prior to initiating the backing maneuver, driver inattention or distraction, and backing at inappropriate velocities. This designation is also used in a legalistic sense (i.e., that the driver struck an obstacle while backing is prima-facie evidence of improper backing).

The causal factor categories “did not see struck vehicle/object/pedestrian” and “improper backing” overlap and together represent a weighted percentage of 87.4 percent. While specific reasons associated with crash causation cannot be identified with the PAR data, the common thread is that the drivers in the two categories discussed above were unaware of the impending impact in sufficient time to avoid the crash. Given this circumstance, it is likely that IVHS crash avoidance countermeasures that warn the driver of the presence of obstacles to the rear will be beneficial.

Table 3-2. Causal Assessments Provided in GES PARs

Causal Status	Cases	Weighted % **
No assessment provided	26	28.4
Causal assessment provided	74	71.5
Total	100	99.9

Causal Assessment	Cases	Weighted % of Reported Assessments
Did not see struck vehicle/object/pedestrian	40	60.8
Improper backing	25	26.6
Vehicle defect	3	5.7
Driving under the influence of alcohol	3	3.0
*Miscellaneous	3	3.9
Total	74	100.0

• Category includes one case where the driver fell asleep, one case where the driver failed to control the vehicle, and one case where a pedestrian caused the crash.

** Weighting scheme is described in Appendix A.

3.4 Comparison of GES Data File and Selected Data Sets

The 1990 GES data file was accessed to determine the relative proportions of the four identified backing crash subtypes within the backing crash population. Search parameters for this run are described in Wang & Knipling (1993). Results, shown in Tables 4-2 and 4-3 of that report, are summarized in Table 3-3. Crash subtypes are defined in the same manner as discussed in Section 3.2. Crashes assigned to the "Not Applicable" category included vehicle failures, instances where there was no driver in the vehicle at the time of impact, and drivers impaired by alcohol and fatigue. The "not applicable" designation refers to the fact that rear-zone object detection systems are likely to be ineffective in alleviating crashes in this category.

The weighted proportions for crash subtypes within the selected data set examined for this effort are duplicated from the middle column of Table 3-l and shown in the last column of Table 3-3. As Table 3-3 shows, the selected data set is skewed in comparison to the GES file, from which estimates of the national crash population are derived. For example, the selected data set contained much higher proportions of "Parallel Path" crashes and "Not Applicable" crashes than were noted in the GES file. Similarly, the proportion of "Straight Crossing Path" crashes were much lower in the selected data set as compared to the GES

Table 3-3. Percentages of Defined Crash Subtypes in 1990 GES File and in the Selected Data Set (Combined)

Crash Subtypes	GES No. of Crashes	Percentage of Crash Population (%)	Weighted % of Selected Data Set
Parallel Path	42,000	23.1	46.4
Curved Path	27,500	15.1	17.3
Pedestrian/ Pedalcyclist	2,500	1.4	1.9
Straight Crossing Path	97,000	53.4	18.4
Not Applicable	12,500	6.9	16.0
Total	181,500	99.9	100.0

file. To enhance the validity of modeling results and the benefit assessment, GES file estimates are utilized in subsequent sections of this report.

The results of the analysis of backing crash circumstances may be summarized as follows: four different crash subtypes were identified including parallel path, curved path, pedestrian/pedalcyclist, and straight crossing paths crashes. Identifying these different subtypes was useful because it prompted development of modeling representations appropriate to each. Additionally, among causal factors inferred from the available data, “did not see struck vehicle/pedestrian/pedalcyclist” and “improper backing” were predominant. Collectively, these causal factor categories indicated that, for whatever reason, the driver involved was unaware of the impending impact in sufficient time to avoid the crash. This suggested that an IVHS crash avoidance countermeasure that alerts the driver to the presence of obstacles to the rear will be of at least some benefit. Therefore, the lessons learned from the analysis of backing crash circumstances provide guidance on the directions modeling should take and the types of countermeasures which might be effective.

4.0 REVIEW OF POTENTIAL IVHS COUNTERMEASURES

The main causal factor categories in backing crashes involve driver-centered problems associated with “improper backing” and “did not see struck vehicle/object/pedestrian.” The specifics associated with these categories are unclear and probably include driver inattention, failure to visually scan the rearward view, and vision obscured by vehicle geometry, among other reasons. A common thread, however, appears to be that the driver of the backing vehicle was unaware that an obstacle was in the way. This suggests that a vehicle-based IVHS countermeasure that warns the driver of obstacles in the backing path will be helpful. Such a countermeasure is generically referred to in this report as a rear-zone object detection system. The effectiveness of a particular system will depend on both its human factors properties as well as on the particular backing crash subtype under consideration.

In Chapter 3.0, a distinction was drawn between the straight crossing path backing crash subtype and the other three subtypes. This is primarily because the passing vehicle in the straight crossing path backing crash subtype is usually traveling at a higher velocity than the backing vehicle. This higher velocity causes more severe consequences for this subtype than all others except pedestrian/pedalcyclist crashes. It may also demand a fundamentally different countermeasure than the vehicle-based rear-zone object detection system. For example, the countermeasure may involve an infrastructure implementation or intervehicle communication. Because these countermeasure concepts would require more complex functional specifications, only rear-zone object detection system countermeasures were considered in this report.

The purpose of Chapter 4.0 is to:

- Review candidate detection system crash avoidance countermeasures in terms of their theory of operation, capabilities, and limitations.

- Identify key countermeasure issues that determine the likely effectiveness of the system for avoidance of backing crashes.

- Identify the functional specifications of a candidate rear-zone object detection system for modeling effectiveness.

4.1 Ultrasonic Countermeasures

One option for the rear-zone object detection system is ultrasonics. This subsection presents an overview of the theory of operation, examples of systems currently on the market, and key performance parameters.

Key parameters that determine the effectiveness of an ultrasonic detection system include:

- Target characteristics
- Ultrasonic frequency characteristics
- Environmental factors

Operation: Ultrasonic sensors transmit acoustic waves through the air toward a target, generally at frequencies between 20 and 200 Khz, and receive the echo reflection from a target (Underwood, 1990). The distance between the target and the sensor is typically measured by comparing the time shift between the triggered pulse and the received pulse of the echo (Clemence & Hurlbut, 1983).

Existing **Ultrasonic Systems:** Several ultrasonic systems are commercially available and are primarily used for commercial vehicles. For example, the Dynatech SCAN" and SCAN II™ systems utilize up to eight ultrasonic sensors for left, right, and rear vehicle coverage. Dynatech claims that the SCAN systems typically measure distances from 1.3 ft to 9.9 ft with a range resolution of 0.1 ft. The full-feature driver alert module consists of an auditory warning and an LED visual display that indicates which of up to seven sensor locations are active. The systems also include an LED digital distance display.

The manufacturer of another example, the PROTEX system, claims that the system detects obstacles in an area 9 ft wide by 6.5 ft deep. Consisting of one processor and two sensors, the system alerts a driver of any object within this zone by an audible beeping tone, which becomes more frequent as the vehicle nears the object.

Most commercial ultrasonic sensors operate at a frequency in the range from 40 to 50 Khz. This range represents a compromise between lower frequencies where background noises propagate and higher frequencies that suffer from excess atmospheric attenuation.

Target Characteristics: Sufficient power must be transmitted to ensure enough echo strength for detection. Although ultrasonic waves are reflected from almost all surfaces, smooth flat surfaces produce stronger echoes than irregularly shaped surfaces. Porous surfaces or targets, such as people and animals, produce a weaker acoustic echo than hard surfaces.

The size of the target influences the propagation of the reflected waves. Assuming that the targets are all equally reflective, larger targets, which intercept more acoustic energy than smaller targets, are more easily detected. The target's angular orientation with respect to the transmitted beam also affects the performance of an acoustic system. Rough surfaces provide a relatively strong echo signal for a wider range of target orientations than do smooth surfaces (Clemence & Hurlbut, 1983).

Taken together, target characteristics jointly determine effective detection ranges for ultrasonic rear-zone object detection systems and detection likelihoods for various targets in different orientations. For example, detection ranges will be shorter for pedestrians and pedalcyclists than for other vehicles.

Frequency Constraints: The beam width of the transmitted wavefront depends on the ratio of the signal wavelength to the transmitter diameter. By increasing the transmitter's diameter and decreasing the wavelength, the beam may be made narrower. However, there are several conflicting requirements:

- The transmitter antenna cannot be made arbitrarily large because of automobile style and space constraints.

- Higher acoustic frequencies undergo greater atmospheric attenuation, which can only be compensated by increased transmitter power.

- Lower acoustic frequencies may be susceptible to environmental noise.

Some backing crash scenarios, such as the curved path, may require sensors with a wide horizontal angle coverage. This may be achieved either by mechanically scanning a narrow beam or by using a wide beam. The wide beam may generate more false alarms than a scanning beam because a wide beam may generate echoes from targets whose location cannot be measured with respect to a particular lane. The read-out from a scanning system can be synchronized spatially so that object location can be determined. From a modeling perspective, then, the sensing envelope is clearly an important consideration and will ultimately be determined by frequency factors, among others.

Environmental: Ultrasonic waves are distorted by atmospheric variables such as temperature and wind speed. For an uncompensated temperature variation of 10° Fahrenheit between transmitter and target at a range of 30 ft, there is a distance error of approximately 4 inches (Clemence & Hurlbut, 1983). With a cross wind speed of 100 ft/s (68 mph) at a range of 24 ft, a distance error of 2.75 inches has been measured for a 1 ft x 1 ft target (Underwood, 1990). These distance errors would probably not significantly affect ultrasonic countermeasures when used for backing crash prevention, as the detection range is short, typically around 15 ft or less as indicated from the commercial products reviewed above.

4.2 Radar Technology

Radar technology may also be used for rear-zone object detection system applications. Radar technology may be referred to as either microwave radar (less than 30 GHz frequency range) or millimeter wave radar (30 to 300 GHz frequency range).

Key system parameters that will determine detection system effectiveness are the same as those listed in Section 4.1.

Operation: Electromagnetic energy is radiated from a transmitter by an oscillator that is connected to an antenna. A switch changes the function of the antenna from a transmitter to a receiver. While in the receiver mode, reflected electromagnetic energy from a target is collected and fed to a mixer that computes target velocity data. Target range can be determined by using the two-way transit time between transmitter and target, and the speed of propagation. False signals due to various noise sources can be partially suppressed by ignoring signals below a preselected level.

Existmg Radar Systems: AM SENSORS, the manufacturers of a microwave backing unit, claims it has a maximum range of 50 ft, but an operating range of 10 ft to minimize false alarms. With a range resolution of 0.1 ft, this system provides obstacle detection by measuring return pulses over predefined ranges (range gating) to differentiate signals from poor reflectors, such as a small child, versus large targets such as automobiles.

SAFETY FIRST claims their system is sensitive to objects in a rear-vehicle area defined by a 6 ft. width at zero ft and a 20 ft width at 20 ft Its range resolution is 0.6 ft. This system also measures signals from predefmed ranges. Both systems operate at 10.525 **GHz + 25 MHz.**

In summary, then, existing radar systems have maximum detection ranges of approximately 10 to 20 ft, as determined by software to minimize false detections. Greater ranges are possible but generally at the cost of significantly higher false detection rates.

Target Characteristics: The strength of a radar return signal from a target depends on target surface roughness, the orientation of the radar's electro-magnetic fields, and its angular orientation with respect to the target. Diffuse scattering of the return signal occurs when the wavelength is approximately the same value as the average target surface roughness. Thus, diffuse scattering predominates at a frequency of 30 GHz when the target surface roughness is approximately 1 cm. The advantage gained by diffuse scattering is that the return signal is relatively independent of the target orientation. Unlike acoustic propagation, which does not have electrical properties, radar emissions may possibly be optimized by adjusting the signal characteristics to maximize return signal levels for a particular target class. These target characteristics suggest that pedestrian and pedalcyclist detection will, all other things being equal, probably be poorer than that for vehicles and metal objects in terms of affixed sensor's detection ranges or detection angles. For modeling the pedestrian/pedalcyclist crash subtype, this range attenuation is important.

Frequency Constraints: Range measurement precision is inversely proportional to the bandwidth, which is approximately one-third of the operating frequency. Thus, radar units, which operate at higher frequencies, have more available bandwidth for greater range precision than do ultrasonic units. This may be of some value to a detection system algorithm to minimize false detections or provide more refined distance information to the driver if useful.

Radar systems require officially assigned bands. The Federal Communication Commission has allocated two frequency bands for field disturbance applications: a 50 MHz band centered at 10.576 GHz and a 250 MHz band centered at 24.125 GHz.

Environmental: Radar is attenuated by the atmosphere due to scattering and absorption phenomena. Rainfall also limits performance. For backing crash applications, these effects should not adversely affect radar systems since the required detection range is likely to be short (about 15 ft).

Other environmental factors could affect a radar unit's performance. For the backing crash scenario, the radar unit would probably be mounted on the rear of the vehicle near the ground, i.e., on the bumper. The electrical properties of the ground may have an effect on the signals issued by or returning to the unit. Puddles of water on the roadway that are rippled by the wind may scatter radar beams or cause antenna pattern lobing. Collectively, these can increase the rate of false or nuisance alarms.

4.3 Active Infrared Laser Technohgy

Active infrared laser is a potential alternative to either ultrasonic or microwave sensors used in proximity detection applications. Although less prevalent than ultrasonic or microwave, a few infrared systems were introduced to the United States in the recent past. Because of the advanced state of development of infrared components such as laser sources, photo detectors, and signal processing electronics, laser proximity sensors could be cost competitive with alternative technologies. Laser systems do not require government frequency band allocations.

Key parameters that determine the effectiveness of an active infrared laser detection system include:

- Environmental factors
- Operating wavelengths

Operation: Laser systems operate by means of a laser source, such as gallium arsenide, whose wavelength is in the range of 0.8 to 0.9 microns (1 micron = 10^{-6} meters). The emitted light, either pulsed or as continuous waves, is reflected from an object. The reflected light is intercepted by a lens and focussed on a photodetector, which converts the light to an electrical signal. Signal processing electronics determine the range between the subject vehicle and an obstacle.

Beam Constraints: The divergence angle of the transmitted laser beam is approximately a few meters at a range of 100 meters. This narrow beam width may be useful for long-distance detection by avoiding obstacles in other lanes (alarms) that would normally be intercepted by a wider beam angle. However, at shorter ranges, the narrow beam width is insufficient for adequate proximity detection. This problem may be circumvented by the use of either multiple beams or by scanning (Sekine, 1992 and Yanagisawa, 1992).

Examples of Systems: An infrared sensor introduced in this country was a unit manufactured by Auto-Sense. It had a transmitter, receiver, and an audio/visual display. According to the manufacturer, this sensor provided a 15 ft operating range, fail-safe warning for malfunction, and various remote visual display options.

In the recent past, dual-mode infrared/ultrasonic sensors systems were marketed in the United States under the trade names of Bats and Scan. The manufacturers claimed both units monitored ranges up to about 10 ft and provided rear and side coverage. Dual-mode systems have the advantage of operating over a greater variety of adverse weather conditions. Infrared sensors perform poorly in fog, which does not effect ultrasonic propagation. Conversely, high wind speed may distort ultrasonic performance, but not impact infrared parameters.

The Japanese have expended considerable effort on laser technology, primarily for headway detection and cruise control applications. The Japanese prefer laser systems because the laser system transmiters are smaller than microwave or ultrasonic antennas, and the cost is attractive. At the time of this report, Japanese frequency band allocations do not provide for automobile radar (Hosaka, 1992). Hamamatsu has designed a laser system that measures distance to an object by radiating infrared energy and then measuring the reflected component by a position sensitive detector. Distance to the object is determined by triangulation, which involves the length between the center of the light emitting diode and the spot on the position sensitive detector. Another example of a Japanese laser system is the Traffic Eye Laser Warning System developed by Nissan (Allen, 1992).

Environmental: Absorption and backscattering of laser light by rain and fog is not as much an issue at short ranges as it is at longer ranges (Sekine, 1992). The accumulation of dirt or snow on the sensor head can be detected by an internal calibration source. Glare from the sun can be reduced by a louver shade (Sekine, 1992).

Operating Wavelength: Important issues concern the operating wave length of a laser system with regard to driver interference and potential eye damage. Visible wavelengths (approximately 0.35 - 0.75 microns) should be avoided to eliminate driver distraction. Eye safety can be achieved by operating laser systems at wavelengths outside the visible range (far-infrared), which eliminates destruction of sensitive eye tissue. For example, in military applications associated with tank fire control systems, CO^2 lasers, which operate at 10.6 microns, have been widely adopted since 10.6 microns is considerably removed from the visible range. However, these lasers tend to be unsuitable for automotive applications because of their size, cost and the need for special components, such as zinc selenide optical windows, which scratch easily.

Neodymium YAG lasers, which operate at 1.06 microns and are common in military range finders, would probably require that their material properties be changed to shift the wave length out a micron or so for eye safety. Gallium arsenide lasers, which operate at 0.8-0.9 microns, are potentially suitable. They may require some level of power restriction, because the operating wave length is just outside the visible range.

The final choice of wavelength will depend on power level, type of operation (i.e., pulse or continuous wave), technical maturity of the system components and conformance with government safety standards.

4.4 Image-Based Countermeasues

Rear obstacle detection can also be accomplished using image-based systems such as closed-circuit television (CCTV) by mounting a camera on the rear of a vehicle. The camera sends a picture to an in-vehicle video display, which provides a black and white visual representation of the area within the camera range (Ryder, 1990). Applicable CCTV countermeasures include traditional tube-based cameras, charge-coupled devices (CCDs) and fiber optic transmission cables. CCD cameras are solid-state devices, which are typically smaller and lighter than tube-type cameras.

Fiber optic transmission cables are an array of optical fibers. These are arranged in a specific order along a tube and transmit a picture to an in-vehicle display unit. This countermeasure is relatively new and requires further development and testing before it is widely available on the commercial market (Ryder, 1990). A major disadvantage of these image-based countermeasures is that they require direct light to capture the image. These systems lose effectiveness in instances of low visibility such as fog or rain and require external illumination to operate at night. Furthermore, as will be discussed in Chapter 5.0, video image-based countermeasures also do not provide warnings ***per se.*** Instead, they provide visual information, which the driver must note and then interpret to decide if there is a hazard present. Image-based systems are being used to assist drivers of commercial vehicles when they back into loading docks and landfills and when they maneuver in congested areas.

4.5 Summary: Rear-Zone Object Detection System

The countermeasures reviewed in this chapter are in operation or are being developed for rear-obstacle detection applications. To date, most of the R&D on rear-blind zone object detection/warning systems has focused on ultrasonic and infrared laser sensors. Ultrasonic sensors are subject to distortions under certain environmental conditions, especially heavy rainfall and severe crosswinds.

Table 4-l lists performance parameters and nominal values for a generic rear-zone object detection system. The values were derived from both ultrasonic and microwave systems and are used for countermeasure modeling in Chapter 6.0. Image-based systems are not modeled at this time, in large part because of human factors considerations discussed in Chapter 5.0.

Figure 4-l presents a stylized depiction of the rear-zone object detection system.

Table 4-l. Performance Parameters and Nominal Values for Rear-Zone Object Detection System Used in Countermeasure Modeling

Range*	15 ft
Range Resolution	Negligible (0.1 ft) (modeled as perfect resolution)
Minimum Width of Coverage at Zero Ft	Width of Car (6 ft)
Maximum Width of Coverage at 15 Ft* *	16.5 ft

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* Range of 15 ft, the midpoint of ranges found in existing systems, assumes that the target is an automobile. Ranges of smaller objects with different reflective properties may be less. For example, a reduction factor of 1/3 for a pedestrian is assumed. This reduction factor is an engineering estimate only and is not supported by a published data source.

** The maximum coverage at 15 ft is determined by interpolation between 6 ft wide coverage at zero ft and 20 ft coverage at 20 ft.

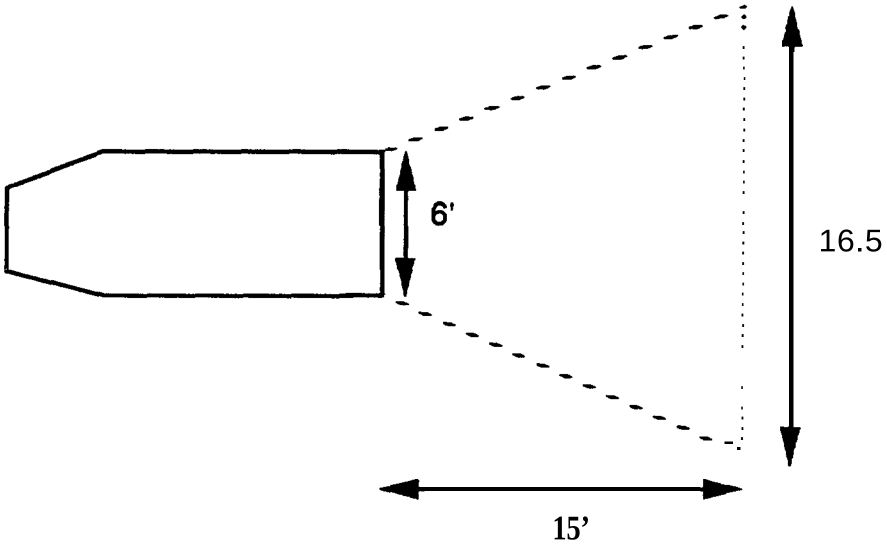


Figure 4-l. Stylized Depiction of Rear-Zone Object Detection System

5.0 DELINEATION OF DRIVER, VEHICLE, AND ENVIRONMENTAL FACTORS RELATED TO PROPOSED COUNTERMEASURES

Two broad classes of IVHS countermeasures have been presented as potentially relevant to backing accidents based on the causal scenarios presented: warning systems and image-based situation displays. Driver, vehicle, and environmental considerations for these countermeasures are discussed below.

5.1 Warning System Technologies

See Table 5-l for a summary of modeling assumptions.

Table 5-l. Summary of Modeling Assumptions about Driver, Vehicle and Environmental Factors

DRIVER		
Factor	**Assumptions**	**Sources**
Warning Response	Driver assumed to brake	Simplification
Warning Interface	Interface assumed fully effective	Simplification
Brake RT	Modeled as lognormal distribution with centrality parameter of .07 and dispersion parameter of .49	Taoka (1989).
Driver Warning Compliance	100%	Simplification
Error Likelihoods	Errorless performance assumed	Hendricks et. al. (1992); simplification
VEHICLE		
Factor	**Assumptions**	**Sources**
Braking Level	.7g assumed	Engineering estimate
Environmental Degradation	No degradation modeled	Wang & Knipling (1992)

5.1.1 Driver/Human Factors Considerations

Driver Behavior: Possible driver responses to a rear-zone object detection system warning include:

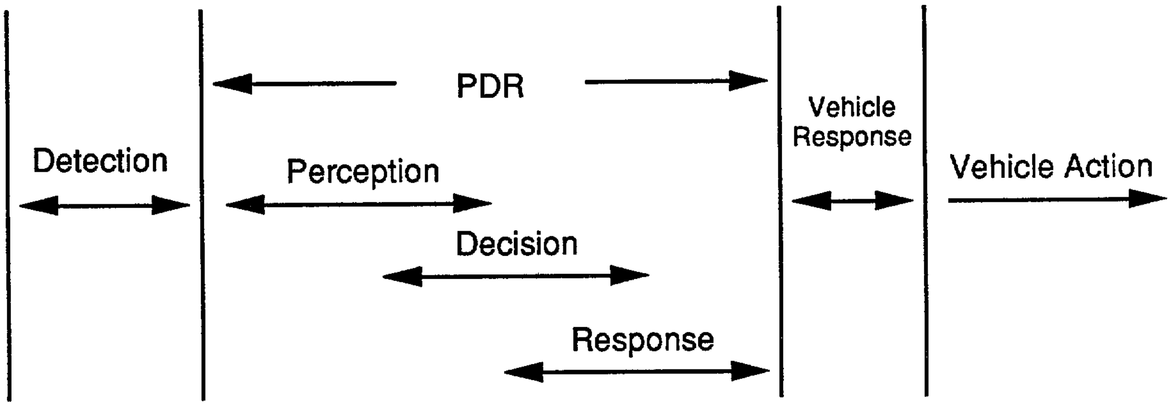
- Braking to a stop when the warning is issued by the system.
- Increasing visual search (checking) to obtain more information before deciding on an action.
- Making a steering correction to avoid a target such as a trash can to one side of the vehicle.
- Slowing to permit another vehicle or pedestrian to pass.
- Doing nothing because the system is unreliable or is known to generate false or nuisance alarms.

The driver's most likely response might be to brake to a stop when the system issues a warning. The driver may then obtain more information and proceed when safe. Depending on the circumstances, however, abrupt stops could create hazards. For example, stopping in response to a parked vehicle adjacent to the travel lane might expose the driver to the hazards of blocking the roadway. The "correct" driver action may, therefore, not be easy to identify. Additional research efforts are required to identify the behaviors drivers exhibit and to obtain estimates of error rates associated with inappropriate responses. In lieu of such data, a simplifying assumption for modeling is that the driver will brake in response to the warning.

Driver System Interface: The type of display used for this system should be addressed in future research. Auditory or visual warnings, or both, could be used with the type of sensing system proposed for the backing crashes. In general, auditory warnings tend to support faster reaction times (Wickens, 1990). It is not known whether this system's warnings will be distinct from those used in other IVHS devices installed in the vehicle or whether a "general purpose" warning will be used for a variety of impending crash situations. Response times to warnings can vary, depending on the design of the warning system.

It is also not known whether the warnings will be coded to include more information than just the presence of a target in a critical area behind the vehicle. For example, visual and auditory coding techniques could be used to denote the location of the target, such as a "surround sound" system to indicate the separation distance and an increased rate of an intermittent tone to indicate decreasing gap distance. This information might be useful to drivers who regularly maneuver into tight parking spaces. However, more complex displays will likely require more time to interpret than will a simple warning. These design issues affect driver performance and merit further research. For purposes of modeling, a simplifying assumption was made that the warning system interface to the driver will be effective and so it was not explicitly modeled, simplifying assumption was made that the warning system interface to the driver will be effective and so it was not explicitly modeled.

Driver Performance: Figure 5-1 clarifies the elements in driver response to emergency situations such as warnings presented in backing situations. While PDRs for alert and surprised response to braking vehicles have been studied (Henderson, 1987), little work has been done for the backing response. Perception time will probably be increased if audio



PDR means Perception-Decision-Response.

Perception involves recognition of target significance and begins after detection and is affected by the nature of the simulus and driver expectancy.

Decision is affected by the development and evaluation of the number of alternative responses.

Response is affected by the time to reach the control once response selection is made.

Vehicle Response is the time lag between driver response to controls and the initiation of vehicle action. For example, this represents delays associated with braking systems.

Vehicle Action is affected by vehicle characteristics such as steering sensitivity, condition of brakes, pavement characteristics, tire conditions, and vehicle speed.

Figure 5-1. Time Elements Affecting Driver Response in Emergency Situations or visual signals are coded to signify rate of closure or location. As discussed earlier, several responses are possible: stop, slow, change direction, or proceed. Hick's law (Welford, 1976) suggests that decision times will increase proportionately with the number of response options.

Expectancy violations (unexpected events) also usually result in increased response times. For example, unexpected events that might increase driver response times are targets reported in locations from which, or at times when, drivers expect no targets.

The driver's visual confirmation of the target is critical when modeling system performance and driver response times. Drivers may often use mirrors and direct looks to the rear to locate targets when a warning is issued. This confirmation time can be quite lengthy depending upon target location and other factors such as target motion, size, and contrast. These delays, collectively referred to as driver RT, could compromise warning system effectiveness.

Task elements in the backing process must be examined. Examples of these tasks are:

- Put vehicle in reverse gear
- Determine desired direction of travel
- Look for potential obstacles
- Locate obstacles
- Assess obstacles relative velocity and distance, if moving
- Assess risk
- Initiate vehicle motion
- Track obstacle during maneuver

To perform initial effectiveness estimates, some driver performance data are needed. Driver brake RT, compliance probabilities, and error likelihoods are relevant inputs to detection system effectiveness estimation, Data from Olsen, Cleveland, Fancher, Kostyniuk, and Schneider (1984) indicated that "surprise reaction times" had a mean = 1.1 s; reaction times ranged from of .81 to 1.76 s (2%-ile to 98%-ile). More recently, Taoka (1989) used a log normal distribution having a centrality parameter of .07 and a dispersion parameter of .49. It should be noted that brake RT include human perception, decision, and response initiation times. Furthermore, detection times can vary depending on whether the signal is visual or auditory.

In the Olsen, et al. (1984) data, the signal was an obstacle in the road, visually perceived. In light of the previous discussion of different display types and different kinds of driver responses, it is not known whether these data are appropriate values for the backing situation. Driver perception, decision, and response times during backing could be much different than those found earlier. Additional research is needed to address this issue. For purposes of modeling, driver brake RT provided by Taoka (1989) are used only as first approximations for modeling backing crashes and warning system effectiveness.

A rear-zone object detection system might be ineffective if the driver ignored the warning altogether or responded only after verifying the warning cause. There are no data in the open literature that addresses the likelihood that a driver would ignore a system warning. This issue is directly related to the false alarm/nuisance alarm issue and the issue of multiple warning systems from which the driver must determine alarm source. This is an area of needed research. The false alarm/nuisance alarm issue is intimately tied to system acceptance by drivers. The specific issues affecting acceptance by drivers include:

- Excessive warnings that occur when the driver is already aware of location of a close proximity target. Here, the information provided by the system is redundant to information already known by the driver.

- Excessive false or nuisance alarms that occur for targets that do not affect the driver. These can result, for example, from the stationary targets in parallel path or curved perpendicular path situations that are perceived by a driver to be too far away to be of concern. Also, moving vehicles or pedestrians that are leaving the sensor’s coverage area can initiate false alarms, which may aggravate the driver. The issue of false or nuisance alarm rates is usually related to the sensor range.

- The system may be unsuitable for preventing certain subtypes of backing crashes, such as straight crossing path crashes. This may lead to acceptance problems if drivers perceive that the system ought to provide protection under any backing circumstances. In this case, drivers may not appreciate the technological challenges associated with providing systems to detect targets under all backing scenarios. The result may be reluctance to trust the device.

In lieu of human performance data on this important issue, full driver compliance is assumed for modeling purposes.

Hendricks, et al. (1992) considered pedal error and determined that this is not likely to impact system effectiveness estimates. Other error types and likelihoods for this crash type are unknown. Thus, driver errors are not explicitly modeled in this report.

5.1.2 Vehicle Considerations

The principal vehicle consideration for effectiveness modeling of detection systems is presumed to be braking level (the constant deceleration rate achieved by the driver/ vehicle/roadway combination). For modeling purposes, a maximum constant vehicle braking level of .7g is assumed. Field measurements taken by Calspan indicate that this is actually a conservative estimate. Given the low travel speeds involved in backing accidents, braking levels as high as .8g may be achieved under some circumstances.

5.1.3 Environmental Considerations

Chapter 4.0 addressed selected environmental factors on sensor technologies. Ultrasonic systems are compromised by conditions such as temperature fluctuations and wind speed, although it appears that distance errors associated with these variables will have relatively little impact in the backing accident application. This conjecture should be verified in a future study.

Radar systems are impaired by precipitation. However, the effects of different precipitants (fog, rain, snow) and the amounts (light, moderate, heavy) merit a systematic literature review to extract degradation factors which might provide more refined estimates of effectiveness. Given that the majority of backing crashes occur under no adverse weather conditions, environmental factors were not specifically modeled.

The operating wave length is a constraint for an active infrared laser system, because visible wavelengths should be avoided so as to prevent eye damage.

5.2 Image-Based Technologies

5.2.1 Driver/Human Factors Considerations

Driver Behavior: Same issues as in Section 5.1.1.

Driver System Interface: Image-based systems are defined here to include such technologies as CCTV, CCD cameras, or fiber optics. All share a common feature: the driver interface is a video display that requires driver visual resources. This, in turn, poses a number of human factors difficulties, as discussed in this subsection, that may substantially reduce such systems' effectiveness for crash avoidance.

[Note: Another class of image-based technologies depends on machine vision or artificial intelligence image processing. Such systems could, in principle, provide warnings to drivers and eliminate the need for a driver video display altogether. Image processing technologies are currently cost-prohibitive for widespread use on cars and so are not considered further in this report. However, they hold promise for alleviating some of the human factors problems discussed below].

Perhaps the most important human factors issue associated with image-based technologies is that they are not warning systems ***per se.*** Image-based systems present views of the scene behind the backing vehicle in a more or less unprocessed way, assuming no machine vision capability. The driver must visually attend to this display and then interpret its contents. Image-based technologies are essentially mute. This is substantially different than a rear-zone object detection system, which sounds an alarm based on currently sensed conditions.

The contents of the video display are subject to many human factors considerations. Displayed images must be of sufficient visual size, contrast, and luminance to be readily discerned. To the extent that automotive video displays are small, this works against object conspicuity. In addition, the clutter in the visual scene may mask critical objects.

The driver's position while backing also affects driver performance with image-based systems. In normal forward driving, the driver faces forward. In contrast, while backing, a driver may face forward and use the mirror system to obtain visual information, or may turn toward the rear and directly view the scene behind the vehicle. In this latter situation, the driver's head could even be partially outside the vehicle if the driver looks to his left through an open side window.

The effect of the driver's position during backing on the effectiveness of a backing sensor system is not known. Clearly, visual display location could be a problem if the driver is looking rearward. A video display on the instrument panel might be ineffective. A video display positioned on the rear-view mirror or mirrors could be more effective. However, it will not be effective when the driver's head is turned to directly look out the back window or when the driver's head is partially outside the vehicle.

Other problems might include interpretation errors for visual displays that use spatial orientation to the driver. For example, while looking at the display from a normal forward-looking driving posture, objects to the left of the sensing unit (camera) might be shown on the right half of the video display. The driver would have to learn that the object is on the passenger's side of the vehicle. Since drivers may use many head orientations during backing, this may be a particularly important concern if the driver's head position during system use is different than the "design" position envisioned by the device manufacturer.

Driver Performance: Same as in Section 5.1.1.

5.2.2 Vehicle Considerations

There are no vehicle considerations specific to image-based systems. However, effectiveness for these technologies, like those for radar or ultrasonic technologies, depend upon maintenance of vehicles for optimal braking levels (.7 g is assumed in the modeling). Furthermore, the number of vehicles suitably equipped will have a substantial impact on overall effectiveness. A simplifying assumption made in the effectiveness modeling of Chapters 6.0 and 7.0 is that all vehicles would be equipped with appropriate equipment and that the equipment would be properly maintained, turned on, adjusted for maximum efficiency, etc. Clearly, real world use will be both gradual and less than perfect.

5.2.3 Environmental Considerations

As noted in Chapter 4.0, imaging systems depend on direct light for their effectiveness. Low Light Level Television (LLLTV) and infrared light sources for night operation are, of course, potential solutions to this problem. Possibly more problematic is reduced image quality caused by obscurants such as fog, rain, snow or resolving power of LLLTV.

5.3 Other Human Factors Considerations for Backing Accident Reduction

Perel (1991) has provided a thoughtful analysis of issues associated with backing accidents involving pedestrians and has identified another potential IVHS countermeasure: an external auditory warning for the pedestrian rather than for the driver. This type of system is similar to backing alarms found on forklifts, garbage trucks, and some heavy vehicles. Based on available analyses, such a system concept has the potential to substantially reduce the incidence of such backing accidents. However, a number of issues merit further research. These include pedestrian behavior toward such alarms. In real world contexts, people may become habituated to such warnings; the effects of age and other factors on warning effectiveness, very young, very old, or hearing-impaired pedestrians may not heed the warning. Also, the nuisance factor is associated with such alarms.

6.0 EFFECTIVENESS MODELING OF A REAR-ZONE OBJECT DETECTION SYSTEM

6.1 Introduction

The pervasiveness of driver "unawareness" as a causal category in backing crashes strongly suggested that a rear-zone object detection system has promise for alleviating parallel path, curved path, and pedestrian/pedalcyclist crash subtypes. On the other hand, preliminary assessment of straight crossing path backing crashes indicated that a vehicle-based rear-zone object detection system is unlikely to be effective. This fourth subtype will probably require a different type of IVHS system and so is discussed separately.

Two different modeling approaches were applied to backing crashes of various subtypes; ***these are*** referred to here as ***factorial modeling*** and ***stochastic modeling.***

Factorial Modeling: In factorial modeling, key factors are identified, fixed levels or values of these factors are selected, and all combinations of all factors are evaluated. The dependent variable evaluated here is **required stopping distance,** which can be compared to **available stopping distance** to determine collision avoidance potential. Factorial modeling is suitable for evaluating multiple factors in combination by means of selected points in the factor space. Occurrence probability may best be estimated by means of joint distributions of the factors involved. Unfortunately, joint distributions were not available, so the assumption adopted here is that the factors manipulated are independent and equally likely to occur as combined. In the analyses reported in this chapter, factorial analysis was used to determine the required stopping distance for a given pre-crash condition. Required stopping distance was compared to available stopping distance to determine whether or not a crash was avoided. By spanning the space of pre-crash factors of interest, the factorial approach provides an estimate of the impact of this set of factors on crash avoidance potential for a countermeasure.

Stochastic Modeling: In stochastic modeling, a key crash parameter (travel velocity at start of braking) is varied to determine its effect on a variable of interest, such as the maximum allowable driver reaction time (t_{RT}) for the vehicle to come to a complete stop within a given distance, e.g., within maximum system sensing range. Then, the cumulative proportion of drivers who can react as fast or faster than the maximum allowable driver RT is determined from an appropriate statistical distribution such as a log normal distribution (cf., Taoka, 1989). Given that the distribution of travel velocities is known or assumed, an overall estimate of crash avoidance potential ***can*** be derived by taking ***the product of the proportion of times a given travel velocity occurs*** and ***the driver RT cumulative proportion (resulting in crash avoidance),*** summed across all velocities under consideration.

Stochastic modeling is well suited to evaluating the impact of a single factor across its full range on a dependent variable, such as maximum allowable driver RT, that may be represented in discrete or continuous form. Since a key element of this approach is to exhaustively assess the full range of a pre-crash factor on a safety-critical dependent variable, this method quickly becomes cumbersome if more than one variable is included in a single assessment. In essence, this approach becomes like the factorial approach but with substantially more combinations. Thus, the stochastic modeling approach is a refinement of the factorial approach. Stochastic modeling allows for a more accurate assessment of a single variable on IVHS warning system effectiveness while factorial modeling allows for an assessment of multiple variables at selected points in the factor space. In one of the analyses reported below, both approaches are applied to the same crash subtype. The results obtained with the two methods appear quite similar. This is to be expected since the same data sources are used in both analyses. Any discrepancy should be attributed to the use of a full continuous distribution in the stochastic case and representative points in the factorial case.

6.2 Parallel Path Backing Crashes

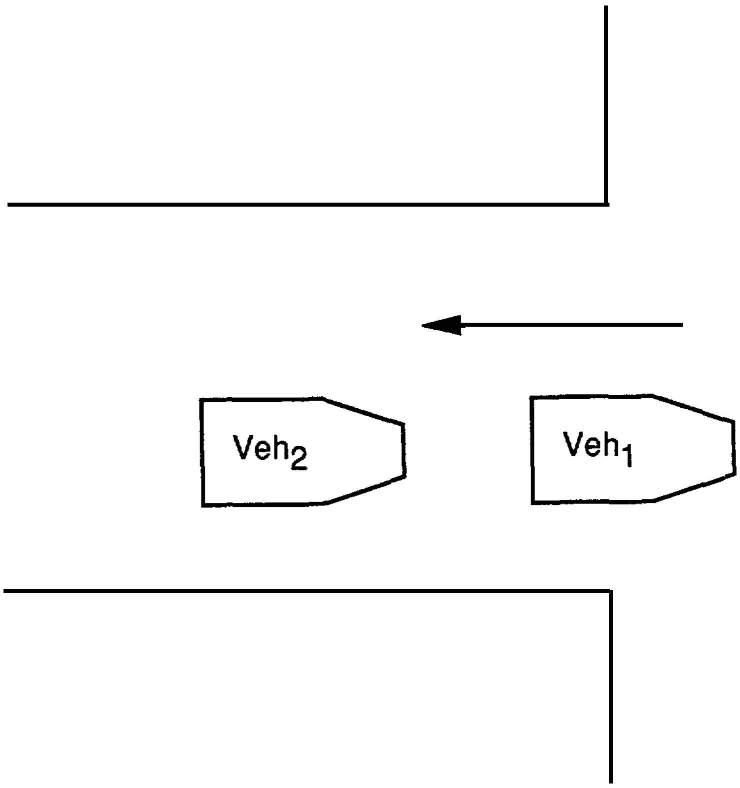
Scenario Description: Parallel path backing crashes typically occur at intersections (Figure 6- 1). The subject vehicle, Vehicle 1 (Veh_1), stops at the intersection beyond a safe stop line and Vehicle 2 (Veh_2) also stops at a gap distance D_{gap} ft behind Veh,. The driver of Veh_1 then shifts into reverse gear and accelerates rearward, hitting the front of Veh_2, which is stationary. This maneuver appears to occur primarily when Veh_1 has stopped in the intersection and is attempting to back out of it.

To prevent the crash, the rear-zone object detection system must alert the Veh, driver to the presence of Veh,. For modeling purposes, it was assumed that Veh_1 will accelerate rearward from rest and continue in motion until the following events occur:

- The detection system detects the following vehicle (Veh_2).
- The system issues a warning to the subject vehicle driver (Veh_1).
- The subject vehicle's (veh_1) driver brakes in response to the system warning.
- Veh_1 reacts to driver braking input.

Modeling Representation: Crash avoidance demands that the detection system provide the driver with adequate time to stop the vehicle within the available gap distance. It was assumed that the system does not issue an alarm until the subject vehicle is placed in reverse gear and rearward movement is initiated. Since the assumed gap distance is usually less than the maximum system range, a warning is immediately issued by the system.

Calculation of distance traveled by Veh_1 before coming to a full stop, when compared to vehicle-to-vehicle gap (available) distance, indicates if the crash can be avoided for a given set of conditions. Veh_1 travels a total distance, D_{vehl}, until reaching a full stop. D_{vehl} is based on the vehicle's acceleration rate, the time available to accelerate (sum of system/vehicle/driver reaction time delays) and the distance required to stop the vehicle once braking is initiated. The equation for the distance traveled is:



- Veh, & Veh, on roadway, traveling in same lane in same direction
- Both vehicles stop
- Veh, reverses direction & hits Veh$_2$

Figure 6-l. Typical Parallel Path Crash Scenario

$$D_{Veh1} = (1/2)a_{accel}(t_{RT} + t_{system\ delay})^2 + V^2/2a_{decel}$$

where: D_{Vehl} = Required stopping distance for subject Vehicle 1

a_{accel} = Acceleration of Veh_1, e.g., 0.11 g or 3.52 ft/s^2

t_{RT} = Driver brake reaction time, e.g., 1.1 s

$t_{system\ delay}$ = Sum of vehicle/system/delays; for example, . 1 s

V = Velocity of Veh_l at start of braking maneuver. Note that $v = a_{accel}(t_{RT} + t_{system\ delay})$, assuming constant acceleration from vehicle start to braking. For example, 3.52 ft/s^2 x 1.2 s = 4.22 ft/s

a_{decel} = Benchmark deceleration rate of 0.7 g = 22.4 ft/s^2

Given the example values above, the distance Vehicle 1 travels before coming to a full stop is

D_{Vehl} = **2.63** ft

Assume that the vehicle-to-vehicle gap was 8.6 ft at the outset of the backing maneuver. Since the distance traveled before coming to a full stop (2.63 ft) is less than the gap distance when the warning is issued (8.6 ft) the crash can be avoided. However, the detection system simply alerts the driver as soon as the vehicle is put in reverse and vehicle motion is initiated. The ensuing alarm may be considered a nuisance in those instances where the driver already knows that there is a vehicle behind the driver's vehicle. Unfortunately, little information is available about the false alarm/nuisance alarm phenomenon in the open driver performance literature and so it was not possible to model it.

Modeling Factors, Fixed and Variable: The above modeling concept next needs to be extended to account for the randomness of the data. Table 6-l lists all of the factors and assumptions used in modeling parallel path backing crash subtype. Values for each variable are indicated along with the source or logic behind the assumptions made.

As can be seen in the table, five driver RTs were chosen. The chosen percentile values represent the centers of their respective quintile ranges. Thus, the 0 - 20th percentile range is represented by the 10th percentile RT; the 20th to 40th percentile range is represented by the 30th percentile; and so on.

Table 6-l also indicates a range of rearward accelerations. These were derived from data presented in Appendix C of this report. Note that no distributional data assumptions about this range of values must be made to arrive at crash avoidance potential.

Table 6-l. Factors Used and Assumptions Made in the Modeling of Parallel Path Backing Crashes

Factor	Level	Source or Selection Rule
Driver Brake RT (t_{RT}):	.57 s (10th percentile) 83 s (30th percentile) 1.07 s (50th percentile) 1.39 s (70th percentile) 2.01 s (90th percentile)	Specific values for each percentile based on Taoka's (1989) log normal distribution with centrality parameter of .07 and dispersion parameter of .49.
Rearward Acceleration Rates (a_{accel}):	0.05g 0.07g 0.09g 0.11g 0.13g	Values span the range of average accelerations found in small scale field study (see Appendix C).
Assumed Vehicle Motion:	Uniformly accelerated motion from vehicle initially at rest until braking	Plausible assumption detailed from analysis of this backing crash subtype.
Initial Gap Distance:	4.80 ft (12.5th percentile) 6.50 ft (37.5th percentile) 9.00 ft (62.5th percentile) 13.50 ft (87.5th percentile)	Values taken from empirical distribution of 271 gaps measured in a field study for this report (see Appendix B).
Assumed Driver Response:	Brake	Simplifying assumption, in lieu of more definitive understanding of range and incidence of various driver pre-crash behaviors.
Assumed Driver Compliance:	Full	Simplifying assumption because no information available to model driver response to false or nuisance alarms.
Driver Error Rate:	No errors	Based on Knipling, et al. (1993) assessment for simple psychomotor errors.
Vehicle Braking Level:	.7g assumed	Engineering estimate for this scenario.
Vehicle Braking System Time Delay:	0.0 s	Assumed essentially instantaneous buildup of brake pressure due to the low travel velocities involved.
Vehicle Travel Velocity at Start of Braking:	a_{accel} (t_{RT} + $t_{system\ delay}$) ft/s	Assumed constant acceleration from initial stationary position until start of braking after a total time delay of (t_{RT} + $t_{system\ delay}$) s.
Detection System Logic:	Warning upon setting gear into "reverse" and initiating motion	Most simple system (barring human factors problems with high false or nuisance alarm rates).
Detection System Time Delay:	.1 s	Assumed time from initial sensing until alert is given to the driver.

Table 6-1. Factors Used and Assumptions Made in the Modeling of Parallel Path Backing Crashes (continued)

Factor	Level	Source or Selection Rule
Detection System Range:	15 ft	Average value of systems currently on the market.
Range Resolution:	.1 ft	Based on review of existing systems. Treated as essentially perfect resolution.

General Note: The NASS cases were reviewed to determine typical values for relevant pre-crash parameters. In general, there was not enough detail available in the case listings to derive needed modeling data. Thus, field observations, assumed values, and data from published sources were used as necessary.

Four initial gap values were chosen for the analysis. The percentile values were determined from the empirical, not theoretical, percentiles obtained from the 271 observations collected in a field study for this effort and summarized in Appendix B of this report. The four values represent the centers of their respective quartiles. Thus, the 12.5 percentile represents the 0 to 25th percentile range; the 37.5th percentile represents the 25th to 75th percentile range; and so on.

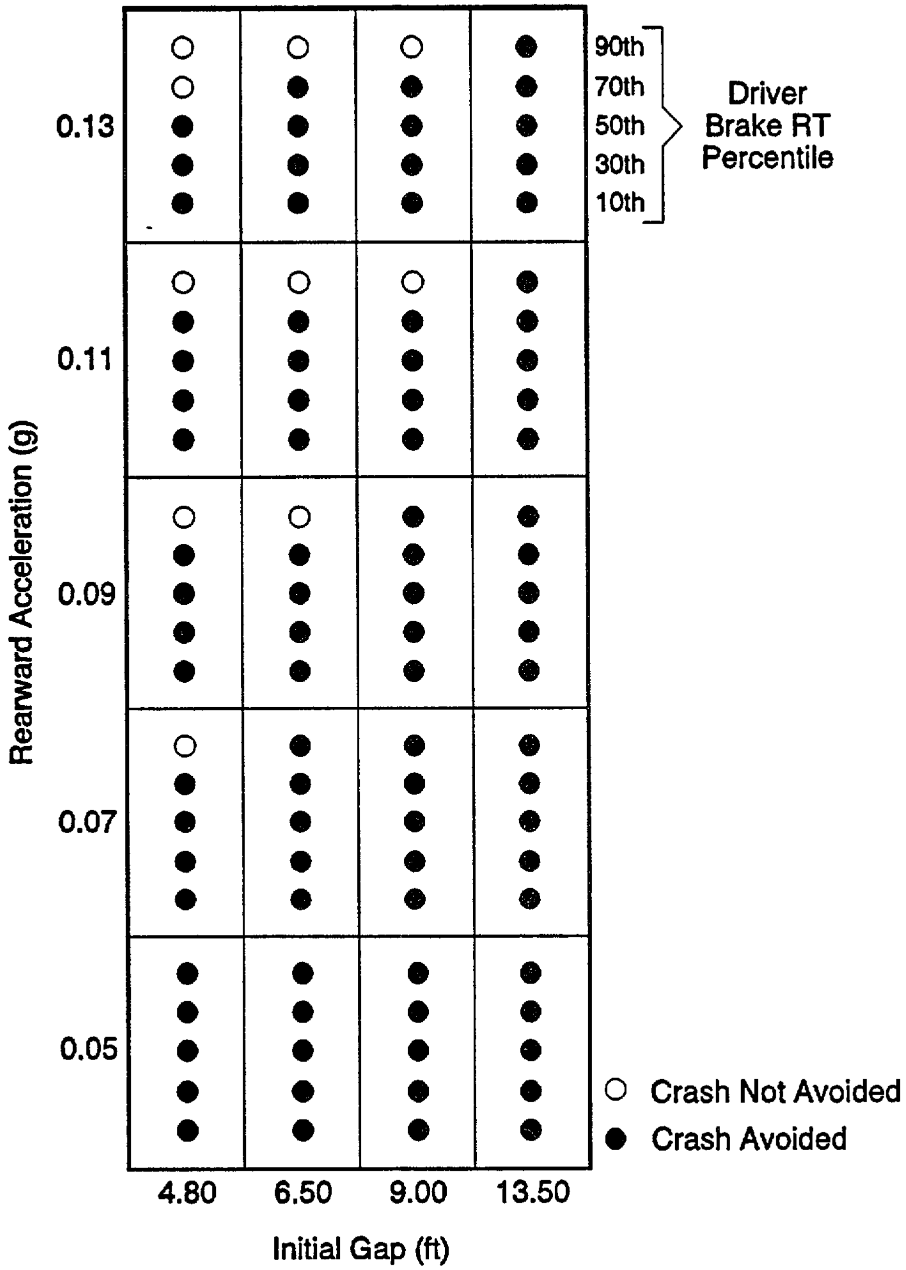
Method: A ***factorial modeling*** method was used in this analysis. As was mentioned earlier, the term "factorial" means that levels of one manipulated factor were systematically combined with factors of another factor. For example, five levels of driver RT combined with four levels of backing acceleration and five vehicle-to-vehicle gap distances generate

5X4X5 = 100 combinations

Effectiveness for each combination is determined and the total warning system effectiveness is the sum of the combinations. This assumes that each combination is equally likely to occur in the real world, a simplifying but often questionable assumption. To provide more precise modeling results, one must know the joint distributions of the factors under study. Unfortunately, this information was not available for this effort, so independence among factors and equal likelihood for combinations of factors were assumed.

Results: The 100 factorial modeling runs for this backing crash subtype are presented in Appendix D. Each combination of driver RT, initial gap distance, and backing acceleration were evaluated to determine if crash avoidance was possible under the conditions assumed.

The results from Appendix D, Table D-l, are presented graphically in a matrix chart in Figure 6-2. This chart depicts the joint effects of backing acceleration, initial vehicle-to-vehicle gap distance, and driver RT on crash avoidance/non-avoidance (depicted as closed



Note: Based on data in Appendix D, Table D-4.

Figure 6-2. Matrix Chart of Parallel Path Crash Modeling Results and open circles), respectively. Higher accelerations, short gap distances, and slower driver RTs lead to more crashes not avoided; this is clear from the increasing number of open circles as one moves from lower right to upper left in the chart and from bottom to top in a cell. The data presented in Figure 6-2 show that problems are generally associated with the slowest drivers. Assuming that all combinations of the three factors are equally likely to occur in the real world, then the crash avoidance potential for the functional rear-zone object detection system is estimated to be 90 percent for this subtype (90 crashes avoided out of 100 scenarios evaluated).

6.3 Curved Path Backing Crashes

Scenario Description. Curved path backing crashes involve a subject vehicle (Veh_1) backing out of a parking space or private driveway along a curved travel path (Figure 6-3). The backing vehicle then strikes a stationary (parked) vehicle (Veh_2) or object.

This backing crash subtype is amenable to vehicle-based rear-zone object detection system technology. Since the struck vehicle or object is stationary, the system is likely to detect the vehicle or object at the system’s maximum range of 15 ft, barring obstructions between the sensor and the potentially struck vehicle. When a vehicle backs out of a driveway, vehicles or objects can be detected at the maximum range of the system if they are within sensor lateral range. Since this distance is usually greater than one-half the width of the typical passenger vehicle, virtually every object within the vehicle’s path is detected at the maximum range of the system. This will, unfortunately, increase false detection rates as well.

Modeling representation. For the IVHS countermeasure to be effective, the system must provide sufficient warning to allow the driver to react and stop the vehicle prior to impact. Specifically, the total distance traveled by the subject vehicle following a system warning must be less than the range of the system (15 ft). The following equation calculates the distance the backing vehicle travels after a warning is issued:

$$D_{vehl} = V(t_{RT} + t_{system\ delay}) + V^2/2a_{decel}$$

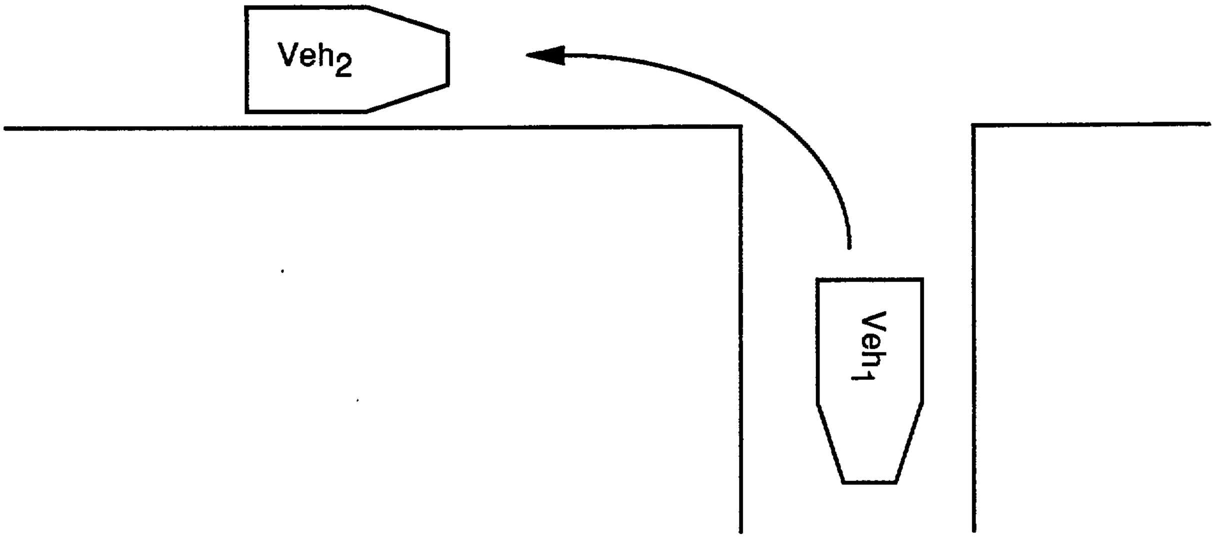
where: D_{Vehl} = Distance traveled after warning alarm until full stop

V = The velocity of the backing vehicle (Veh_1) at start of braking, for example, 5 mph (7.33 ft/s)

t_{RT} = Driver brake reaction time, for example, 1.1 s

$t_{system\ delay}$ = Total system delay, for example, .1 s

a_{decel} = Benchmark deceleration rate of 0.7 g = 22.4 ft/s^2



- Veh$_2$ stationary
- Veh$_1$ backs into Veh$_2$

Figure 6-3. Typical Curved Path Crash Scenario

Given the previous example values, the total distance traveled from alarm to full stop is approximately

$$D_{Veh1} = 10 \text{ ft}$$

Since the distance traveled before coming to a full stop (10 ft) is less than the linear gap distance when the warning is issued (15 ft) the crash can be avoided. Again, the detection system simply alerts the driver as soon as the vehicle is put in reverse and vehicle motion is initiated. The alarm may be considered a nuisance in those instances when the driver already knows that there is a vehicle or obstruction behind the driver's vehicle. Unfortunately, little is available about the false alarm/nuisance alarm phenomenon in the open driver performance literature, so it was not possible to model it.

Modeling Factors, Fixed and Variable: Again, as in the previous section, this modeling concept next needs to be extended to account for the randomness of the data. Table 6-2 lists all of the factors and assumptions used in modeling the curved path backing crash subtype. Values for each variable are indicated along with the source or logic for the assumptions. Essentially, driver RT, vehicle travel velocity, and the start of braking were varied; all other key factors were fixed in the analysis.

Table 6-2. Factors Used and Assumptions Made in the Modeling of Curved Path Backing Crashes

Factor	Level	Source or Selection Rule
Driver Brake RT (t_{RT}):	.57 s (10th percentile) .83 s (30th percentile) 1.07 s (50th percentile) 1.39 s (70th percentile) 2.01 s (90 percentile)	Specific values for each percentile based on Taoka's (1989) log normal distribution with centrality parameter .07 and dispersion parameter of 49.
Driver Brake RT Alternate:	Log normal distribution with centrality parameter = .07 and dispersion parameter = .49	Taoka (1989) log normal distribution model of surprisal brake reaction time data.
Rearward Travel Velocity:	1 to 10 mph in 1 mph increments	Chosen based on engineering judgment to span the range of likely velocities. Empirical distribution unknown. In lieu of distribution, a simplifyiig assumption was made that all velocities are equally likely.
Assumed Vehicle Motion:	Constant velocity motion when vehicle enters sensor range. No acceleration assumed.	Plausible assumption given characteristics of this crash subtype.
Assumed Driver Response:	Brake	Simplifying assumption, in lieu of more definitive understanding of range and incidence of varied driver precrash behaviors.
Assumed Driver Compliance:	Full	Simplifying assumption since no information was available concerning driver response to false or nuisance alarms.
Driver Error Rate:	No errors	Based on Knipling, et al. (1993) assessment for simple psychomotor errors.
Vehicle Braking Level:	.7g assumed	Engineering estimate for this scenario.
Vehicle Braking System Time Delay:	0.0 s	Assumed essentially instantaneous buildup of brake pressure due to the low travel velocities involved.
Detection System Logic:	Warning upon setting gear into "reverse* and motion.	Most simple system (barring human factors problems with high false or nuisance alarm rates).
Detection System Tie Delay:	.l s	Assumed time from initial sensing until alert is given to the driver.
Detection System Range:	15 R	Average value of systems currently on the market.
Range Resolution:	.l ft	Based on review or existing systems. Assumed essentially accurate ranging.

Table 6-2. Factors Used and Assumptions Made in the Modeling of Curved Path Backing Crashes (continued)

Factor	Level	Source or Selection Rule
Effects of Curved Path:	Nil	Simplifying assumption for first approximation modeling effort. Based on lateral sensing range supported by existing systems. Assumes no object (e.g., a building) occludes sensor line of sight.
Location:	On-roadway Off-roadway	Based on GES data. Assumed to make no difference in system effectiveness.

General Notes: The NASS cases were reviewed to determine typical values for relevant pre-crash parameters. In general, there was not enough detail available in the case listings to derive needed modeling data. Thus, field observations, assumed constant values, and data from published sources were used as necessary.

As in the previous analysis, five driver RTs were chosen for factorial modeling. The chosen percentile values represent the centers of their respective quintile ranges. Thus, the 0 - 20th percentile range is represented by the 10th percentile RT, the 20th to 40th percentile range is represented by the 30th percentile, and so on.

Method. Two different modeling approaches were applied for this backing crash subtype. The first method is ***stochastic modeling.*** As was mentioned earlier, in the stochastic modeling method, a key crash parameter (travel velocity at start of braking) is varied to determine the maximum allowable driver RT for the vehicle to come to a complete stop within the sensing range (15 ft). Then, the cumulative proportion of drivers who can react as fast or faster than the maximum allowable driver RT is determined from a log normal distribution (cf., Taoka, 1989). Given that the distribution of travel velocities is known, or is assumed, an overall estimate of crash avoidance potential can be derived by taking the product of the proportion of times a given travel velocity occurs and the driver RT cumulative proportion, these products summed across all velocities under consideration. Table 6-3 presents the results of this analysis.

Table 6-3. Stochastic Modeling of Curved Path Backing Crashes

(1) Rearward Travel Velocity (mph)	(2) Rearward Travel Velocity (ft/s)	(3) Prop. of Pop. (P)	(4) Max. Allowable Driver RT to Stop in Time (s)	(5) Prop. of Drivers Reacting as Fast or Faster (P_{RT})	(61 Crash Avoidance Potential (P_{avoid})
1	1.47	.1	10.07	.9999	.09999
2	2.93	.1	4.95	.9991	.09991
3	4.40	.1	3.21	.9875	.09875
4	5.86	.1	2.33	.9429	.09429
5	7.33	.1	1.78	.8485	.08485
6	**8.80**	**.1**	**1.41**	**.7123**	**.07123**
7	**10.27**	**.1**	**1.13**	**.5675**	**.05675**
8	**11.73**	**.1**	**.92**	**.3783**	**.03783**
9	**13.20**	**.1**	**.74**	**.2236**	**.02236**
10	**14.67**	**.1**	**.59**	**.1112**	**.01112**
				Cumulative Crash Avoidance Potential:	.677

Notes:

(1): Engineering estimate of rearward velocities with which to conduct the modeling;

(2):

(3): Actual distribution unknown. Assumed uniform distribution over range 1 to 10 mph as first approximation model.

(4): $t_{RT} = ((D_{veh1} - V2/2a_{decel})/V) - t_{systemdelay}$. Derived from distance traveled equation in Section 6.2 of th report. Note that D_{veh1} = 15 ft sensing range. Value of a_{decel} assumed to be 22.4 ft/s^2.

(5): Given log normal distribution for driver RTs, $Z_{pRT} = (\ln(t_{RT}) - .07)/.49$ (from Taoka, 19891, Z is normally distributed N(O,I). For any Z, corresponding values of P_{RT} are found in a table of standard normal deviates (e.g., Devore, 1982).

(6): $P_{avoid} = P_V P_{RT}$. Cumulative Crash Avoidance Potential is the sum of all P_{avoid} values.

The factorial modeling approach was the second method used to model this backing crash subtype. Each of 5 driver RTs were combined with each of 10 travel velocities at the start of braking to yield 50 factorial combinations. If the countermeasure is to prevent the crash, the distance calculated must be less than 15 ft, the range at which the system detects the object/vehicle. At 15 ft the system resolution is .1 ft, so it was assumed to be essentially 100 percent accurate. Appendix D presents the results of this analysis.

Results: Assuming a uniform distribution of travel velocities from 1 to 10 mph, Table 6-3 indicates that the total crash avoidance potential is estimated to be approximately 67.7 percent using the stochastic modeling method.

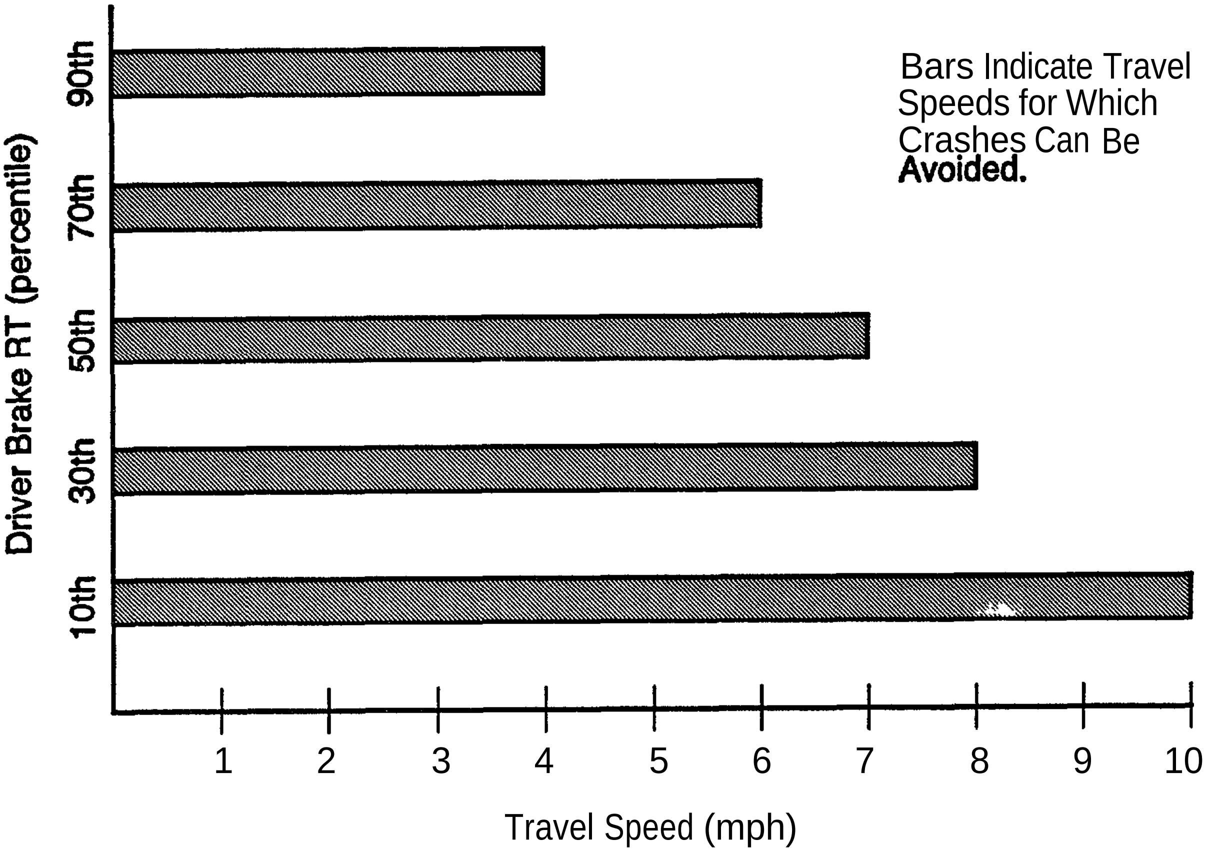
The results from Appendix D, Table D-2, are graphically presented in Figure 6-4. This figure uses a bar chart format to illustrate the maximum pre-crash travel speed at which crashes can be avoided, assuming a given percentile driver RT. In general, over the range of 1 to 10 mph, the range of "safe" travel speeds reduces from 10 mph for the fastest (10th percentile) driver RTs evaluated to 5 mph for the slowest (90th percentile RTs). The factorial modeling results yield an estimated crash avoidance potential of 70 percent for this subtype (35 crashes avoided out of 50 scenarios evaluated). Although the two modeling methods were different, the results were quite similar.

On-roadway vs. off-roadway (e.g., parking lot) scenarios provide identical effectiveness estimates since the same equation applies to both. In the parking lot circumstance, however, the system will detect a number of vehicles at the 15 ft range while the subject vehicle backs along a curved trajectory. These multiple detections are likely to trigger multiple warnings, thus creating a potential for false or nuisance alarms. While evaluation of false or nuisance alarms is beyond the scope of the current effort, this issue must be addressed in future evaluations.

6.4 Pedestrian/Pedalcyclist Backing Crashes

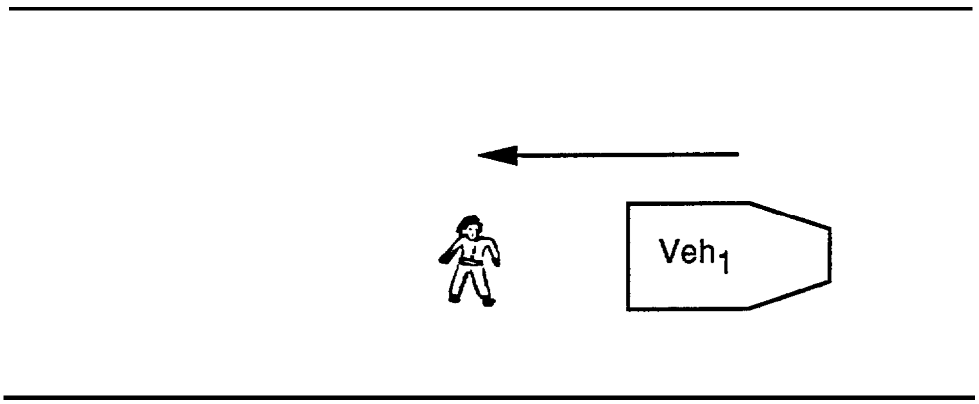
Scenario Description: This subtype includes all pedestrian/pedalcyclist crashes that occur while the subject vehicle is backing on the roadway or in off-roadway locations. Due to the severity of injuries sustained by the pedestrian/pedalcyclist, this crash type has the most severe injury consequences of the four identified crash subtypes (with the possible exception of straight crossing fatal crashes). A schematic depiction of a typical pedestrian/pedalcyclist crash is provided in Figure 6-5.

Analytical modeling of this subtype was difficult due to the lack of detail in available case reports; therefore, several basic assumptions were made. For example, it was assumed that the pedestrian/pedalcyclist and the driver either did not observe the other party or that both parties anticipated that the other party would stop. A second assumption involved the initial separation distance between the vehicle and the pedestrian/pedalcyclist. This distance could not be established with available case data. Therefore, it was assumed that the pedestrian/pedalcyclist is located within the maximum effective range limit of the system when the crash avoidance sequence is initiated.



Note: Based on data in Appendix D, Table D-2.

Figure 6-4. Crash Avoidance/Non-Avoidance Thresholds, in mph, for Curved Path Backing Crashes



- Pedestrian or pedalcyclist behind Veh,
- Veh, backs and hits pedestrian or pedalcyclist

Figure 6-5. Typical Pedestrian/Pedalcyclist Crash Scenario

Modeling Representation: This backing crash subtype has two major variations to consider in the modeling. One type occurs when the backing vehicle is reversing with uniform acceleration from a rest position. The other type occurs when the vehicle is backing at a constant velocity (no acceleration). Backing from rest occurs in on-roadway crashes (e.g., at intersections) but it is even more likely to be seen in off-roadway crashes, such as in parking lots or residential driveways. Backing at constant velocity more likely occurs in on-roadway crashes. These simplifying assumptions are used later to estimate potential effectiveness of the rear-zone object detection system for the pedestrian/pedalcyclist.

Consider the case where the subject vehicle is initially at rest and backs up with uniformly accelerated motion over a specified gap distance between the vehicle and the unseen pedestrian/pedalcylist. Here the following model representation is appropriate.

First, the subject vehicle velocity when it enters the sensing range must be known. To determine this, calculate the following:

$\text{Initial Gap} - R = \text{Gap}_{\text{before}}$ where Initial Gap = Assumed initial distance (in ft) between vehicle and pedestrian, e.g., 9 ft

R = Sensor range, e.g., 5 ft

$\text{Gap}_{\text{before}}$ = The distance traveled (in ft) before vehicle is within sensing range, 9 ft - 5 ft = 4 ft

The following basic kinematic equation can be used to determine the time required to cover the $\text{Gap}_{\text{before}}$ distance:

$$\text{Gap}_{\text{before}} = V_o t + 1/2\ a_{\text{accel}}\ t^2$$

where V_o = Initial velocity (0 ft./s since vehicle initially at rest)

t = Travel time for vehicle to cover $\text{Gap}_{\text{before}}$ distance

a_{accel} = Backing acceleration, e.g., 2.88 ft/s^2.

so

$$\mathbf{t = SQRT\{\ (Gap_{before} - V_o t)/(1/2\ \ a_{accel})\}.}$$

For the example above, the $\text{Gap}_{\text{before}}$ distance is covered in t = 1.67 s.With this and the backing acceleration value, one can calculate the vehicle travel velocity when it reaches the sensing range distance from the pedestrian/pedalcyclist by the equation

$$V = V_o + a_{\text{accel}}\ t.$$

For the example, V equals 4.8 ft./s.

Now that the vehicle's travel velocity upon reaching the sensor range is known, the required stopping distance can be determined by the following equation:

$$D_{vehl} = V_b(t_{RT} + t_{system\ delay}) + (1/2)a_{accel}\,(t_{RT} + t_{system\ delay})^2 + V^2/2a_{decel}$$

where:

D_{vehl} = Distance traveled after warning alarm until full stop

V_b = The velocity of the backing vehicle (Vehicle 1) just <u>before</u> it reaches the sensor range to the pedestrian/pedalcyclist. e.g., 4.8 ft/s

t_{RT} = Driver brake reaction time, e.g., 1.39 s

$t_{system\ delay}$ = Total system delay, e.g., . 1 s

a_{accel} = Backing acceleration of Veh,, e.g., 2.88 ft/s^2

V^2 = The square of the subject vehicle's velocity when braking commences. Since the vehicle continues to uniformly accelerate during the $(t_{RT} + t_{system\ delay})$ period, then $V = V_b + a_{acccl}\,((t_{RT} + t_{system\ delay}))$, e.g., 9.09 ft/s from the values given above

a_{decel} = Benchmark deceleration rate of 0.7 g = 22.4 ft/s^2.

Given the example values above, the distance Veh, travels before coming to a full stop would be

$$D_{vehl} = 12.19 \text{ ft}$$

The effective system detection range for this crash subtype is assumed to be 5 ft, an engineering estimate based roughly upon pedestrian/pedalcyclist cross-sections and the reflectivity from the human body. In the illustration above, since the distance traveled before coming to a full stop (12.19 ft) is more than the stopping distance available when the warning is issued (5 ft), the crash cannot be avoided. Again, the detection system logic simply alerts the driver as soon as the vehicle is put in reverse and vehicle motion is initiated. The ensuing alarm may be considered a nuisance when the driver already knows that there is a pedestrian or pedalcyclist behind the backing vehicle. Unfortunately, little is available about the false alarm/nuisance alarm phenomenon in the open driver performance literature and so it was not possible to model it.

In the case where the vehicle is already in motion when it enters the sensing range of the detection system, the following modeling representation is appropriate:

$$D_{vehl} = V \; (t_{RT} + t_{system\ delay}) + V^2/2a_{decel}$$

where: D_{vehl} = Distance traveled after warning alarm until full stop

V = The velocity of the backing vehicle (Veh_1) at start of braking, for example, 2 mph or 2.93 ft/s

t_{RT} = Driver brake reaction time, for example, 1.1 s

$t_{system\ delay}$ = Total system delay, for example, .l s

a_{decel} = Benchmark deceleration rate of 0.7 g = 22.4 ft/s^2

For the example values provided, the distanced traveled would be

D_{vehl} = 3.74 ft

Given that the detection system effectively provides an available stopping distance of 5 ft, crash avoidance is achievable in this instance.

Modeling Factors, Fixed and Variable: The above modeling concepts next need to be extended to account for the randomness of the data. Table 6-4 lists all factors considered in the modeling of the pedestrian/pedalcyclist case.

An important simplifying assumption made about the pedestrian or pedalcyclist involved is that the person essentially “freezes” once in the vehicle’s path. This may not be realistic, particularly for pedalcyclists. The assumption is adopted in lieu of detailed information concerning pedestrian/pedalcyclist behavior under such situations in order to support a first approximation model.

Method: A factorial modeling approach was used for the pedestrian/pedalcyclist backing crash subtype. In the case where the backing vehicle is in motion at the time of the system warning, driver RT and vehicle velocity are varied and all other factors are fixed. In the case where the backing vehicle is initially at rest at the time of system warning, driver RT and vehicle rearward accelerations are varied and all other factors are fixed.

Results when the backing vehicle uniformly accelerates from rest arc graphically depicted in the matrix chart of Figure 6-6; these data are from Appendix D, Table D-3. Figure 6-6 shows, in comparison to the matrix chart of Figure 6-2, that:

- Fewer crashes are avoided in the pedestrian/pedalcyclist case.

Table 6-4. Factors Used and Assumptions Made in the Modeling of Pedestrian/Pedalcyclist Backing Crashes

Factor	Level	Source or Selection Rule
Driver Brake RT (t_{RT})	.57 s (10th percentile) .83 s (30th percentile) 1.07 s (50th percentile) 1.39 s (70th percentile) 2.01 s (90th percentile)	Specific values for each percentile based on Taoka's (1989) log normal distribution with centrality parameter of .07 and dispersion parameter of .49.
Rearward Travel Velocity (constant velocity scenario):	1 to 10 mph in 1 mph increments	Chosen based on engineering judgment to span the range of likely velocities. Empirical distribution unknown. In lieu of a distribution, a simplifying assumption was made that all velocities are equally likely.
Rearward Acceleration Rates (a,,) (uniform acceleration from rest scenario):	0.01 g (0.32 ft./s^2) 0.03g (0.96 ft/s^2) 0.05g (1.60 ft/s^2) 0.07g (2.24 ft/s^2) 0.09g (2.88 ft/s^2)	Values span the range of average accelerations found in small scale field study (Appendix C). Values have been adjusted downward based on engineering estimate that is intended to better appproximate off-roadway backing.
Assumed Driver Response:	Brake	Simplifying assumption, in lieu of more definitive understanding of range and incidence of varied driver behaviors.
Assumed Driver Compliance:	Full	Simplifying assumption because no information available concerning driver response to false or nuisance alarms.
Driver Error Rate:	No errors	Based on Knipling, et al. (1993) assessment for simple psychomotor errors.
Vehicle Braking Level:	.7g assumed	Engineering estimate for this scenario.
Vehicle Braking System Time Delay:	0.0 s	Assumed essentially instantaneous buildup of brake pressure due to the low travel velocities involved.
Detection System Logic:	Warning upon setting gear into "reverse" and initiating motion	Most simple system (barring human factors problems with high false or nuisance alarm rates).
Detection System Time Delay:	.I s	Assumed time from initial sensing until alert is given to the driver.

Table 6-4. Factors used and Assumptions Made in the Modeling of Pedestrian/Pedalcyclist Backing Crashes (continued)

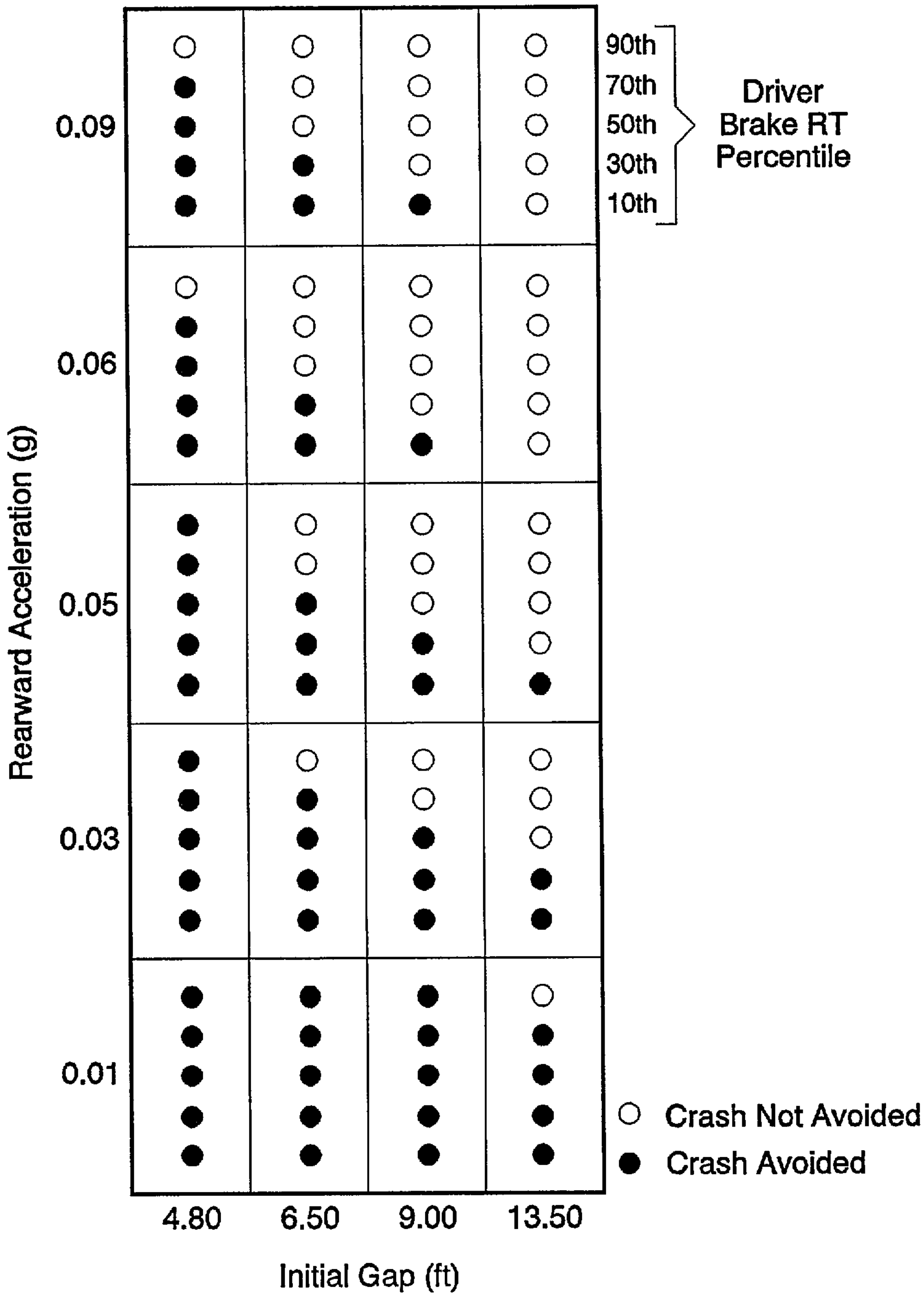
Factor	Level	Source or Selection Rule
Detection System Range:	5 ft	Engineering estimate assuming 1/3 of 15 ft range due to pedestrian and pedalcyclist cross-section and reflectance. Not supported by a published data source or measurements.
Range Resolution:	.1 ft	Based on review or existing systems. Assumed essentially accurate range.
Pedestrian/Pedalcyclist Location:	Pedestrian or pedalcyclist assumed to be behind backing vehicle until collision or collision is avoided.	Simplification.
Initial Gap between Vehicle and Pedestrian (uniform acceleration from rest scenario):	4.80 ft (12.5th percentile) 6.50 ft (37.5th percentile) 9.00 ft (62.5th percentile) 13.50 ft (87.5th percentile)	Values taken from empirical distribution of 271 vehicle-to-vehicle gaps measured in a field study for this effort (see Appendix B). These data used in lieu of more data, which were unavailable at the time of this analysis.

General Note: The NASS cases were reviewed to determine typical values for relevant pre-crash parameters. In general, there was not enough detail available in the case listings to derive needed modeling data. Thus, field observations, assumed values, and data from published sources were used as necessary.

- The patterning of crashes not avoided increases from lower left to upper right rather than from lower right to upper left.

These differences result because the analysis assumed a warning system range of 15 ft in the parallel path case. This implies that, in the scenarios modeled, drivers receive an alert immediately upon backing.

In the pedestrian/pedalcyclist case, however, the assumed sensing range is only 5 ft. Therefore, an interval exists during which the vehicle is gaming velocity before it reaches the 5 ft sensing range and the alert starts. The larger the initial gap, the longer is this interval

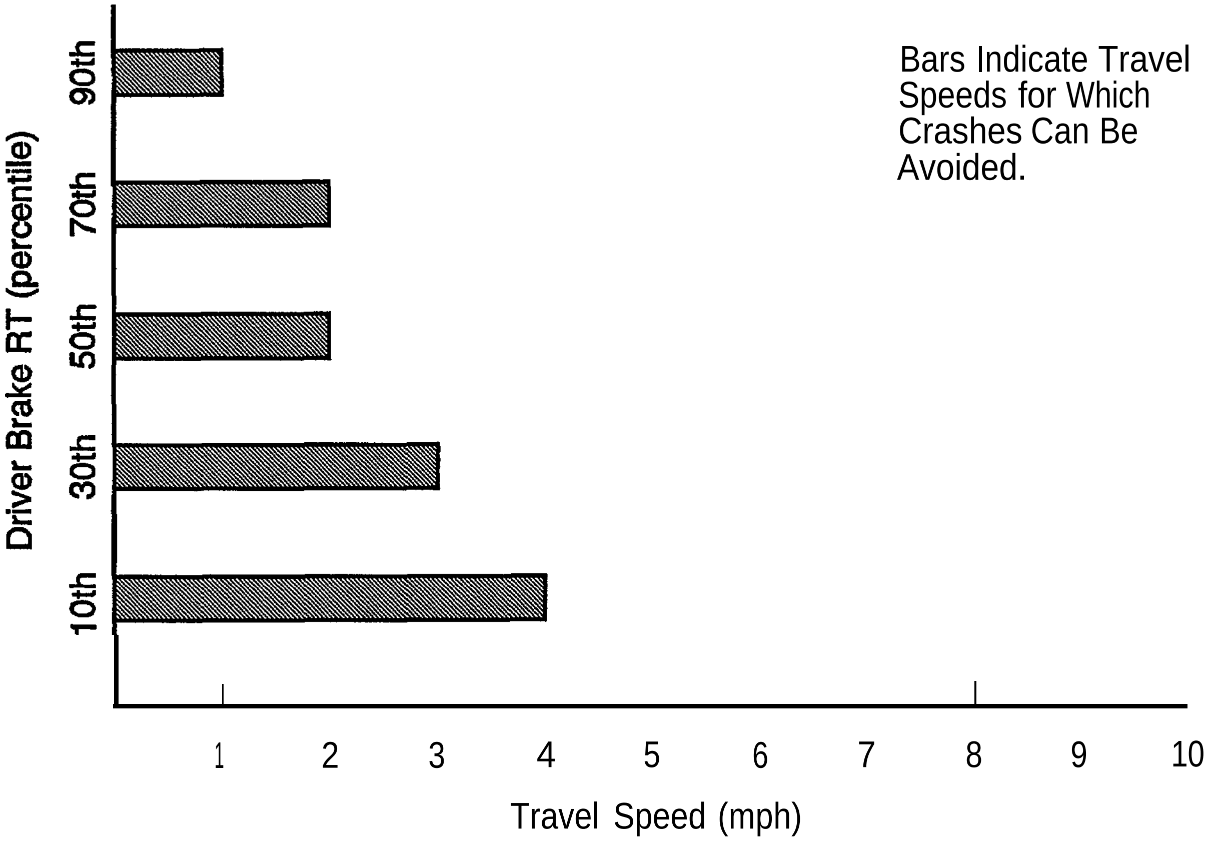


Note: Based on data in Appendix D, Table D-3.

Figure 6-6. Matrix Chart of Pedestrian/Pedalcyclist Modeling Results: Vehicle Uniformly Accelerated from Rest

and consequently the faster the vehicle is going by the onset of the alert. This places greater demands on driver response, which, as the analysis indicates, cannot be met in many instances. The factorial modeling results indicate an estimated 58 percent crash avoidance potential for this case (58 crashes avoided out of 100 scenarios evaluated).

Figure 6-7 illustrates the results of the pedestrian/pedalcyclist evaluation when the backing vehicle is in motion with constant velocity. As can be seen, the 5 ft assumed sensing range limits maximum pre-crash travel speeds within which crash avoidance is feasible. Indeed, even the 10th percentile driver cannot exceed about 4 mph and still hope to avoid a crash. As indicated in Appendix D, Table D-4, the crash avoidance potential is relatively poor, estimated at only 24 percent (12 crashes avoided out of 50 scenarios evaluated).



Note: Based on data in Appendix D, Table D-4.

Figure 6-7. Crash Avoidance/Non-Avoidance Thresholds, in mph, for Pedestrian/ Pedalcyclist Modeling Results: Vehicle in Motion with Constant Velocity

The actual distribution of travel velocities and rearward accelerations are unknown for either case. A uniform distribution for each was assumed for illustrative purposes and to provide some first approximation for further refinement. The relationship between these variables and driver RT is also unknown and was assumed to be independent. More refined analyses are possible with the method as more information is obtained about how these critical variables vary in real world contexts.

The pedestrian/pedalcyclist analysis results can be considered further in light of the differences between pedestrian and pedalcyclist behaviors. The simplifying assumption made in the modeling reported above is that the pedestrian or pedalcyclist essentially is at a standstill behind the vehicle during the pre-crash period. Consider that, instead, the pedestrian or pedalcyclist is moving. Pedestrian and pedalcyclist movement rates determine the time the individual is within the IVHS warning system's lateral sensing zone (the sensing range longitudinally is assumed to be a constant 5 ft). This time in the lateral sensing zone, in turn, sets an upper boundary on the time available for driver warning, which may be further reduced by vehicle backing speed.

Hulbert (1982) presents data from several studies of walking rates from adult, elderly and child samples. Data from one of the cited studies is presented in Table 6-5. As

Table 6-5. Walking Rates for Adults and the Associated Time Within the Sensing Range

(1) Walking Rate ft/s	(2) Adult Percentile %ile	(3) Lateral Sensing Range ft	(4) Time in Sensing Range s
3.1	10	7.75	7.75/3.1 = 2.50
4.1	30	7.75	7.75/4.1 = 1.89
4.6	50	7.75	7.75/4.6 = 1.68
5.6	70	7.75	7.75/5.6 = 1.38
6.7	90	7.75	7.75/6.7 = 1.16

Notes:

(1) and (2): Data taken from Hulbert (1982).

(3): Lateral Sensing range, assuming a longitudinal sensing range of 5 ft. computed as:

Lateral Sensing Range (5 ft) = 6 ft + (.5) (5/20) (20-6) ft = 6 + 1.5) 3.5 ft = 7.75 ft. The (5/20) (20-6) expression interpolates lateral range given the information gleaned from Chapter 4.0. Consider that the pedestrian moves into range from one side of the vehicle. Then one might take half of the 3.5 ft additional lateral range and assume the pedestrian or pedalcyclist is available to be sensed for 3.5/2 or 1.75 ft plus 6 ft for a total of 7.75 ft.

(4): The Time in Sensing Range is simply the Lateral Sensing Range divided by the Walking Rate.

indicated, these values vary from 3.0 ft/s to over 7.0 ft/s. The corresponding times the adult pedestrian would be in the rear-zone object detection system is determined in the table to range from 2.5 s to 1.16 s. As upper bounds, these values indicate the appropriateness of the driver RTs used in the effectiveness modeling; even at 6.7 ft/s, the time the pedestrian is in the sensing zone is longer than the average driver RT. Future analyses that build on the analyses reported here should more fully investigate the impact of pedestrian walking rates on backing crash avoidance potential.

Hulbert (1982) also provides data on bike speeds. According to one of the sources cited, bike speeds measured in Davis, California ranged from 7 mph (10.3 ft/s) to 15 mph (22 ft/s) with an average of between 10 and 11 mph (16.1 ft/s). Average cycle length is 5.75 ft. The bike must fully clear the 6 ft wide vehicle to avoid a collision; otherwise, it is possible that the bike might be clipped and injury could still occur. Table 6-6 indicates the times the pedalcyclist is in the warning system sensing zone at a 7, 11, and 15 mph. Respectively, these times are 1.28, .82, and .6 s. Comparing these times to the range of driver RTs used in the effectiveness modeling, it suggests that, for even average bike speeds, less than 30 percent of the driver population could hope to respond in time. On the other hand, a moving object may be more readily detected by the driver. A further analysis of the pedalcyclist case should be undertaken to more fully explore this situation.

Table 6-6. Bike Speeds and the Associated Time Within the Sensing Range

(1) Bike/Riding Rate ft/s	(2) Bike Speed Category	(3) Lateral Sensing Range ft	(4) Time in Sensing Range s
10.3	Bike (slow)	13.25	13.25/10.3 = 1.28
16.1	Bike (average)	13.25	13.25/16.1 = .82
22.0	Bike (fast)	13.25	13.25/22.0 = .60

Notes:

(1) and (2): Data taken from Hulbert (1982).

(3): Lateral Sensing Range, assuming a longitudinal sensing range of 5 ft, computed as 7.5 ft. In addition, bike length of 5.75 ft is added to allow for the extra time the bike is within the crash hazard zone.

(4): The Time in Sensing Range is simply the Lateral Sensing Range divided by the Walking Rate.

6.5 Straight Crossing Path Backing Crashes

The fourth subtype, straight crossing paths, is qualitatively different from the first three. This difference is primarily because the other vehicle involved is traveling at a high velocity relative to the backing vehicle. It suddenly comes upon the backing vehicle as the backing driver inadvertently backs into the travel lane. Modeling efforts confirmed a suspicion that the straight crossing path backing crash will require a different type of IVHS countermeasure than the other three subtypes. In particular, an effective vehicle-based IVHS rear-zone warning system could not be envisioned. Modeling the rear-zone object detection system used in the other three subtypes yielded very minimal benefits and is not presented here.

Future work should be directed toward addressing this subtype alone, especially since the straight crossing path backing crash is the most prevalent of all backing crashes – 53.4 percent of the 1990 GES backing crash population. It is possible that infrastructure-based approaches may be effective. For example, sensors embedded in the pavement might telemeter warning or situation display information to the backing driver so the driver can wait until there are no approaching vehicles before backing. This approach may well be cost prohibitive, however, and so is not modeled here.

6.6 Summary and Conclusions

Baseline performance levels for the rear-zone object detection system are summarized in Table 6-7. Modeling results indicate that this IVHS countermeasure is likely to have a significant effect in reducing backing crashes, particularly the parallel path backing crashes. Over the range of travel speeds assumed, the IVHS countermeasure is also quite effective in reducing the curved path backing crashes. Although somewhat less effective for the pedestrian/pcdalcyclist backing crash subtype, the countermeasure provides results that are highly dependent on the vehicle scenario (moving at uniform acceleration from rest vs. moving at constant velocity). The results are also affected by the assumed limited range.

The values for crash avoidance potential developed in the modeling effort should be considered preliminary only. Due to lack of data, many assumptions were made to complete the modeling. The validity of these assumptions and the sensitivity of the results should be verified. In particular, knowledge of vehicle backing velocities, accelerations, and combinations of these and other variables are needed to improve predictions. Similarly, driver behavior in the face of high false or nuisance alarm rates must be better understood and eventually incorporated into the modeling for improved prediction.

A number of parameters were empirically derived, using relatively small experimental samples. For example, the value used for the typical backing acceleration rate was established with a sample of six drivers who completed 30 acceleration runs. In terms of validity considerations, the value should be established with much larger samples. This same

Table 6-7. Rear-Zone Object Detection System Effectiveness Rates

Crash Subtype	Crash Avoidance Potential %
Parallel Path	
On-Roadway	90
Off-Roadwav	90
Curved Path	
On-Roadway	70
Off-Roadwav	70
Pedestrian/Pedalcyclist	
Vehicle moving at uniform acceleration from rest	58
Vehicle moving at constant velocity	24
Straight Perpendicular Path	
On-Roadway	*
Off-Roadway	*

Note: *) Rear-zone object detection system is not considered suitable for this crash type.

deficiency applies to several other parameters, such as the constant velocity backing rate. To increase the validity and applicability of the modeling conducted for this effort, it is recommended that additional efforts be devoted to firmly establishing the modeling parameters.

Percentage estimates of modeling data are provided to the first decimal place for individual cases. This convention may imply a finer level of precision than is actually warranted, given the simplifying assumptions made for modeling and the **many** driver, vehicle, and environmental factors that will affect actual system effectiveness. Nevertheless, this rounding convention has been adopted to help show trends in the data across multiple variables. The results ***are theoretical approximations*** based on various simplifying assumptions and limited case samples. The results do not incorporate a consideration of driver, vehicle and environmental factors, which were addressed in Chapter 5.0.

7.0 ESTIMATE OF BENEFITS FROM THE PROPOSED COUNTERMEASURES

Modeling results demonstrate that a vehicle-based rear-zone object detection system would reduce the magnitude of the backing crash problem significantly. Baseline performance levels and effectiveness rates were established in Chapter 6.0. Those rates are used in this chapter to estimate the total proportion of backing crashes that could be avoided with introduction of this countermeasure.

7.1 Calculation of Benefit

The final effectiveness rates established in Chapter 6.0 are reproduced from Table 6-7 and are shown as the first numeric column of Table 7-l. The percentage of all backing crashes represented by each crash subtype was originally presented in Table 3-3. These proportions are presented in the second numeric column of Table 7-l weighted by the proportion, .874, of causal factor incidence for which the rear zone object detection system is suited. Note that this assumes the distribution of causal factors affects all crash subtypes similarly. The crash subtypes are further designated by on-roadway or off-roadway crash location and these data, taken from Wang and Knipling (1993), are also presented in the second numeric column. For the pedestrian/pedalcyclist backing crash subtype, off-roadway statistics are assumed to apply to the uniform acceleration from rest scenario. The on-roadway statistics are assumed to apply to the constant velocity scenario.

The percentage of all backing crashes avoided by applying the rear-zone object detection system countermeasure to the specific conditions within each crash subtype is shown in the second numeric column. This column represents the product of multiplying the first and third columns. As indicated by the total at the bottom of the table, it is estimated that the rear-zone object detection system countermeasure, as modeled, could achieve crash avoidance in approximately 28 percent of backing crashes that occur each year. Note that, for the backing crash subtypes to which the vehicle-based rear-zone object detection system applies, this translates to approximately 70 percent potential effectiveness ([28/(23.1+ 15.1+ 1.4)]x100). In addition, such a system might also provide crash severity reduction in those cases where crash avoidance is not feasible.

Table 7-l. Estimated Benefits Calculations

Crash Subtype/ Condition	(1) Crash Avoidance Potential (P)	(2) Percentage of Applicable Backing Crashes	(3) Percentage of All Backing Crashes Avoided (%)
Parallel Path			
On roadway	.90	22.8 (.87) = 19.9	17.9
Off roadway	.90	0.3 1.87) = 0.3	.3
Curved Path			
On roadway	.70	10.4 (.87) = 9.0	8.3
Off roadway	.70	4.7 (.87) = 4.1	2.9
Pedestrian/Pedalcyclist			
Vehicle moving at uniform acceleration from rest	.58	0.7 (.87) = 0.6	0.3
Vehicle moving at constant velocity	.24	0.7 (.87) = 0.6	0.1
Straight Crossing Path		*	
On roadway	*	*	*
Off roadway	*	*	
“Not applicable”	*	*	*
Total			27.8

Notes:

(1) Data taken from Table 6-7.

(2) Each percentage is multiplied by the proportion which represents the unaware driver as a crash casual factor, i.e. .874 or about 87% from Section 3.3.

(3) Estimated percentage of all backing crashes avoided, by row, is the product of column (1) and column (2). The total given in the lower right hand corner is the sum of all products across crash subtypes.

(*) A rear-zone object detection system is not considered suitable for this crash type.

(a) See text in Chapter 3.0 for discussion of crash cases in this category.

8.0 RESEARCH AND DEVELOPMENT NEEDS

The purpose of this chapter is to present R&D needs associated with IVHS crash avoidance technology for backing crashes. Issues in human factors, data collection and modeling, and sensor system development are discussed. Table 8-1, located at the end of the chapter, summarizes these needs.

8.1 Human Factors Research Needs

8.1.1 Driver Response to False or Nuisance Alarms

Information Needed: Throughout the modeling effort, driver reaction to false or nuisance alarms was not considered, due to lack of data. Yet, it may be the single greatest threat to the success of an otherwise useful IVHS crash avoidance countermeasure. Driver behavior in the face of false detections, as well as missed detections, is critical to designing effective rear-zone object detection systems. What is needed is a better understanding and quantitative characterization of the following key points:

- What constitutes "high" false alarms?
- What are driver reactions to false or nuisance alarms? The driver might disregard the warning (which affects the probability of a response), spend time to verify the warning (which affects the latency of a response), or some combination of both.
- What are the situational variables that affect driver reactions to false or nuisance alarms? Drivers may tolerate false or nuisance alarms much better under certain driving conditions than others, for example, when backing from a driveway in a residential neighborhood with many children.
- What system design features might enhance driver acceptance of the system? Examples might include a simple means to turn off the alarm given an appropriate action by the driver, e.g., touches the brake pedal.

General R&D Approach: A literature review could be conducted to describe current knowledge about human response to false or nuisance alarms. Unfortunately, relatively few references are likely to be found in the open literature and many will undoubtedly deal with military or process control applications. Care should be taken to determine the degree to which lessons learned in these areas apply to backing crashes.

Driver behaviors in response to a warning system during various levels of false alarm rates could be determined by experimental methods. Backing crash scenarios could be designed to explore the range of driver behaviors exhibited. In particular, the theory of signal detection (McNichol, 1972; Green and Swets, 1966) may be an appropriate theory to apply to this problem. Particular attention could be devoted to assessing whether two detectors (driver and system) working together have lower sensitivity than the more sensitive detector alone, because of false or nuisance alarms. Ultimately, a quantitative representation of the false detection problem could aid in both future modeling and in countermeasure development.

8.1.2 Appropriate Driver Response to a Rear-Zone Object Detection System Warning While Backing

Information Needed: Chapter 6.0 modeling assumed that the driver always braked to a stop within a certain reaction time after receiving a system warning. However, Chapter 5.0 listed other possible driver responses, such as making a steering correction, looking rearward before making a change in vehicle trajectory, and so on. A better understanding of driver pre-crash behavior could support better predictive modeling since driver behaviors affect what happens. Insights into what drivers really do just before a backing crash might also help with the design of more effective rear-zone object detection systems.

General R&D Approach: A review of the driver performance literature could provide initial information upon which to build an empirical study. Carefully crafted test scenarios, built from a database of actual backing crashes, could be used to collect empirical data such as driver behaviors and latencies associated with various driver activities; and measurements of key vehicle parameters such as rearward velocity, acceleration, braking profile, and trajectory. The range of the independent variables (e.g., IVHS system vs. no IVHS system) in each scenario could be manipulated to elicit a complete picture of the driver’s response. Each experiment could measure entities such as attention to certain perceptual cues and response times. Driver acceptance of the rear-zone object detection system might be measured by observational techniques or post-experiment driver interviews.

8.1.3 Driver Error Rates

Information Needed: The incidence of various driver errors such as pedal error, steering error, and recognition error in backing crash scenarios is not known. Crash avoidance countermeasure effectiveness modeling could be improved with an assessment of which errors occur, under what conditions, and with what relative frequencies.

General R&D Approach: A combination of archival research and empirical methods using a wide range of simulated driving scenarios might be a sound R&D approach. A literature review could provide insights into the issue of human errors in general and driver errors in particular. As drivers make errors in an experimental context, the scenarios could be adjusted to explore the causes of the errors and possible remedies to these errors. Post-experiment interviews could be conducted to understand whether or not the driver was cognizant of error sources. Interviews could also provide a way to elicit driver recommendations for eliminating errors. However, the goal of understanding causes and remedies for driver errors is probably of greater practical importance than only knowing the frequency of the errors. It could be difficult to experimentally develop defensible human error probabilities since they are generally infrequent.

8.1.4 Format of the Rear-Zone Object Detection System Display

Information Needed: The type of display used for this system is an issue that could be addressed before continuing with modeling efforts. Either auditory or visual warnings, or both, could be used with the type of sensing system proposed for backing crashes. It is not known whether the warnings from this system will be distinct from those used in other IVHS devices or whether a general warning will be used for a variety of impending crash situations. Response times to warnings can vary, depending on the design of the warning system; it may be desirable to gather information about these response times.

General R&D Approach: First, the literature could be searched for information on the content of warning displays in the backing scenario. Then, an array of displays could be developed and driver interactions and responses measured during various simulated driving scenarios. Auditory and visual cues would probably vary across the types of displays; quantitative and qualitative assessments of their effectiveness could be made.

8.1.5 Content of the Rear-Zone Object Detection System Driver Interface

Information Needed: Warnings may be coded to include more information than just the presence of a target in a critical area behind the vehicle. The location of the target, the separation distance, closing velocity, and other data might be encoded using visual or auditory cues. An understanding of the information required by drivers to avoid the backing crash could therefore be useful.

Another possibility is that crash avoidance for many backing crashes might be achieved with an information display rather than a warning. Perhaps a situation display might be designed that warns of possible collision hazards. Chapter 5.0 suggested some of the human factors challenges to designing a robust display for drivers engaged in backing maneuvers, but the benefits of a such a system could make the effort worthwhile. Therefore an assessment of the effectiveness of an information-only system probably merits consideration.

General R&D Approach: The literature could be searched about warning formats. Much potentially relevant work has been done in aviation and military contexts about warning presentation and situation displays; some lessons learned in those settings might be applied to the roadway environment.

Empirical work could follow the literature review to investigate the effect of information displays and warnings of various types on the driver. Driver behaviors and response times to various interfaces could be used to ascertain the effect of alternative design concepts in various backing crash scenarios. Driver acceptance of these interface designs could also be assessed using subjective methods such as interviews and psychological scaling.

8.1.6 Driver's Position Relative to the Warning Display During the Backing Maneuver

Information Needed: The relationship between the driver's position during backing and a backing sensor system's effectiveness is not known. One could hypothesize that driver response times might be longer or more variable than those observed for other kinds of in-vehicle displays because of the additional head and body movements required to view displays or reach controls. Display location is an important factor.

Another concern is the possible misinterpretation of visual and auditory displays that use spacial orientation when presenting target location information. This may be important in the backing maneuver if the driver's head position is different than envisioned by the device's manufacturer.

General R&D Approach: Empirical studies of the driver's position during backing could be performed for a full range of driving scenarios after a review of the literature. The range of driver positions, ability to reach various configurations of warning system controls, effectiveness of auditory and visual cues to avoid collisions during backing, and driver acceptance are examples of the data that could be collected.

8.1.7 Driver Reaction Times

Information Needed: The driver reaction times for braking (from Taoka, 1989) were presented and used in modeling. These RTs were obtained from studies of "surprised" drivers who responded to objects or events occurring in the road ahead of the vehicle. It is not known whether these data are appropriate values for the backing situation. Driver Perception-Decision-Response (PDR) times during backing could be different than those found earlier.

General R&D Approach: The literature on driver reaction times could be reviewed. Then, scenario-based empirical studies could be conducted to collect driver RT (i.e., perceptual information, decision-making, and response execution time) to a variety of warning systems during backing. Collected data could be compared to data in the literature to deduce the generalizability of the studies in the literature to the backing scenario and to augment the knowledge base with data collected in a backing context.

8.2 Data Collection and Modeling

8.2.1 Accident Knowledge Database for Collision Avoidance

Information Needed: The ability to model a variety of crash types in many ways could be very beneficial. To do this efficiently, a collision dynamics database is needed. It could enable a researcher to use a common database for a variety of crash modeling efforts. A collision dynamics database could provide information such as the identifying locations and relative motions of vehicles and fixed objects for modeling backing crashes. This type of database could complement data on normal vehicle kinematics and driver behaviors with data specific to conditions that led to a crash.

General R&D Approach: Detailed crash descriptions could be collected and analyzed. This work could build on current accident reconstruction analyses. A database could be designed that uses the types of data available in these detailed descriptions after the data are cataloged and entered into the database.

8.2.2 Market Penetration

Information Needed: The effectiveness estimates in Chapter 7.0 assumed that all involved vehicles are equipped with the proposed IVHS crash avoidance technology. Actually, technology will be gradually introduced into the vehicle population. Therefore, the proportion of suitably equipped vehicles will probably be lower in the early years of market penetration than it will be in later years. It could be useful to model this.

General R&D Approach: The model could cover a planning horizon and explicitly incorporate the results into effectiveness estimates. It could use parameters such as: estimates for vehicle replacement rates, the initial numbers of drivers using the technology, and the year when government mandates occur. Comparing the model both with and without the market penetration variable could provide useful insights into the optimum rate of technology introduction to maximize cost effectiveness and safety.

8.2.3 Distribution of Subject Vehicle Kinematic Variables

Information Needed: The modeling effort in this report generally suffered from insufficient information about the distribution of key kinematic variables such as travel velocity and rearward accelerations over the crash population. It could be helpful to collect such information to support future effectiveness modeling and the development of detection systems. Furthermore, data on the joint distribution of key pre-crash variables, such as the correlation between travel speed and acceleration, could also enhance the modeling effort and predicted results.

General R&D Approach: Empirical data collection in test track conditions might be used for some of the data collection. Scenarios that reconstruct the major backing crash subtypes could be used in this data collection effort and instrumented cars could provide an effective means for data capture. One could use accident case listings to determine pre-crash vehicle conditions and their incidence.

8.3 Sensor System Effectiveness

8.3.1 Appropriateness of Existing Backing Sensors for Passenger Vehicles

Information Needed: Backing sensors are used for commercial environments such as loading docks, depots, and construction sites. They may or may not be appropriate for passenger vehicle applications. For example, the existing sensors may not provide sufficient range for a passenger vehicle to stop in time to prevent a particular type of backing crash. Thus, these sensor systems could be evaluated for non-commercial situations.

Information is needed about:

- Detection ranges versus target types, sizes, materials and orientations with respect to the backing sensor antenna pattern.
- Target detection range as a function of transmitter power/signal wave form and frequency.
- Effectiveness of the backing sensor under a variety of conditions, including various initial backing velocities, deceleration rates, driver reaction times, and driver compliance levels.

General R&D Approach: Field tests could be performed using backing sensors installed on passenger vehicles. The tests could involve various backing scenarios and a representative driver population. Measurements could include detection ranges related to target types and backgrounds, driver RTs, and compliance levels.

8.3.2 IVHS Countermeasure for the Straight Crossing Path Backing Crash

Information Needed: Over one-half of the backing crashes reported in the 1990 GES were straight crossing path crashes. The vehicle-based rear-zone object detection system modeled for the other three backing crash subtypes would be largely ineffective in straight crossing path backing situations, based on preliminary modeling efforts not reported here. There is a need to develop an IVHS crash avoidance countermeasure for this crash type, but it is not clear what form this countermeasure should take.

General R&D Approach: Alternatives to the vehicle-based technologies could be considered, such as infrastructure or combined infrastructure/vehicle-based technologies. In addition, alternative driver interface concepts could be developed and tested with a sample of drivers. For instance, a simple driver-information display may be effective if it lights up when another vehicle is within a danger zone. The driver could use this to make decisions about when, or whether, to proceed with the backing maneuver. The straight crossing path backing problem is difficult to assess because of the velocity differences and directions of vehicles involved, but any gains in collision avoidance would be worth investigating.

Table 8-l. Priority R&D Needs for Use of IVHS Technology in Preventing Backing Accidents

Human Factors	
R&D Needs	Key Issue to be Addressed
Driver Response: False or Nuisance Alarms	Types of responses to warning
Driver Response: Detection System Warnings	Types of responses to warning
Driver Error Rates	Incidence of inappropriate responses by type
Warning Design: Format	Appropriate modalities and codes for rear zone object detection systems
Warning Design: Content	Necessary and sufficient warning information on backing
Driver's Position	Relationship between driver's position and sensor display
Driver Reaction Times	Reaction time specific to backing problem; appropriate distribution mode
Data Collection and Modeling	
R&D Needs	Key Issue to be Addressed
Accident Knowledge Database	Develop library of accurate scenarios for modeling purposes
Market Penetration	Estimate proportion of equipped vehicles over time
Distribution of Kinematic Variables	Insufficient empirical data to support modeling effort
Sensor Systems	
R&D Needs	**Key** Issue to be Addressed
Appropriateness of Existing Sensors for Passenger Vehicles	Determine effectiveness of existing sensors for passenger vehicles
IVHS Countermeasures for Straight Crossing Path Crash Type	Develop and test alternative IVHS technologies.

APPENDIX A

CASE WEIGHTING SCHEME FOR COMBINED GES/PAR AND NASS SAMPLE

Crash Severity	# in Sample	% of Sample	% of 1990 GES	Case Weight	% Rep. by Each Case	Weighted % of Sample
0 (0)	103	69.13	90.96	1.32	0.883	90.95
1 (C)	25	16.78	5.62	0.33	0.225	5.63
2 (B)	8	5.37	2.61	0.49	0.326	2.61
3/4 (A/K)	13	8.72	0.82	0.09	0.063	0.82
Total	149	100.00	100.01			100.01

NOTES:

1) GES crash severity based on cases involving all vehicle types. Cases of unknown severity were counted as "0" cases.

2) There was an implicit assumption that, within each severity level, the combined GES PAR and NASS sample was representative of the national crash experience. In other words, there were no biases in the GES PAR and NASS case selection processes.

3) Severity levels 3 and 4 (A and K) were combined because of the small number of 4 (K) severity cases.

4) Case weights are the ratio (% of 1990 GES) / (% of Sample).

5) % Represented by Each Case is the ratio (% of 1990 GES) / (# in Sample).

6) Weighted Percents are (# in Sample) x (% Rep. by Each Case).

APPENDIX B

DETERMINATION OF VEHICLE-TO-VEHICLE GAP DISTANCES

Introduction

To perform the crash modeling and countermeasure effectiveness assessment for the parallel path crash subtype, typical vehicle-to-vehicle gap distances had to be determined. Due to a lack of appropriate reference material for this subject, direct measurements were performed at various roadway, traffic control and community locations. Contained in this appendix is a description of the sample sites, method of data collection and data collected.

Sample Sites

Since the object of the measurement effort was to determine the gap a following driver establishes when stopping at an intersection, distinct intersection types with different traffic control and intersection locations were selected. A total of eleven sites involving eight distinct intersection types were monitored to obtain the data contained in this appendix. Table B-l provides a summary description of site locations. An effort was made to seek a diverse site sample so that no one situation predominated. As is evident in the table, however, business locations form a large part of the sample. This was required to have sufficient traffic flow to allow efficient data collection and was not a deliberate effort to skew the data.

Method of Data Collection

To obtain the data presented in this appendix, initial gap distances were measured from 271 sample observations of “typical” vehicle-to-vehicle gap distances. The gap distances were established when a lead and following vehicle came to a complete stop. These data include car to car, car to truck, truck to car, and truck to truck entries; no effort was made to differentiate the gap types. As each vehicle came to complete stop, the gap between the lead rear bumper and following forward bumper were marked on the pavement. With this method four to five vehicle gap samples could be acquired within a given traffic signal cycle. Measurement of the marked gaps was completed using a measuring wheel. These measurements were then recorded in sequence on a standardized field log.

Sample Data

The data collected during this exercise are summarized in Table B-l. This table provides the location, sample size, minimum, maximum, statistical average (mean) and standard deviation of the sample. A final average of 8.6 feet is a weighted average derived to remove biases caused by unequal samples.

Table B-l. Gap Distance Data Summary

Item	Roadway	No.	Min	Max	Mean	S.D.
1	4-way int. stop light residential	24	5.0	17.0	11.0	3.36
2	4-way int. stop light business	21	5.4	17.4	10.4	3.61
3	3-way "T" int.. stop sign rural	12	2.2	12.2	6.9	4.03
4	4-way int. stop light business	5	5.6	13.5	8.1	3.19
5	4-way int. stop light business	14	2.7	17.6	9.8	5.18
6	4-way int. stop light business	16	4.4	12.8	8.3	2.75
7	4-way int. stop light residential	31	3.6	16.1	7.4	2.94
8	4-way int. stop light business	32	2.9	17.3	9.2	4.13
9	4-way int. stop light business	30	2.4	11.5	5.7	2.11
10	4-way int. stop light business	50	3.7	15.6	7.2	2.91
11	3-way "T" int. stop light rural	36	5.2	22.5	11.4	4.19

Total Samples: 271

APPENDIX C

DETERMINATION OF VEHICLE BACKING ACCELERATIONS

Introduction

During the course of the modeling presented in Chapter 6.0, the need for vehicle backing acceleration rate data became apparent. These data were essential for modeling those crash subtypes where the vehicle was accelerating from rest. A literature review indicated that the required parameters are not well documented. Therefore, an experiment was devised to establish typical acceleration values from a convenience sample of drivers. This appendix describes the test and the data acquisition method, and shows graphs of the results.

Test Description

Although it would have been preferable, from a statistical viewpoint, to establish backing acceleration values with a large sample of diverse drivers and a large fleet of test vehicles, time constraints did not allow this. Therefore, data points were limited to six drivers (four male and two female) who performed backing maneuvers in one instrumented vehicle. Typical data runs were 8 to 11 seconds.

The G-analyst”, a tri-axial accelerometer with a hand-held recording unit, was used to determine vehicle backing acceleration. The recording unit can gather data for eight minutes at a rate of 10 samples per second per channel. A liquid crystal diode (LCD) monitor allows the user to monitor peak G levels in real-time and to replay data. The G-analyst” is mounted to the vehicle and the operator sits in the vehicle passenger seat. The device was installed in a 1984 Dodge Aries equipped with a 2.2 liter four-cylinder motor and automatic transmission.

Each driver performed two backing maneuvers in a controlled test track environment and repeated the maneuvers five times. These maneuvers may be described as follows:

- Acceleration from rest onto a perpendicular roadway. This procedure was intended to duplicate typical accelerations of vehicles backing from a driveway onto a roadway.
- Acceleration from rest for a length of 30 ft. This procedure was intended to duplicate a driver’s acceleration rate for a driver backing on the roadway. The test started with the vehicle moving forward. The driver stopped the vehicle, reversed gear, and backed for the 30 ft interval.

Backing Acceleration Rates

Table C-1 summarizes the acceleration data gathered in the experiments. The values listed are the average accelerations of the five separate runs each driver performed. Peak acceleration and average acceleration rates are provided for both backing scenarios. The mean of the average acceleration values was used for the modeling described in Chapter 6.0.

Table C-1. Summary of Backing Accelerations

		Curved Path		Straight Path	
Driver	M/F	Peak (g)	Average (g)	Peak (g)	Average (g)
1	M	0.11	0.04	0.30	0.12
2	M	0.17	0.06	0.26	0.10
3	F	0.14	0.05	0.22	0.09
4	M	0.14	0.05	0.17	0.08
5	F	0.15	0.05	0.23	0.09
6	M	0.24	0.08	0.27	0.10

Figures C-1 and C-2 show typical time histories of acceleration acquired during this effort. In both maneuvers it can be observed that the acceleration occurs for only 4 to 5 seconds. The remaining event time includes motion at a constant or slowly decreasing velocity (coasting) and then braking. In the examples shown, the braking portion of the time history is excluded. These graphs are included for completeness.

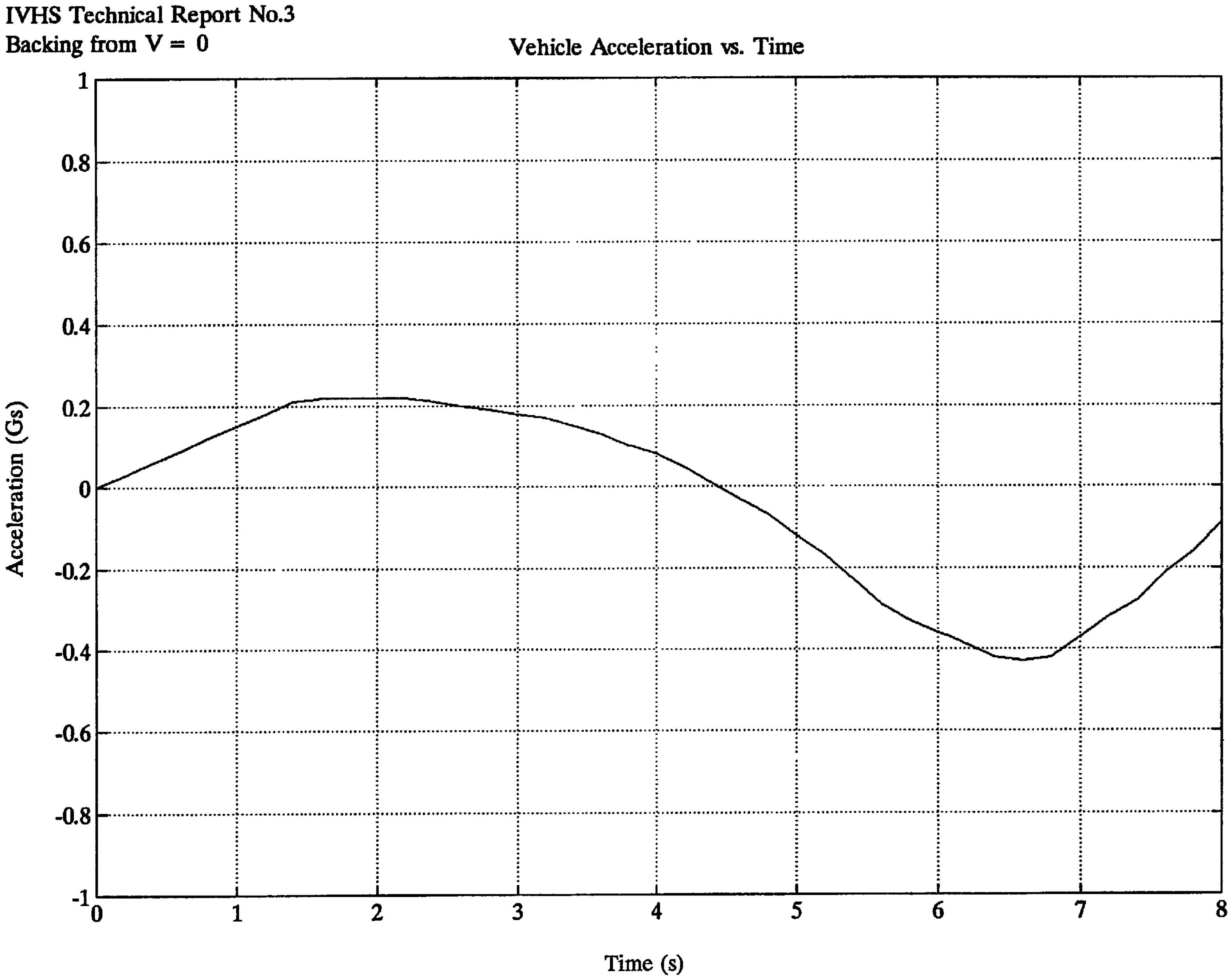


Figure C-1. Acceleration Data Trace of Vehicle Backing Straight

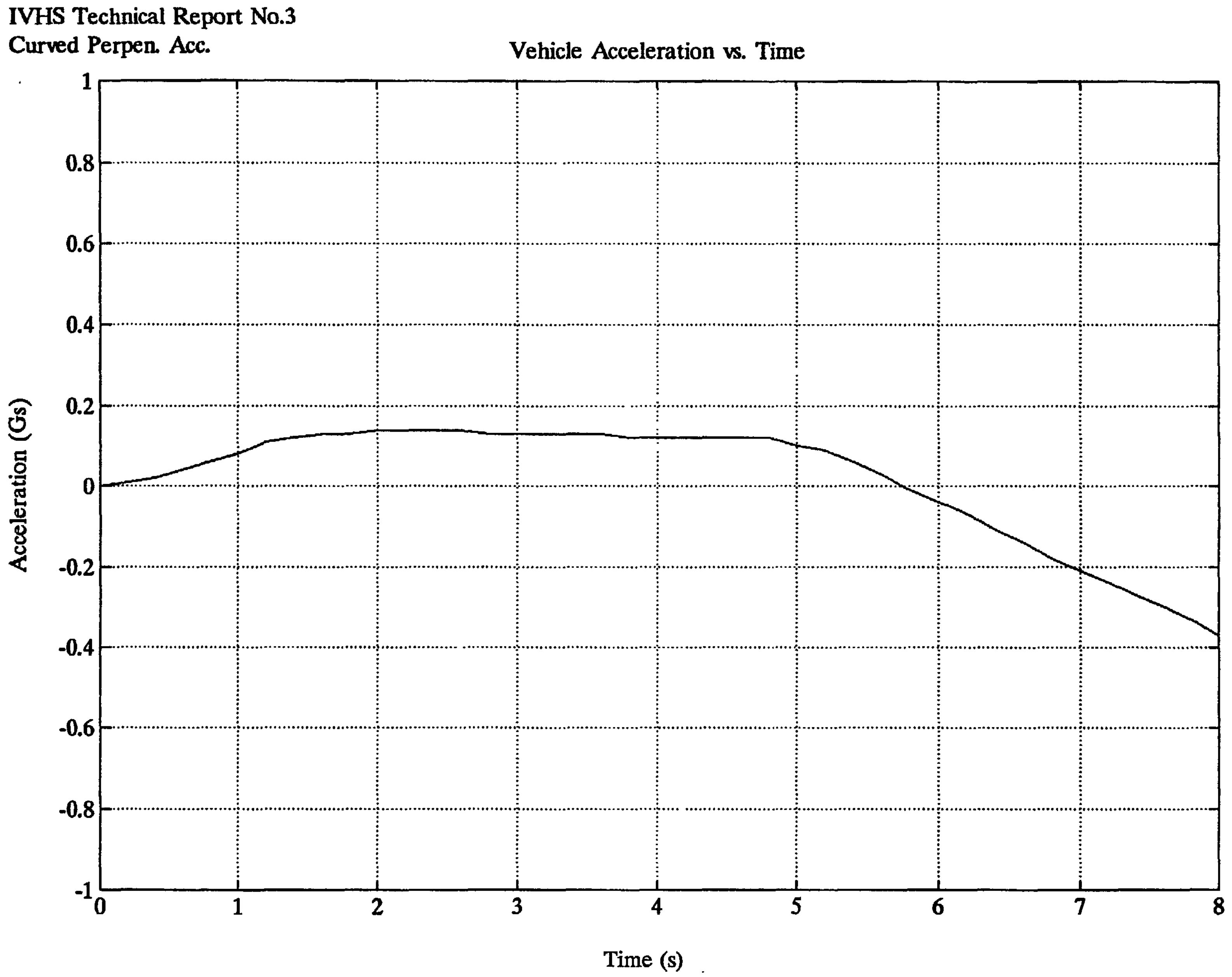


Figure C-2. Acceleration Data Trace of Vehicle Executing a Curved Path Backing Maneuver

APPENDIX D

FACTORIAL MODELING RESULTS

Introduction

This appendix explains the factorial modeling process used in this report and includes the results of the modeling performed for the parallel path, curved path, and pedestrian/pedalcyclist backing crash subtypes.

The modeling for each subtype used the relevant equations in Chapter 6.0. Key factors such as driver RT, rearward vehicle acceleration rates, initial gap distances and vehicle velocities were identified and combinations of these factors were evaluated. To determine if a crash would occur, the distance that the vehicle would travel before stopping was compared to the initial gap distance. If the final gap distance was greater than zero, crash avoidance was inferred; if not, a crash was presumed.

The following sections discuss the parameters manipulated for each subtype that was modeled.

Parallel Path Crash Subtype

The parallel path backing crash subtype was modeled using variable ranges for the driver RT, vehicle acceleration rate and initial gap distance parameters. Values for these variables were used in the parallel path equation. A crash was avoided if the equation's result was a positive gap distance; a crash occurred if the result was negative.

Five RTs, five vehicle acceleration rates and four initial gap distances were evaluated (see Chapter 6.0 for a full listing of how these values were derived and additional modeling assumptions). This resulted in 100 trial cases.

Table D-l lists the results of the parallel path crash modeling. Of the 100 trials evaluated, 90 percent resulted in crash avoidance.

Curved Path Crashes

The curved path backing crash subtype was modeled using variable ranges for the driver RT, and vehicle velocity ranges. Values for these variables were used in the curved path equation. A crash was avoided if the equation's result was a positive gap distance; a crash occurred if the result was negative.

Five RTs and ten velocities were used. (See Chapter 6.0 for a description of all modeling assumptions). This resulted in 50 trial cases.

Table D-1. Parallel Path Crash Modeling Results

Modeling of Parallel Path Backing Crashes

Driver RTs:
0.57 s (10th percentile)
0.83 s (30th percentile)
1.07 s (50th percentile)
1.39 s (70th percentile)
2.01 s (90th percentile)

Accelerations:
0.05g (1.60 ft/s^2)
0.07g (2.24 ft/s^2)
0.09g (2.88 ft/s^2)
0.11g (3.52 ft/s^2)
0.13g (4.16 ft/s^2)

Initial Gap Distances:
4.80 ft (12.5th percentile)
6.50 ft (37.5th percentile)
9.00 ft (62.5th percentile)
13.50 ft (87.5th percentile)

Number of trials: 100

Number of negative results (crashes): 10

Estimated Crash Avoidance Potential: (100 - 10)/100 = .9 or 90%

Driver Brake RT (s)	Backing Accel (ft/s^2)	Initial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
0.57	1.60	4.80	0.38	4.42
0.57	1.60	6.50	0.38	6.12
0.57	1.60	9.00	0.38	8.62
0.57	1.60	13.50	0.38	13.12
0.57	2.24	4.80	0.55	4.25
0.57	2.24	6.50	0.55	5.95
0.57	2.24	9.00	0.55	8.45
0.57	2.24	13.50	0.55	12.95
0.57	2.88	4.80	0.73	4.07
0.57	2.88	6.50	0.73	5.77
0.57	2.88	9.00	0.73	8.27
0.57	2.88	13.50	0.73	12.77
0.57	3.52	4.80	0.91	3.89
0.57	3.52	6.50	0.91	5.59
0.57	3.52	9.00	0.91	8.09
0.57	3.52	13.50	0.91	12.59
0.57	4.16	4.80	1.11	3.69
0.57	4.16	6.50	1.11	5.39
0.57	4.16	9.00	1.11	7.89
0.57	4.16	13.50	1.11	12.39

Table D-l. Parallel Path Crash Modeling Results (continued)

Driver Brake RT (s)	Backing Accel (ft/s^2)	Initial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
0.83	1.60	4.80	0.74	4.06
0.83	1.60	6.50	0.74	5.76
0.83	1.60	9.00	0.74	8.26
0.83	1.60	13.50	0.74	12.76
0.83	2.24	4.80	1.07	3.73
0.83	2.24	6.50	1.07	5.43
0.83	2.24	9.00	1.07	7.93
0.83	2.24	13.50	1.07	12.43
0.83	2.88	4.80	1.41	3.39
0.83	2.88	6.50	1.41	5.09
0.83	2.88	9.00	1.41	7.59
0.83	2.88	13.50	1.41	12.09
0.83	3.52	4.80	1.76	3.04
0.83	3.52	6.50	1.76	4.74
0.83	3.52	9.00	1.76	7.24
0.83	3.52	13.50	1.76	11.74
0.83	4.16	4.80	2.13	2.67
0.83	4.16	6.50	2.13	4.37
0.83	4.16	9.00	2.13	6.87
0.83	4.16	13.50	2.13	11.37
1.07	1.60	4.80	1.17	3.63
1.07	1.60	6.50	1.17	5.33
1.07	1.60	9.00	1.17	7.83
1.07	1.60	13.50	1.17	12.33
1.07	2.24	4.80	1.69	3.11
1.07	2.24	6.50	1.69	4.81
1.07	2.24	9.00	1.69	7.31
1.07	2.24	13.50	1.69	11.81
1.07	2.88	4.80	2.22	2.58
1.07	2.88	6.50	2.22	4.28
1.07	2.88	9.00	2.22	6.78
1.07	2.88	13.50	2.22	11.28
1.07	3.52	4.80	2.79	2.01
1.07	3.52	6.50	2.79	3.71
1.07	3.52	9.00	2.79	6.21
1.07	3.52	13.50	2.79	10.71
1.07	4.16	4.80	3.38	1.42
1.07	4.16	6.50	3.38	3.12
1.07	4.16	9.00	3.38	5.62
1.07	4.16	13.50	3.38	10.12

Table D-l. Parallel Path Crash Modeling Results (continued)

Driver Brake RT (s)	Backing Accel (ft/s2)	Initial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
1.39	1.60	4.80	1.90	2.90
1.39	1.60	6.50	1.90	4.60
1.39	1.60	9.00	1.90	7.10
1.39	1.60	13.50	1.90	11.60
1.39	2.24	4.80	2.74	2.06
1.39	2.24	6.50	2.74	3.76
1.39	2.24	9.00	2.74	6.26
1.39	2.24	13.50	2.74	10.76
1.39	2.88	4.80	3.61	1.19
1.39	2.88	6.50	3.61	2.89
1.39	2.88	9.00	3.61	5.39
1.39	2.88	13.50	3.61	9.89
1.39	3.52	4.80	4.52	0.28
1.39	3.52	6.50	4.52	1.98
1.39	3.52	9.00	4.52	4.48
1.39	3.52	13.50	4.52	8.98
1.39	4.16	4.80	5.48	-0.68
1.39	4.16	6.50	5.48	1.02
1.39	4.16	9.00	5.48	3.52
1.39	4.16	13.50	5.48	8.02
2.01	1.60	4.80	3.82	0.98
2.01	1.60	6.50	3.82	2.68
2.01	1.60	9.00	3.82	5.18
2.01	1.60	13.50	3.82	9.68
2.01	2.24	4.80	5.48	-0.68
2.01	2.24	6.50	5.48	1.02
2.01	2.24	9.00	5.48	3.52
2.01	2.24	13.50	5.48	8.02
2.01	2.88	4.80	7.24	-2.44
2.01	2.88	6.50	7.24	-0.74
2.01	2.88	9.00	7.24	1.76
2.01	2.88	13.50	7.24	6.26
2.01	3.52	4.80	9.07	-4.27
2.01	3.52	6.50	9.07	-2.57
2.01	3.52	9.00	9.07	-0.07
2.01	3.52	13.50	9.07	4.43
2.01	4.16	4.80	10.98	-6.18
2.01	4.16	6.50	10.98	-4.48
2.01	4.16	9.00	10.98	-1.98
2.01	4.16	13.50	10.98	2.52

Table D-2 lists the results of the curved path crash modeling. Of the 50 trials evaluated, 35 (70 percent) resulted in crash avoidance.

Pedestrian/Pedalcyclist Backing Crashes

Pedestrian/pedalcyclist crashes may involve one of two distinct situations; the vehicle may be initially at rest or the vehicle may be in motion. Therefore, this crash subtype was modeled twice.

The model for the pedestrian/pedalcyclist crash subtype where the vehicle is initially at rest used the parallel path backing crash equation. Therefore, it was modeled using variable ranges for driver RT, vehicle acceleration rate, and initial gap distance parameters. A crash was avoided if the equation's result was a positive gap distance; a crash occurred if the result was negative.

Five RTs, five vehicle acceleration rates and four initial gap distances were evaluated. This resulted in 100 trial cases. The RT values were "surprise" reaction times listed in the Driver ***Performance Data Book*** for lOth, 3Oth, 5Oth, 7Oth, and 90th percentile. The vehicle acceleration rates were determined from data collected in the trials described in Appendix C, and span the range of values recorded. The initial gap values varied from 1 to 5 ft, the maximum system range, in 1 foot increments.

Table D-3 lists the results of the pedestrian/pedacyclist modeling where the vehicle is initially at rest. Of the 100 trials evaluated, 58 (58 percent) resulted in crash avoidance.

The pedestrianlpedacyclist crash where the vehicle is in motion was modeled using variable ranges for the driver RT and vehicle velocity ranges. Values for these variables were used in the equation given in Chapter 6.0. A crash was avoided if the equation's result was a positive gap distance; a crash occurred if the result was negative.

Five RTs and ten velocities were used. This resulted in 50 trial cases. The RT values were "surprise" reaction times listed ***in the Driver Performance Data Book*** for lOth, 3Oth, 5001, 7Oth, and 90th percentile. The velocities ranged from 1 mph to 10 mph, in 1 mph intervals. These values represent the possible backing velocities for a vehicle. The values on the lower part of the range are more representative of vehicles that are decelerating to a stop once in the roadway.

Table D-4 lists the results of the pedestrian/pedacyclist modeling where the vehicle is in motion. Of the 50 trials evaluated, 13 (24 percent) resulted in crash avoidance.

Table D-2. Curved Path Crash Modeling Results

Modeling of curved path crash scenario

Driver Reaction Times: 0.57 s (10th percentile)
0.83 s (30th percentile)
1.07 s (50th percentile)
1.39 s (70th percentile)
2.01 s (90th percentile)

Vehicle Vl velocity range: 1.0 to 10.0 mph or
1.47 ft/s to 14.67 ft/s in 1.47 ft/s increments

Number of trials: 50

Number of negative results (crashes): 15

Estimated Crash Avoidance Potential: (50 - 15)/50 = .7 or 70%

Driver Brake RT (s)	Travel Velocity (ft/s)	Backing Distance (ft)	Initial Gap Distance (ft)	Final Gap Distance (ft)
0.57	1.47	1.03	15.00	13.97
0.57	2.93	2.16	15.00	12.84
0.57	4.40	3.38	15.00	11.62
0.57	5.87	4.70	15.00	10.30
0.57	7.33	6.11	15.00	8.89
0.57	8.80	7.62	15.00	7.38
0.57	10.27	9.23	15.00	5.77
0.57	11.73	10.93	15.00	4.07
0.57	13.20	12.73	15.00	2.27
0.57	14.67	14.63	15.00	0.37
0.83	1.47	1.41	15.00	13.59
0.83	2.93	2.92	15.00	12.08
0.83	4.40	4.52	15.00	10.48
0.83	5.87	6.22	15.00	8.78
0.83	7.33	8.02	15.00	6.98
0.83	8.80	9.91	15.00	5.09
0.83	10.27	11.90	15.00	3.10
0.83	11.73	13.98	15.00	1.02
0.83	13.20	16.17	15.00	-1.17
0.83	14.67	18.44	15.00	-3.44
1.07	1.47	1.76	15.00	13.24
1.07	2.93	3.62	15.00	11.38
1.07	4.40	5.58	15.00	9.42
1.07	5.87	7.63	15.00	7.37
1.07	7.33	9.78	15.00	5.22
1.07	8.80	12.02	15.00	2.98
1.07	10.27	14.37	15.00	0.63
1.07	11.73	16.80	15.00	-1.80
1.07	13.20	19.33	15.00	-4.33
1.07	14.67	21.96	15.00	-6.96

Table D-2. Curved Path Crash Modeling Results (continued)

Driver Brake RT (s)	Travel Velocity (ft/s)	Backing Distance (ft)	Initial Gap Distance (ft)	Final Gap Distance (ft)
1.39	1.47	2.23	15.00	12.77
1.39	2.93	4.56	15.00	10.44
1.39	4.40	6.99	15.00	8.01
1.39	5.87	9.51	15.00	5.49
1.39	7.33	12.13	15.00	2.87
1.39	8.80	14.84	15.00	0.16
1.39	10.27	17.65	15.00	-2.65
1.39	11.73	20.56	15.00	-5.56
1.39	13.20	23.56	15.00	-8.56
1.39	14.67	26.66	15.00	-11.66
2.01	1.47	3.14	15.00	11.86
2.01	2.93	6.38	15.00	8.62
2.01	4.40	9.72	15.00	5.28
2.01	5.87	13.15	15.00	1.85
2.01	7.33	16.67	15.00	-1.67
2.01	8.80	20.30	15.00	-5.30
2.01	10.27	24.02	15.00	-9.02
2.01	11.73	27.83	15.00	-12.83
2.01	13.20	31.74	15.00	-16.74
2.01	14.67	35.75	15.00	-20.75

Table D-3. Pedestrian/Pedacyclist Crash Modeling Results
Vehicle Initially at Rest

Modeling of Pedestrian/Pedalcylist Crash Modeling Results where vehicle is in uniformly accelerated motion starting at rest.

Driver RTs:
0.57 s (10th percentile)
0.83 s (30th percentile)
1.07 s (50th percentile)
1.39 s (70th percentile)
2.01 s (90th percentile)

Accelerations:
0.01g (0.32 ft/s^2)
0.03g (0.96 ft/s^2)
0.05g (1.60 ft/s^2)
0.07g (2.24 ft/s^2)
0.09g (2.88 ft/s^2)

Initial Gap Distance between Vehicle and Pedestrian/Pedalcylist:
4.80 ft (12.5th percentile)
6.50 ft (37.5th percentile)
9.00 ft (62.5th percentile)
13.50 ft (87.5th percentile)

Number of trials: 100

Number of negative results (crashes): 42

Estimated Crash Avoidance Potential: (100 - 42)/100 = .58 or 58%

Table D-3. Pedestrian/Pedacyclist Crash Modeling Results
Vehicle Initially at Rest (continued)

Driver Brake RT (s)	Backing Accel (ft/s2)	Intial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
0.57	0.32	4.80	0.07	4.93
0.57	0.32	6.50	0.76	4.24
0.57	0.32	9.00	1.22	3.78
0.57	0.32	13.50	1.78	3.22
0.57	0.96	4.80	0.22	4.78
0.57	0.96	6.50	1.47	3.53
0.57	0.96	9.00	2.33	2.67
0.57	0.96	13.50	3.41	1.59
0.57	1.60	4.80	0.38	4.62
0.57	1.60	6.50	2.06	2.94
0.57	1.60	9.00	3.24	1.76
0.57	1.60	13.50	4.74	0.26
0.57	2.24	4.80	0.55	4.45
0.57	2.24	6.50	2.61	2.39
0.57	2.24	9.00	4.07	0.93
0.57	2.24	13.50	5.95	-0.95
0.57	2.88	4.80	0.73	4.27
0.57	2.88	6.50	3.14	1.86
0.57	2.88	9.00	4.87	0.13
0.57	2.88	13.50	7.11	-2.11
0.83	0.32	4.80	0.14	4.86
0.83	0.32	6.50	1.09	3.91
0.83	0.32	9.00	1.71	3.29
0.83	0.32	13.50	2.46	2.54
0.83	0.96	4.80	0.43	4.57
0.83	0.96	6.50	2.14	2.86
0.83	0.96	9.00	3.29	1.71
0.83	0.96	13.50	4.72	0.28
0.83	1.60	4.80	0.74	4.26
0.83	1.60	6.50	3.03	1.97
0.83	1.60	9.00	4.59	0.41
0.83	1.60	13.50	6.55	-1.55
0.83	2.24	4.80	1.07	3.93
0.83	2.24	6.50	3.87	1.13
0.83	2.24	9.00	5.80	-0.80
0.83	2.24	13.50	8.23	-3.23
0.83	2.88	4.80	1.41	3.59
0.83	2.88	6.50	4.68	0.32
0.83	2.88	9.00	6.96	-1.96
0.83	2.88	13.50	9.84	-4.84

Table D-3. Pedestrian/Pedacyclist Crash Modeling Results
Vehicle Initially at Rest (continued)

Driver Brake RT (s)	Backing Accel (ft/s^2)	Intial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
1.07	0.32	4.80	0.22	4.78
1.07	0.32	6.50	1.41	3.59
1.07	0.32	9.00	2.18	2.82
1.07	0.32	13.50	3.11	1.89
1.07	0.96	4.80	0.69	4.31
1.07	0.96	6.50	2.82	2.18
1.07	0.96	9.00	4.24	0.76
1.07	0.96	15.50	5.98	-0.98
1.07	1.60	4.80	1.17	3.83
1.07	1.60	6.50	4.03	0.97
1.07	1.60	9.00	5.94	-0.94
1.07	1.60	13.50	8.32	-3.32
1.07	2.24	4.80	1.69	3.31
1.07	2.24	6.50	5.17	-0.17
1.07	2.24	9.00	7.53	-2.53
1.07	2.24	13.50	10.48	-5.48
1.07	2.88	4.80	2.22	2.78
1.07	2.88	6.50	6.30	-1.30
1.07	2.88	9.00	9.08	-4.08
1.07	2.88	13.50	12.56	-7.56
1.39	0.32	4.80	0.36	4.64
1.39	0.32	6.50	1.86	3.14
1.39	0.32	9.00	2.84	2.16
1.39	0.32	13.50	4.01	0.99
1.39	0.96	4.80	1.11	3.89
1.39	0.96	6.50	3.81	1.19
1.39	0.96	9.00	5.59	-0.59
1.39	0.96	13.50	7.75	-2.75
1.39	1.60	4.80	1.90	3.10
1.39	1.60	6.50	5.51	-0.51
1.39	1.60	9.00	7.90	-2.90
1.39	1.60	13.50	10.84	-5.84
1.39	2.24	4.80	2.74	2.26
1.39	2.24	6.50	7.13	-2.13
1.39	2.24	9.00	10.07	-5.07
1.39	2.24	13.50	13.70	-8.70
1.39	2.88	4.80	3.61	1.39
1.39	2.88	6.50	8.74	-3.74
1.39	2.88	9.00	12.19	-7.19
1.39	2.88	13.50	16.47	-11.47

Table D-3. Pedestrian/Pedacyclist Crash Modeling Results Vehicle Initially at Rest (continued)

Driver Brake RT (s)	Backing Accel (ft/s^2)	Intial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
2.01	0.32	4.80	0.72	4.28
2.01	0.32	6.50	2.84	2.16
2.01	0.32	9.00	4.20	0.80
2.01	0.32	13.50	5.84	-0.84
2.01	0.96	4.80	2.23	2.77
2.01	0.96	6.50	6.03	-1.03
2.01	0.96	9.00	8.50	-3.50
2.01	0.96	13.50	11.48	-6.48
2.01	1.60	4.80	3.82	1.18
2.01	1.60	6.50	8.88	-3.88
2.01	1.60	9.00	12.19	-7.19
2.01	1.60	13.50	16.21	-11.21
2.01	2.24	4.80	5.48	-0.48
2.01	2.24	6.50	11.65	-6.65
2.01	2.24	9.00	15.71	-10.71
2.01	2.24	13.50	20.66	-15.66
2.01	2.88	4.80	7.24	-2.24
2.01	2.88	6.50	14.43	-9.43
2.01	2.88	9.00	19.18	-14.18
2.01	2.88	13.50	24.99	-19.99

Table D-4. Pedestrian/Pedacyclist Crash Modeling Results
Vehicle in Motion

Modeling of Pedestrian/Pedalcyclist Crash Scenario where vehicle is moving
at constant velocity (no acceleration assumed).

Driver RTs:	0.57 s (10th percentile)
	0.83 s (30th percentile)
	1.07 s (50th percentile)
	1.39 s (70th percentile)
	2.01 s (90th percentile)

Travel velocities: 1 mph to 10 mph in 1 mph increments
or
1.47 ft/s to 14.67 ft/s in 1.47 ft/s increments

Number of trials: 50

Number of negative results (crashes not avoided): 38

Crash Avoidance Potential estimate: (50 - 38)/ 50 = .24 or 24%

Driver Brake RT (s)	Travel Velocity (ft/s)	Initial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
0.57	1.47	5.00	1.03	3.97
0.57	2.93	5.00	2.16	2.84
0.57	4.40	5.00	3.38	1.62
0.57	5.87	5.00	4.70	0.30
0.57	7.33	5.00	6.11	-1.11
0.57	8.80	5.00	7.62	-2.62
0.57	10.27	5.00	9.23	-4.23
0.57	11.73	5.00	10.93	-5.93
0.57	13.20	5.00	12.73	-7.73
0.57	14.67	5.00	14.63	-9.63

Table D-4. Pedestrian/Pedacyclist Crash Modeling Results
Vehicle in Motion (continued)

Driver Brake RT (s)	Travel Velocity (ft/s)	Initial Gap (ft)	Required Braking Distance (ft)	Final Gap Distance (ft)
0.83	1.47	5.00	1.41	3.59
0.83	2.93	5.00	2.92	2.08
0.83	4.40	5.00	4.52	0.48
0.83	5.87	5.00	6.22	-1.22
0.83	7.33	5.00	8.02	-3.02
0.83	8.80	5.00	9.91	-4.91
0.83	10.27	5.00	11.90	-6.90
0.83	11.73	5.00	13.98	-8.98
0.83	13.20	5.00	16.17	-11.17
0.83	14.67	5.00	18.44	-13.44
1.07	1.47	5.00	1.76	3.24
1.07	2.93	5.00	3.62	1.38
1.07	4.40	5.00	5.58	-0.58
1.07	5.87	5.00	7.63	-2.63
1.07	7.33	5.00	9.78	-4.78
1.07	8.80	5.00	12.02	-7.02
1.07	10.27	5.00	14.37	-9.37
1.07	11.73	5.00	16.80	-11.80
1.07	13.20	5.00	19.33	-14.33
1.07	14.67	5.00	21.96	-16.96
-1.39	1.47	5.00	2.23	2.77
1.39	2.93	5.00	4.56	0.44
1.39	4.40	5.00	6.99	-1.99
1.39	5.87	5.00	9.51	-4.51
1.39	7.33	5.00	12.13	-7.13
1.39	8.80	5.00	14.84	-9.84
1.39	10.27	5.00	17.65	-12.65
1.39	11.73	5.00	20.56	-15.56
1.39	13.20	5.00	23.56	-18.56
1.39	14.67	5.00	26.66	-21.66
2.01	1.47	5.00	3.14	1.86
2.01	2.93	5.00	6.38	-1.38
2.01	4.40	5.00	9.72	-4.72
2.01	5.87	5.00	13.15	-8.15
2.01	7.33	5.00	16.67	-11.67
2.01	8.80	5.00	20.30	-15.30
2.01	10.27	5.00	24.02	-19.02
2.01	11.73	5.00	27.83	-22.83
2.01	13.20	5.00	31.74	-26.74
2.01	14.67	5.00	35.75	-30.75

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