U.S. Department
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DOT HS 808 561

February 1994

Interim Report

IVHS Countermeasures for Rear-End Collisions, Task 1

Volume I: Summary

Technical Report Documentation Page

1. Report No. DOT HS 808 561	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle IVHS Countermeasures for Rear-End Collisions Task 1 Interim Report Volume I: Summary		**5. Report Date** February 25, 1994 **6. Performing Organization Code**
7. Author(s) **Terry** Wilson		**8. Performing Organlration Report No.**
9. Performing Organization Name and Address Fronber Engineering Advanced Program Division 7655 E. Reclfield Drive, Suite 10 Scottsdale, AZ 85260		**10. Work Unlt No. (TRAIS)** **11. Contract or Grant No.** DTNH22-93-C-07326
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration (NHTSA) U. S. Department of Transportation (DOT) 400 Seventh Street, S.W. Washington, D.C. 20590		**13. Type of Report and Period Covered** Interim May 1993 - February 1994 **14. Sponsoring Agency Code** NRD-51
15. Supplementary Notes NHTSA Contracting Officers Technical Representative (COTR): Arthur Carter		
16. Abstract See Attached		
17. Key Words Collision Avoidance, Rear-end Collision, Crash Analysis, Performance Specifications, Causal Factors, Dynamic Situations, Human Factors	**16. Distribution Statement** This document is available to the public from the National Technical Information Service (NTIS), Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	**20 Security Classif. (of this page)** Unclassified	**21. No. of Pages** 49 / **22. Price** n/a

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

EXECUTIVE SUMMARY / ABSTRACT

The attached report is from the NHTSA sponsored program, "IVHS Countermeasures for Rear-End Collisions," contract #DTNH22-93-C-07326. The program's primary objective is to develop practical performance guidelines or specifications for rear-end collision avoidance systems. The program consists of three Phases: Phase one: "Laying the Foundation" (Tasks l-4), Phase two: "Understanding the state-of-the-art" (Tasks 5 & 6), and Phase three: "Testing and Reporting" (Tasks 7-9). This work focuses on light (primarily passenger) vehicles and emphasizes autonomous in-vehicle based equipment (as opposed to cooperative infrastructure-based equipment.)

Phase I of this contract, Laying the Foundation, consisted of 4 Tasks: Task 1: a detailed analysis of the rear-end crash problem, Task 2: development of system-level functional goals, Task 3: hardware testing of existing technologies, and Task 4: development of preliminary performance specifications or guidelines. The goals of Tasks 1, 2 and 3 were to develop the background needed to write the preliminary performance guidelines (Task 4).

Task 1, a detailed analysis of the rear-end Crash Problem, consisted of analysis, both clinical and statistical, of available mass accident data bases, some of which include the pre-crash variables, and an initial human factors study. The goal here was to identify, determine the nature of, and quantify the causes of rear-end type crashes. A report volume was written for each of these areas.

The Task 1 Interim Report consists of six volumes. This Volume, Volume I, "Summary," presents background information, an overview of the framework used to analyze the rear-end collision problem, an overview of the initial human factors studies, and summarizes the clinical and statistical analysis of the accident data. This report (all volumes) forms the foundation for the work in the later stages of the contract. Descriptions of Volumes II - Vl are as follows:

a. Volume II, "Statistical Analysis," presents the statistical ana lysis of rearend collision accident data that characterizes the accidents with respect to their frequency, severity, thne and place of occurrence, the vehicle, and the involved drivers. Data for this Volume includes NHTSA's Fatal Accident Reporting System (FARS), NHTSA's General Estimates System (GES), and some state accident data files for recent years.
b. Volume III "1991 NASS CDS Clinical Case Analysis," presents the results of the detailed analysis of cases from NHTSA's 1991 National Accident Sampling System (NASS) Crashworthiness Data System (CDS) crash data.
c. Volume IV, "1992 NASS CDS Clinical Case Analysis," presents the results of the detailed analysis of 200 cases from the 1992 NASS CDS crash data including the new pre-crash variables.
d. Volume V, "1985 NASS Analysis, ' presents the results of the analysis of the 1985 NASS crash data. Data from 1985 was selected for analysis because it provided more insight into roadway variables that are no longer available in the current CDS or GES databases.
e. Volume VI, "Human Factors," presents the results of the initial human factors literature review and study.

From this detailed analysis of the accident databases a framework of the dynamic situations of rear-end collisions was developed and used to analyze the rear-end collision problem. From an in-depth analysis of the dynamic situations it was discovered that most rear-end collisions occur with the following vehicle traveling at a constant velocity and the lead vehicle decelerating to a stop, i.e. the close-following or platooning situation. It was determined that the primary causal factors for rear-end collisions were inattention and following too closely. Also determined was a list of preliminary specification information.

The results presented during Phase I, including the Preliminary Performance Guidelines or Specifications, are based on work carried out with limited interactions with the academic, research, and industry communities, any conclusions drawn from the results presented must bear this in mind.

Phase II goals include a detailed state-of-the-art review of technologies related to rear-end collision avoidance systems and the design of a test bed system. Phase II will complete in June 1996. Phase III goals include the construction and test of the test bed system, the generation of the final performance guidelines or specifications, and the final reporting on all aspects of the project. Phase III will finish in early 1998. Work continues throughout Phase II and III to add to, and to refine, these preliminary performance guidelines or specifications. Numerous items still need to be determined (TBD) throughout the remainder of the research.

Key words: Collision Avoidance, Rear-end Collision, Crash Analysis, Performance Specifications, Causal Factors, Dynamic Situations, Human Factors.

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SECTION 1
INTRODUCTION

This document is Volume I of the Task 1 Interim Report, deliverable item 5, for IVHS Countermeasures for Rear-End Collisions, Contract DTNH22-93-C-07326. The Task 1 Interim Report consists of six volumes as listed below:

- Volume I — Summary
- Volume II — Statistical Analysis
- Volume III — 1991 NASS CDS Clinical Analysis
- Volume IV — 1992 NASS CDS Clinical Analysis
- Volume V — 1985 NASS Analysis
- Volume VI — Human Factors

The primary objective of this program, as stated in the contract statement of work, is to develop practical performance specifications for rear-end collision avoidance systems. Section 1.1 sets forth certain terms and definitions related to this program. This is done to provide background into the rear-end collision avoidance problem and to standardize terminology.

1.1 TERMS AND DEFINITIONS

According to the National IVHS Program Plan, rear-end collision warning and control falls under the longitudinal collision avoidance category. A longitudinal collision is a two-vehicle collision in which vehicles are moving in essentially parallel paths prior to the collision or one in which the struck vehicle is stationary. This category is further divided into rear-end, backing and head-on collisions as well as struck pedestrians. There are four type of systems that will provide the longitudinal collision avoidance service. They are:

- Rear-end collision warning and control
- Head-on collision warning and control
- Passing warning (on two lane roads)
- Backing collision warning

Rear-end collision warning and control is the specific thrust of this program. Rear-end collision warning and control is considered a sub-service of the longitudinal collision avoidance service. These systems would, through driver notification and vehicle control, help avoid collisions with the rear-end of either a stationary or moving vehicle. These collisions are often associated with too short a headway with the vehicle in front. The driver maintains full longitudii control of the vehicle until a dangerous condition, such as a stationary vehicle on the roadway ahead, is detected. Then the driver is warned, and if the driver does nothing, appropriate vehicle control actions to avoid the danger could be taken automatically. There are three general categories of rear-end collision warning and control systems:

1. Those that present information about other vehicles and situations in the vicinity of the vehicle. (Headway maintenance systems)
2. Those that direct the driver to take evasive action to avoid a collision. (Driver action systems)
3. Those that take control of the vehicle away from the driver and automatically take evasive action. (Automatic control systems)

A headway maintenance system presents information about other vehicles and situations in the forward path of the vehicle. The headway maintenance system includes three subgroups:

- A manual operations system.
- An autonomous intelligent cruise control system (AICC).
- A cooperative intelligent cruise control system (CICC).

A manual operations system presents information to the driver such that the driver can maintain adequate headway from the vehicle in front. The driver maintains full control of the vehicle.

An AICC system allows the driver to select a cruise control feature that tracks the vehicle in front of it and automatically maintains safe headway. A distinction should be made that two types of autonomous intelligent cruise control systems are possible: one that requires a vehicle in front to follow; and a smarter system that can acquire and drop slower or faster moving lead vehicles while maintaining a safe headway or fixed vehicle speed.

A CICC system is an extension of AICC in which leading vehicles include a rearward-looking transponder or other means of transmitting information of vehicle dynamics to a following vehicle. Two or more properly-equipped vehicles can cooperatively “platoon” on the highway using basic sensing plus inter-vehicle communication and on-board computer processing. CICC concepts may also include receiving information from the infrastructure about the roadway such as speed limit in order to maintain a lawful vehicle speed.

Driver action systems would, through driver notification, help avoid collisions with the rear end of either a stationary or moving vehicle. A driver response, or action, would be elicited upon detection of a dangerous situation or impending collision. The driver maintains full control of the vehicle. One type of system would merely notify the driver of a dangerous situation, while another type would tell the drivers what actions to take.

Automatic control systems are an extension of driver action systems. Automatic control systems would take temporary control of the vehicle to avoid a dangerous situation or impending collision when no response, or an improper response, from the driver is detected. The control of the vehicle could include braking and, in severe cases, steering the vehicle out of the path of the collision. Automatic vehicle actions must be compatible with vehicle and driver capabilities and limitations.

Throughout this document "sensor" will refer to the device that is mounted on the following vehicle looking forward and performs the function of sensing the vehicle in front. References to "system" imply an entire rear-end collision avoidance system to include, at a minimum, a sensor, processor and either a driver display or vehicle interface.

1.2 OVERVIEW

To arrive at a performance specification for a rear-end collision countermeasures system, several steps must be taken. First, the rear-end crash problem must be thoroughly analyzed to determine the causes of, the events leading to and the quantity of rear-end collisions. Determination of the exact cause and the events leading to rear-end crashes aids in identifying valid crash countermeasures for each crash situation. Quantifying the different causes aids in tradeoffs of cost and benefit. Analysis of the rear-end crash problem will lead to the establishment of functional goals to evaluate existing systems and to design and evaluate new systems and, finally, to the establishment of a performance specification.

Section 2 of this volume presents the preliminary framework that will be used to develop the performance specification for rear-end collision avoidance systems, as well as tying the framework to the simulation effort (Task 4) and the testing of existing systems (Task 3).

NHTSA has analyzed rear-end crash data previously. The results of this analysis are in the reports, "Rear-End Crashes: Problem Size Assessment and Statistical Description" by Ronald R. Knipling, et al, May, 1993, and "Assessment of IVHS Countermeasures for Collision Avoidance: Rear-End Crashes" by Ronald R. Knipling, et al, May, 1993. Section 3 provides an overview of the results, detailed in Volume II of this report, of the statistical analysis conducted to verify the results of the NHTSA reports and provide additional background information for the rear-end collision problem. The statistical analysis also provides information for the performance specification.

Section 4 provides an overview of the results from the clinical analysis performed on the 1991 National Accident Sampling System (NASS) Crashworthiness Data System (CDS) and presented in Volume III of this report.

Section 5 provides an overview of the results from the clinical analysis performed on the 1992 NASS CDS and described in Volume IV of this report.

Section 6 provides an overview of the results from the analysis performed on the 1985 NASS and described in Volume V of this report.

Section 7 provides an overview of the study of the human factors involved in rear-end collisions which will aid in understanding and specifying the driver interface. The effort consisted primarily of a literature search and is described in Volume VI of this report.

Section 8 of this volume ties the data presented in this report to the framework presented in Section 2 of this volume. This framework is also tied to the development of functional goals as part of the effort of Task 2 of this program.

SECTION 2
SPECIFICATION REQUIREMENTS

2.1 INTRODUCTION

As previously stated, the primary objective of this program is to develop practical performance specifications for rear-end collision avoidance systems. Section 2 presents a list of information that needs to be obtained in order to develop a performance specification for rear-end collision avoidance systems. The list is not necessarily all inclusive or complete, but it reflects knowledge and information gathered to this point in the program. The list is essentially technology independent, and the items within the list are not broken down by the type of system (i.e., headway maintenance system, driver warning system or automatic control system). As a result, not all items are applicable to all three system types. A final performance specification will be unique to the type of system.

2.2 PRELIMINARY SPECIFICATION INFORMATION

The information necessary for' a performance specification breaks down into six primary categories: (1) accident conditions; (2) environmental conditions; (3) roadway characteristics; (4) vehicle characteristics; (5) driver characteristics; (6) system characteristics. Sub-categories are contained in the following list.

1. Accident conditions
   - Dynamic situations
   - Accident type
   - Lead vehicle moving versus lead vehicle stationary
   - Pre-crash variables
   - Travel speed
2. Environmental conditions
   - Atmospheric condition
   - Light condition
3. Roadway characteristics
   - Roadway surface conditions
   - Roadway surface type
   - Roadway coefficient of friction
   - Roadway alignment (horizontal)
   - Roadway alignment (vertical)
   - Lanewidth

4. Vehicle characteristics
    - Vehicle body type
    - Struck vehicle cross section
    - Vehicle braking dynamics
    - Vehicle steering dynamics
    - Vehicle acceleration dynamics
5. Driver characteristics
    - Driver reaction time
6. System characteristics
    - Qualitative system characteristics
        - What situations was the system designed for?
        - Does the system minimize occurrence of driver error?
        - Does the system provide sufficient information to maintain headway?
        - Does the system provide sufficient information to avoid a collision?
        - Does the system enhance driver reaction time?
        - Is the system perceived by the driver as reliable?
        - Is the system effective for drivers of differing abilities?
        - Can the system's expected production cost be made cost effective?
        - Do automatic braking or steering systems cause loss of control?
        - How does the system respond when approaching a vehicle that the sensor is not locked to?
    - Quantitative system characteristics
        - What is the minimum and maximum range capability?
        - What is the range accuracy?
        - What is the range resolution?
        - What is the minimum and maximum range rate capability?
        - What is the range rate accuracy?
        - What is the range rate resolution?
        - Is the system capable of self-test?
        - What is the system's power requirements?
        - Are the system's parameters adjustable for different driving situations?
        - Are the system's parameters adjustable for different driver types?
        - Is the system adjustable for different weather conditions?
        - Do system warning or control times adjust for different dynamic situations?
        - Is the system response time adequate?
        - Does the automatic cruise control maintain a safe distance behind lead vehicles?

- Does the system take control of the vehicle's driving functions at the appropriate time?
- Does the system make proper adjustments to avoid the accident?
- What is the system's mean time before failure? (reliability)
- What is the system's mean time to repair? (maintainability)
- What is the required operating environment for the system?
- What is the required storage environment for the system?

- Sensor characteristics
  - What is the specific type of technology used by the sensor?
  - Does the sensor transmit a safe power level per applicable standards?
  - Is the sensor's frequency of operation compliant per applicable standards?
  - Is the sensor beam fixed or scanned?
  - If scanned, is it an electrical scan or a mechanical scan?
  - What is the sensor's horizontal angular resolution?
  - What is the sensor's vertical angular resolution?
  - Is the sensor affected by mutual interference?
  - Is the sensor affected by non-mutual interference?
- Processor characteristics
  - Does the system have a very low false alarm rate under clutter free conditions?
  - Does the system alarm on objects other than the vehicle in front? How often?
  - Does the system fail to detect the vehicle in front? How often?
  - Are the algorithms used adequate to maintain headway or avoid a collision?
  - Do the algorithms take into account the speed and deceleration of the two vehicles?
  - Is the algorithm adequate to determine when to take control of the vehicle?
  - Is the algorithm adequate to determine the extent of the required control?
- Driver Display characteristics
  - What type of display is used (visual, audio, tactile, combination)?
  - If the display is visual, what type of display technology is used?
  - Does the display give accurate information?
  - Is the display non-confusing to the driver?
  - Is the display of information salient and understandable?
  - Does the display of information startle the driver?
  - If the display is visual, is the display effective in all luminance levels?
  - Does the display of information focus the attention of the driver on the - hazard?

- If audio, how well can it be heard?
- If tactile, where is it felt? How well can it be felt?
- Does the system inform the driver when it has taken control of the vehicle?
- Is the display of information continuous or only active when driver action is needed?

- Vehicle interface characteristics
  - Does the vehicle interface have the capability to control the vehicle?
  - Does the vehicle interface cause loss of control?
  - Are the vehicle actions compatible with vehicle and driver capabilities and limitations?
  - What parts of the vehicle does the system interface with?
  - Does the system provide partial or full braking?
  - Does the system control the accelerator?
  - Does the system control the steering?

In analyzing rear-end collisions the dynamic situations leading up to the accidents are an important factor to consider. Environmental characteristics, roadway characteristics, vehicle characteristics and driver characteristics are modifiers of the dynamic situations. System characteristics are organized in such a manner as to imply directly to the testing of existing systems in Task 3. The following paragraphs help to further define the items in the preliminary specification list. A summary of the results of this analysis relating to selected item within this list is contained in Section 6.

2.3 ACCIDENT CHARACTERISTICS

The characteristics of accidents allow the events leading to the accident and the accident itself to be subdivided down into smaller groups to be addressed on an individual basis. The coarsest division is whether the lead vehicle was moving or stationary when it was struck. A further division is into velocity profiles or dynamic situations. Dynamic situations describe the motion of the two vehicles with respect to each other prior to either driver recognizing a potential collision problem.

2.3.1 Lead Vehicle Moving; Versus Lead Vehicle Stationary

An classification of an accident within the rear-end crash category that was stressed in the NHTSA report was whether the lead vehicle is stationary (LVS) or moving (LVM). The statistics of these two types of rear-end crashes are different in many respects. There are more than twice as many LVS crashes (-70%) as LVM crashes (-30%). However, LVM crashes, though less frequent, are somewhat more severe on average than are LVS crashes. Still, LVS crashes constitute the larger overall problem in terms of the number of crashes, injuries, and fatalities.

2.3.2 Dynamic Situations

The following paragraphs provide an overview of the dynamic situations to be considered in the accident analysis: Study of the available accident data shows that some dynamic situations occur with such infrequency that they can be ignored for all practical purposes but all known dynamic situations are presented here for completeness. Table 2.3.2-1 shows a matrix of dynamic situations and references the accompanying figure that graphically illustrates the situation.

Table 2.3.2-l Dynamic Situations

Lead Vehicle	Following Vehicle		
	Accelerating	**Constant Velocity**	**Decelerating**
Stopped	See Figure 2.3.2-1	See Figure 2.3.2-2	See Figure 2.3.2-3
Constant Velocity	See Figure 2.3.2-4	See Figure 2.3.2-5	See Figure 2.3.2-6
Decelerating	See Figure 2.3.2-7	See Figure 2.3.2-8	See Figure 2.3.2-9
Accelerating	See Figure 2.3.2-10	See Figure 2.3.2-11	See Figure 2.3.2-12
Decel & Stopped	See Figure 2.3.2-13	See Figure 2.3.2-14	See Figure 2.3.2-15

The following figures show representative samples of the dynamic situations. The origin of the graph represents the point when a rear-end collision avoidance system acquires, or senses, the vehicle in front. Groups of profiles are included on the same graph that are logically related. In the figures, the lead vehicle is represented by a solid line and the following vehicle by a dashed line. The lettered curves represent different conditions at acquisition.

Figure 2.3.2-l represents the situation that occurs when the lead vehicle is stopped and the following vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position.

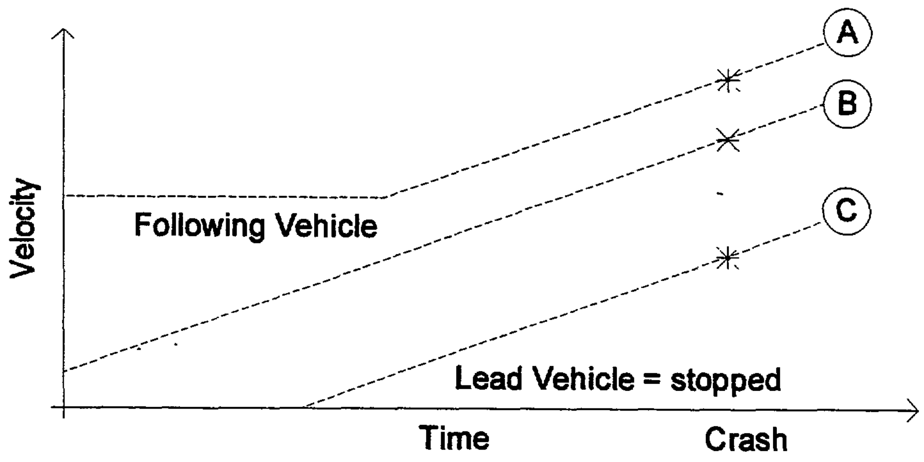

Figure 2.3.2-1 Lead Vehicle Stopped, Following Vehicle Accelerating

Figure 2.3.2-2 shows the situation when the lead vehicle is stopped and the following vehicle is at a constant velocity.

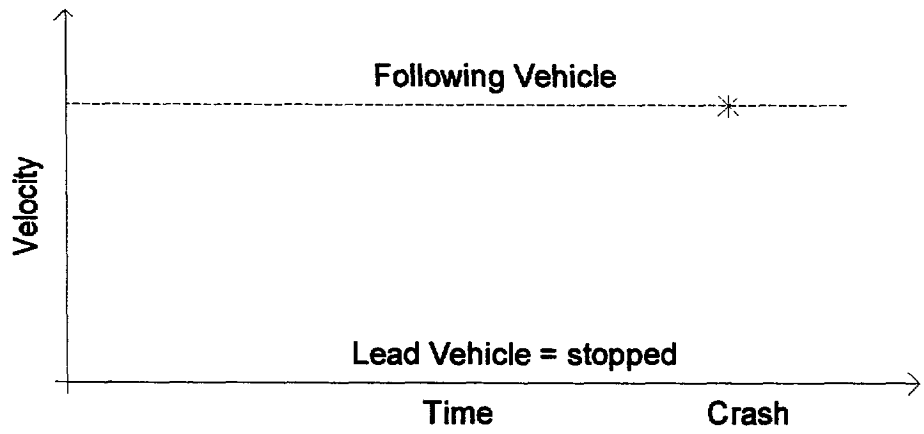

Figure 2.3.2-2 Lead Vehicle Stopped, Following Vehicle Constant Velocity

Figure 2.3.2-3 shows the situation when the lead vehicle is stopped and the following vehicle is decelerating or decelerating from a constant velocity. Also included in this dynamic situation are panic deceleration where the striking vehicle's driver becomes aware of a problem and brakes too late to avoid a collision.

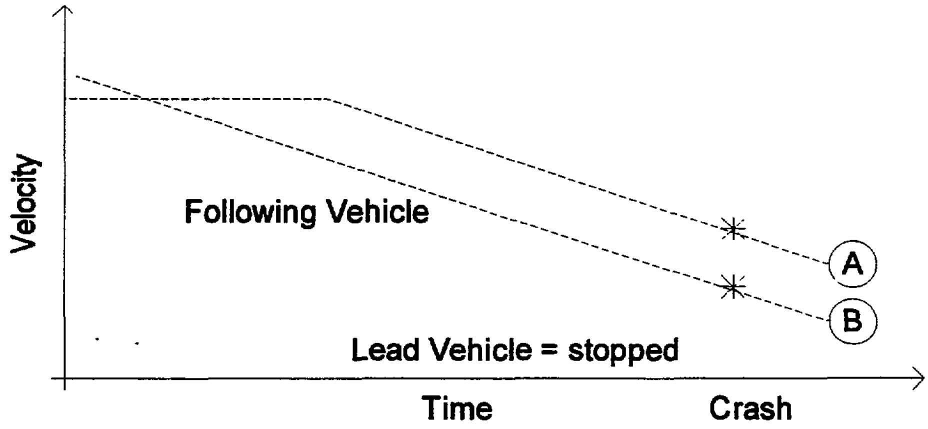

Figure 2.3.2-3 Lead Vehicle Stopped, Following Vehicle Decelerating

Figure 2.3.2-4 shows the situation where the lead vehicle is at a constant (slower) velocity and the following vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position.

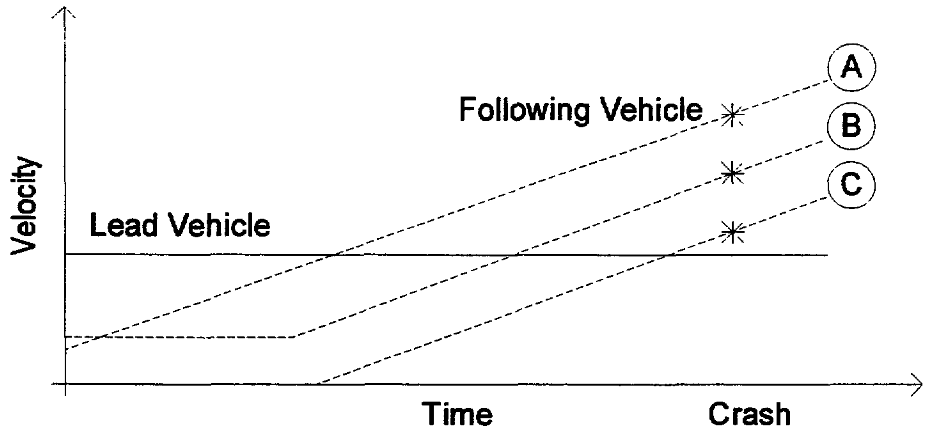

Figure 2.3.2-4 Lead Vehicle Constant Velocity, Following Vehicle Accelerating

Figure 2.3.2-5 shows the situation when the lead vehicle is at a constant (slower) velocity and the following vehicle is at a constant (higher) velocity.

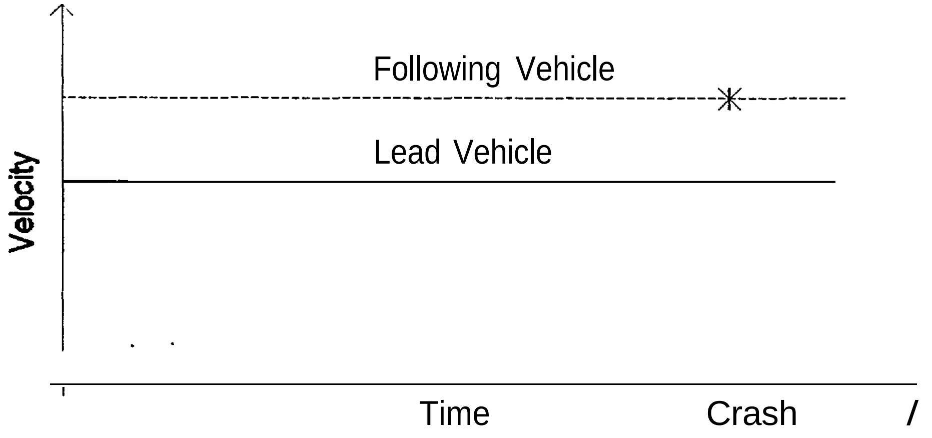

Figure 2.3.2-5 Lead Vehicle Constant Velocity, Following Vehicle Constant Velocity

Figure 2.3.2-6 shows the situation when the lead vehicle is at a constant (slower) velocity and the following vehicle is decelerating or decelerating from a constant velocity. Included in this dynamic situation are panic deceleration where the striking vehicle's driver becomes aware of a problem and brakes too late to avoid a collision.

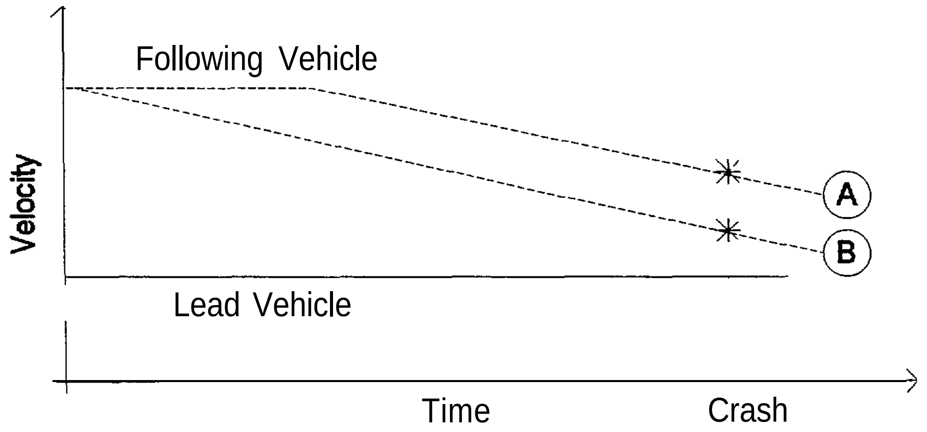

Figure 2.3.2-6 Lead Vehicle Constant Velocity, Following Vehicle Decelerating

Figure 2.3.2-7 shows the situation when the lead vehicle is decelerating or decelerating from a constant velocity and the following vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position.

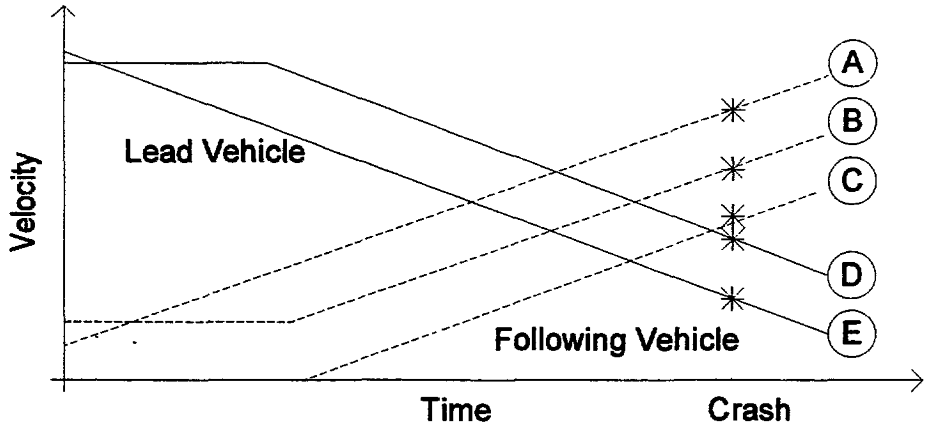

Figure 2.3.2-7 Lead Vehicle Decelerating, Following Vehicle Accelerating

Figure 2.3.2-8 shows the situation when the lead vehicle is decelerating or decelerating from a constant velocity and the following vehicle is at a constant velocity.

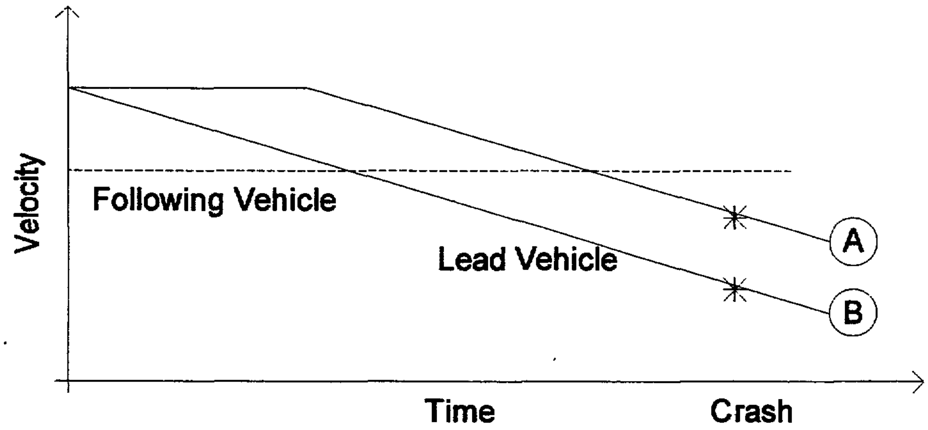

Figure 2.3.2-8 Lead Vehicle Decelerating, Following Vehicle Constant Velocity

Figure 2.3.2-9 shows the situation when the lead vehicle is decelerating or decelerating from a constant velocity and the following vehicle is decelerating or decelerating from a constant velocity.

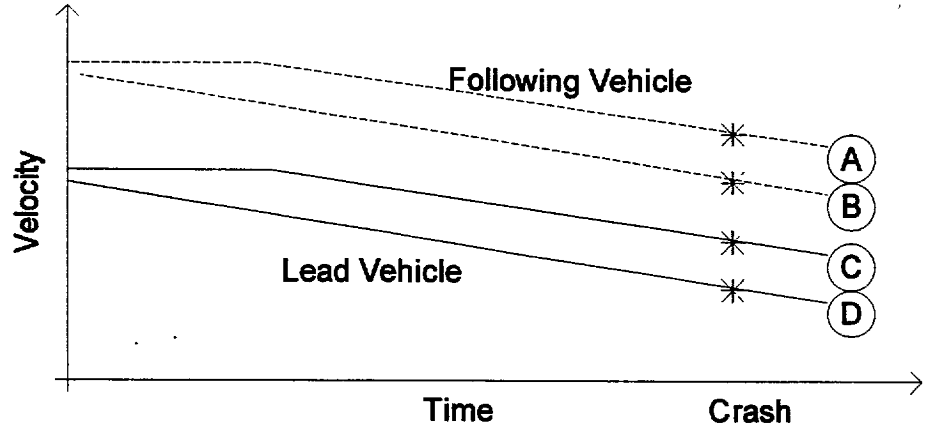

Figure 2.3.2-9 Lead Vehicle Decelerating, Following Vehicle Decelerating

Figure 2.3.2-10 shows the situation when the lead vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position and the following vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position.

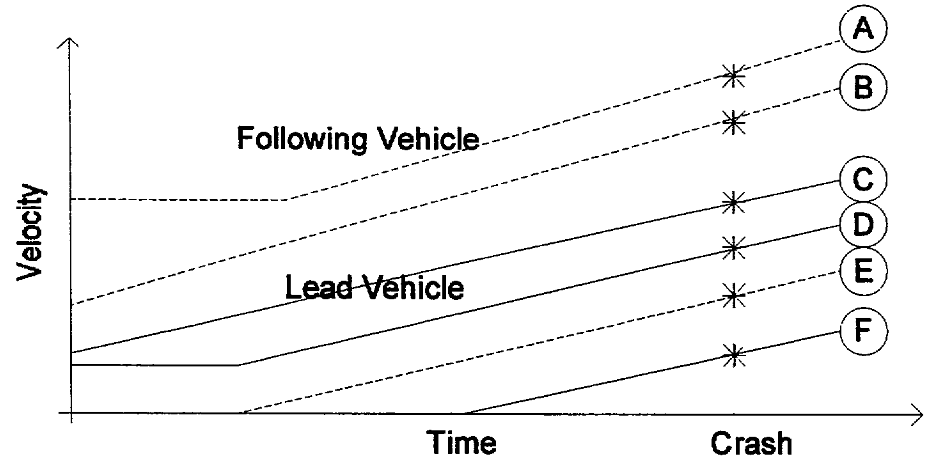

Figure 2.3.2-10 Lead Vehicle Accelerating, Following Vehicle Accelerating

Figure 2.3.2-11 shows the situation when the lead vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position and the following vehicle is at a constant velocity.

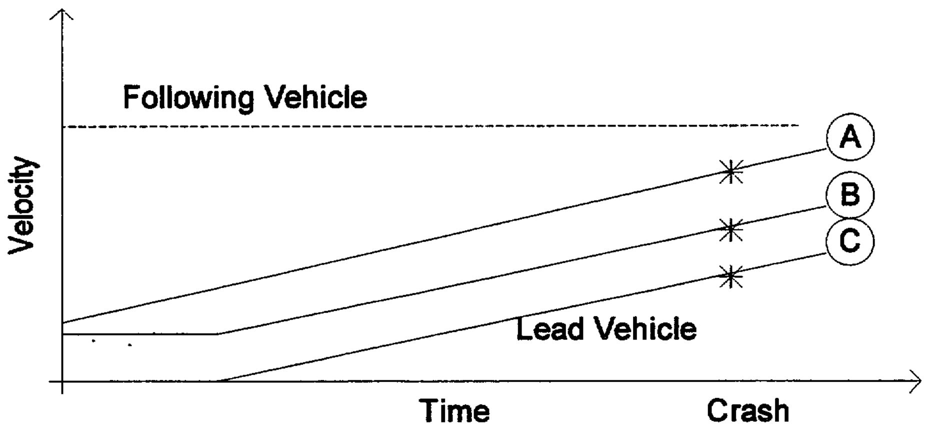

Figure 2.3.2-11 Lead Vehicle Accelerating, Following Vehicle Constant Velocity

Figure 2.3.2-12 shows the situation when the lead vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position and the following vehicle is decelerating or decelerating from a constant velocity.

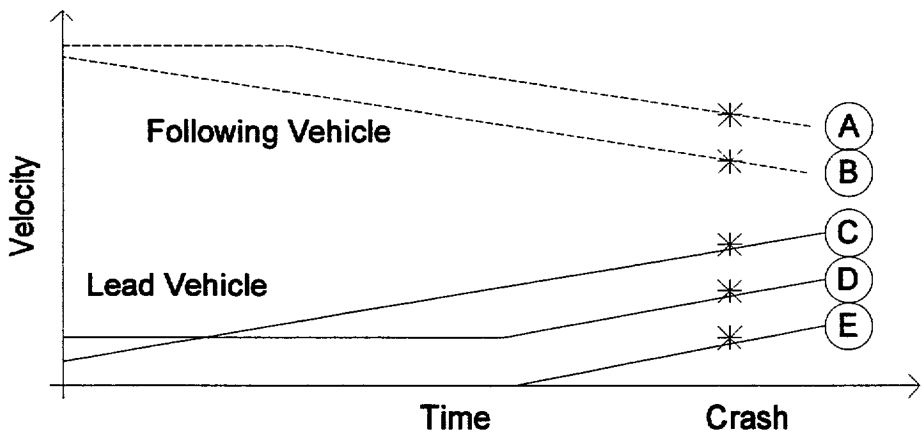

Figure 2.3.2-12 Lead Vehicle Accelerating, Following Vehicle Decelerating

Figure 2.3.2-13 shows the situation when the lead vehicle is decelerating to a stop and the following vehicle is accelerating, accelerating from a constant velocity or accelerating from a stopped position.

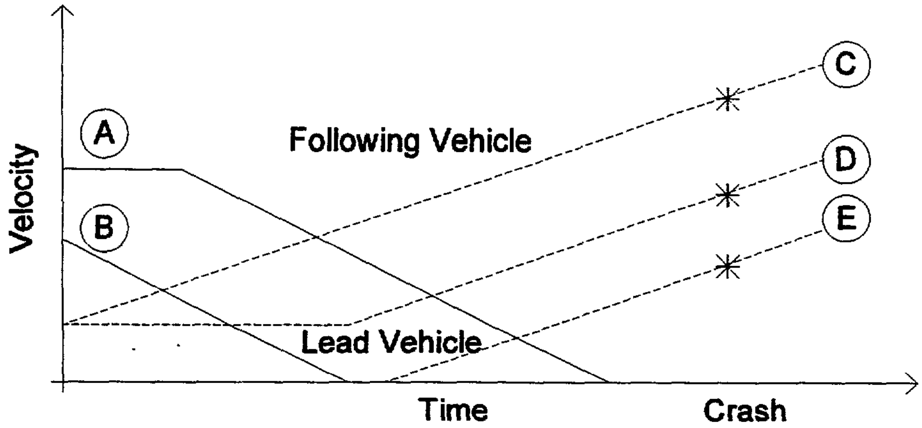

Figure 2.3.2-13 Lead Vehicle Decelerating & Stopped, Following Vehicle Accelerating

Figure 2.3.2-14 shows the situation when the lead vehicle is decelerating to a stop and the following vehicle is at a constant velocity.

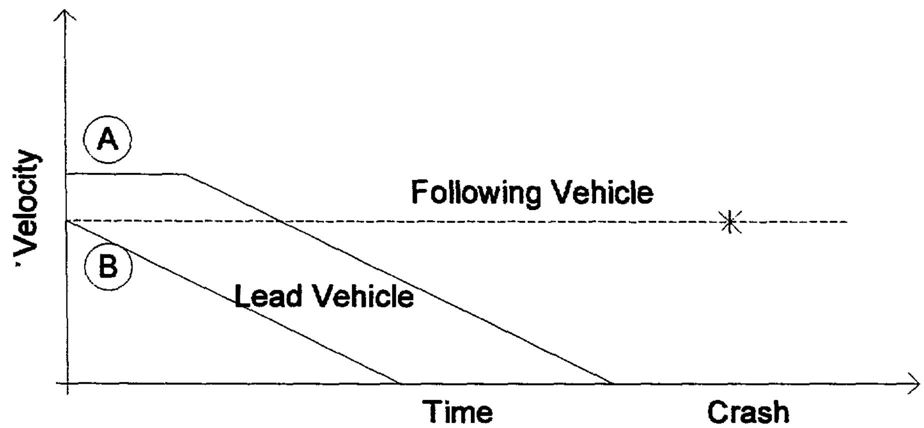

Figure 2.3.2-14 Lead Vehicle Decelerating & Stopped, Following Vehicle Constant Velocity

Figure 2.3.2-15 shows the situation when the lead vehicle is decelerating to a stop and the following vehicle is decelerating or decelerating from a constant velocity.

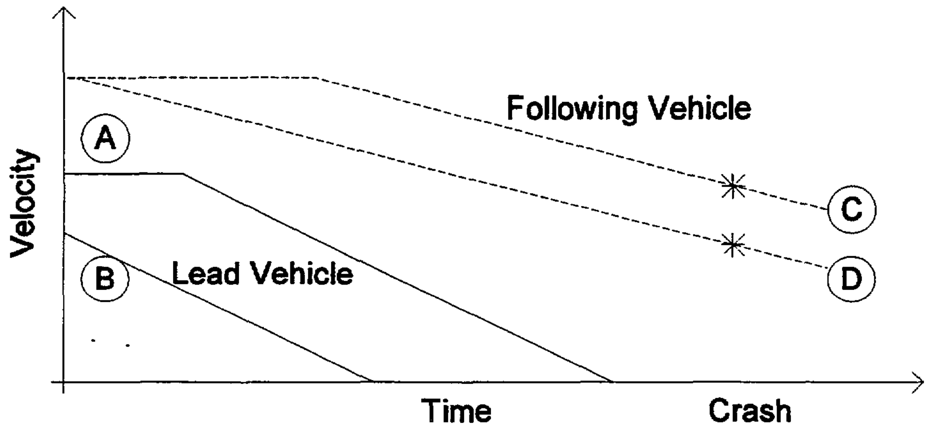

Figure 2.3.2-15 Lead Vehicle Decelerating & Stopped, Following Vehicle Decelerating

2.3.3 Accident Type

The accident type provides information regarding driver intentions from the standpoint of the lead (struck) vehicle. The accident type variable comes directly from the coding in the NASS mass database. The accident type is helpful in determining the pre-crash dynamics from the vehicles involved. The coding of the accident type is shown in Figure 2.3.3-1. The numbers shown in Figure 2.3.3-1 correspond to the actual codes for accident type in the NASS data files.

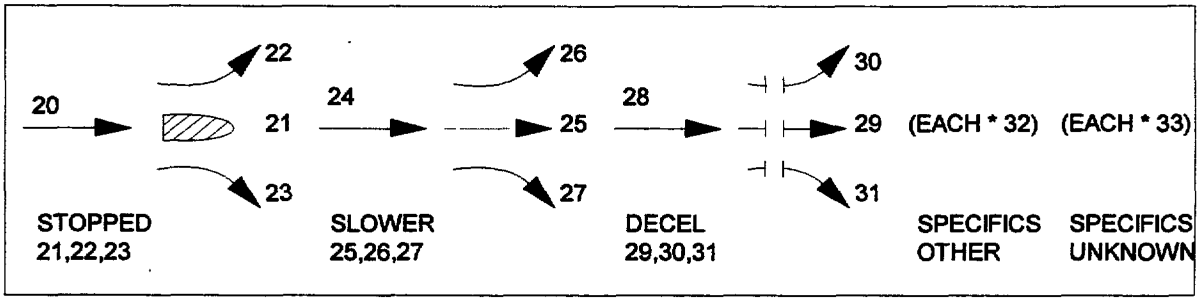

Figure 2.3.3-1 Accident Type

2.3.4 Pre-Crash Variables

The pre-crash variables are new to the 1992 NASS GES and 1992 NASS CDS. They are a collection of five variables that help describe or define events leading up to the collision. Table 2.3.4-1 shows the five pre-crash variables for both the NASS CDS and NASS GES. The pre-crash variables along with the accident type can be used to make an estimation of the dynamic situation.

Table 2.3.4-l Pre-crash Variables

NASS CDS	NASS GES
Pre-event movement	Movement prior to critical event
Critical pre-crash event	Critical event
Attempted avoidance maneuver	Corrective action attempted
Pre-crash stability after avoidance maneuver	Vehicle control after corrective action
Pre-crash directional consequences of avoidance maneuver	Vehicle path after corrective action

2.3.5 Travel Speed

The travel speed helps quantify the range of velocities that are typically encountered for different rear-end collisions. Although the travel speed would not necessarily be used in a specification, the range and distribution of travel speed is useful in the analysis and simulation efforts in Task 4.

2.4 ENVIRONMENTAL CONDITIONS

2.4.1 Atmospheric Condition

The atmospheric condition relates to the weather that the system's sensor must "see" through in order to detect vehicles in the forward path. All systems will be somewhat affected by weather conditions. Most rear-end collisions, about eighty percent, occur during clear weather conditions, but a few, approximately fifteen percent, occur during ram conditions.

2.4.2 Light Condition

The light condition is related to the amount of light that a system "sees" while operating. This is very important to systems that work within the visual spectrum of light since some degradation may occur during low light conditions and very bright light conditions.

2.5 ROADWAY CHARACTERISTICS

2.5.1 Roadway Surface Conditions

The roadway surface condition refers to the weather related condition of the road surface such as dry, wet, snow, ice, etc. The roadway surface condition dramatically effects the stopping distance of a vehicle, and, therefore, systems that adjust the safe headway based on the surface condition of the roadway would be optimum. The roadway surface condition can also affect the amount of reflected energy from the roadway that the sensor "sees" which can cause degradation in system performance.

2.5.2 Roadway Surface Type

The roadway surface type is related to the physical characteristics of the roadway construction. The roadway surface type will affect the coefficient of friction and may change the required stopping distance of the vehicle. The roadway surface type may also affect its reflection characteristics making it more difficult for the system to detect vehicles in the forward path.

2.5.3 Roadway Coefficient of Friction

The roadway coeffkient of friction is directly related to the stopping distance required for a vehicle. The minimum and maximum boundaries must be specified in order for the system designer to create an effective system.

2.5.4 Roadway Alignment

The roadway's horizontal alignment refers to whether the roadway is straight, curved right or curved left.

2.5.5 Roadway Profile

The roadway's profile refers to whether the roadway is level, has a grade, hillcrest, etc.

2.5.6 Lane Width

The lane width relates to the physical width of the travel lane. Lane width is important to the system designer in specifying beam width for the sensor and scan width for scanned systems.

2.6 VEHICLE CHARACTERISTICS

2.6.1 Striking Vehicle Body Type

By knowing the body type of the vehicle in which the rear-end collision avoidance system is installed the system designer can tailor certain system parameters, such as stopping distance required, to that particular vehicle.

2.6.2 Struck Vehicle Body Type

The struck vehicle body type is important because it allows quantification of the vehicle cross section as explained below.

2.6.3 Struck Vehicle Cross Section

The amount of transmitted energy that is reflected from the lead vehicle is a function of the vehicle's cross section for the particular sensor technology. This is important in the detection of the lead vehicle.

2.6.4 Vehicle Braking Dynamics

Information on the vehicle braking dynamics is necessary for systems that automatically control the vehicle. Based on the year, make, model and curb weight of the vehicle, some indication of the vehicle's stopping distance can be made. Vehicle braking dynamics may also be necessary for autonomous and cooperative intelligent cruise control systems.

2.6.5 Vehicle Steering Dynamics

Information on the vehicle steering dynamics is necessary for systems that automatically control the steering of the vehicle.

2.6.6 Vehicle Acceleration Dynamics

Information on the vehicle acceleration dynamics is necessary for systems that automatically control the accelerator of the vehicle such as autonomous and cooperative intelligent cruise control systems.

2.7 DRIVER CHARACTERISTICS

2.7.1 Driver Reaction Time

The reaction time for the driver is probably one of the biggest variances for a driver warning system. This is the time required for the driver to respond to the display and take evasive action.

2.8 SYSTEM CHARACTERISTICS

2.8.1 Qualitative System Characteristics

Qualitative system characteristics are those items that cannot necessarily be quantified regarding a rear-end collision avoidance system but are important in defining a system. Very few of these items would be considered specification issues but are included here for a basis of evaluating existing systems in Task 3.

2.8.2 Quantitative System Characteristics

Quantitative system characteristics are typically those items that describe the function of the rear-end collision avoidance system by numerical means. An example is the minimum and maximum range of the system. Some of the quantitative system characteristics presented are not specification issues but are presented as items of interest for evaluating existing systems in Task 3.

2.8.3 Sensor Characteristics

The sensor characteristics are those items that relate directly to the sensor being used by the rear-end collision avoidance system.

2.8.4 Processor Characteristics

The processor refers to the intelligence of the rear-end collision avoidance system. The processor accepts information from the sensor, uses this data in a collision avoidance algorithm and outputs this information to either the driver display or the vehicle interface.

2.8.5 Driver Display Characteristics

The driver display characteristics relate to the interface between the rear-end collision avoidance system and the driver.

2.8.6 Vehicle Interface Characteristics

The vehicle interface characteristics relate to the interface of the system to the vehicle. This would only be necessary on autonomous or cooperative intelligent cruise control or automatic control type systems.

2.9 SUMMARY

The list of preliminary specification information is not necessarily complete, but it forms the basis for crash data analysis. Additional items may be added or deleted as required during testing of existing systems in Task 3 and the simulation and analysis effort in Task 4. The results of the statistical and clinical analysis will provide input to the analysis and simulation effort and will drive the selection of test profiles required for system testing. Conclusions regarding some of the performance inputs are presented in Section 8.

SECTION 3
STATISTICAL ANALYSIS

3.1 INTRODUCTION

This section is a summary of the results of an effort to supplement the NHTSA report in characterizing rear-end traffic accidents in the U.S. The details of this work are contained in Volume II of the Task 1 Interim Report. Additional statistical information presented within this report is important to some aspects of system design and analysis and in system trade-off and benefits analysis. Data sources used include the NHTSA Fatal Accident Reporting System (FARS), various aspects of the National Accident Sampling System (NASS), particularly the General Estimates System (GES), state data files from Michigan Texas and Washington and some reference to the literature.

The report consists of the following:

- A discussion of the data sources used in the NHTSA reports.
- A presentation of tabular and graphical material concerning the frequency of rear-end collisions as observed in several accident files.
- A study of the 1992 NASS GES with the five new pre-crash variables.

These items are summarized in the following paragraphs,

3.2 CRITIQUE OF PROBLEM SIZE ASSESSMENT

The NHTSA FARS and NASS GES seem to provide the best source of information available for initial inquiry into the rear-end collision problem. Additional data used to make more subtle analysis should be obtained through the use of clinical data and use of the GES or FARS should be limited to verification of the clinical data. The NHTSA FARS database is a census and should be considered a relatively complete record of U.S. fatal accidents, and any random biases that occur within the data file are presumed small enough to be neglected. The GES database appears robust enough to allow reasonable estimates of the characteristics of the rear-end collisions. However, large discrepancies exist between databases such as the 1992 NASS GES and the 1991 NASS CDS or MDAI files. In most cases the GES can be used to make broad reasonable estimates of the rear-end crash problem, but more subtle, or more accurate, analysis should come from in-depth review of clinical cases with a sufficiently large sample size to provide statistical meaning.

Also, numerous discrepancies exist when new variables are introduced in any database collection. This can typically be caused by lack of instruction and guidance to the investigators, problems with providing uniquely interpreted variable, new variables contradicting other established or existing variables, or errors pertaining to entering the codes for the new variables (this is a problem even for existing variables).

The following recommendations exist when working with any of the mass databases:

- Increase the estimated number of police reported rear-end collisions by 15%.
- A similar increase or decrease should be considered for the number of non-police reported rear-end collisions. Further study is required to determine a more defensible number.
- Decrease the estimated number of "A" injuries for the southern region of the U.S. by 50% or decrease the total estimated "A" injuries in rear-end collisions by 25%.
- Increase by 40% the GES estimated number of rear-end collisions in urban areas and adjust the effects thereof, like time of day, etc.
- For conflicts between old variables and new variables added to the mass database, err on the side of the old variables.
- Only use the mass database to estimate broad (high) statistical meaning. For subtle analysis, and/or in-depth analysis use a clinical type database and use the mass database to verify the findings.
- Be aware that numerous conflicts exist in the coding present within all the databases GES, CDS, etc.

3.3 ACCIDENT FACTORS OBSERVED IN SEVERAL DATA SETS

This section presents the analysis of three accident data files, the 1989 NASS GES and state files from Michigan and Texas to supplement or confirm the NHTSA analysis. In most cases the results of the analysis confirm the previous NHTSA analysis.

The results of the 1989 NASS GES analysis may be summarized as follows:

- Eighty-five percent of rear-end collisions involve only two vehicles.
- Forty-six percent occurred in areas with populations of <25,000 and 29% in areas with populations >100,000.
- Rear-end collisions were about equally split between occurring at a non-junction and at an intersection or access.

- There was about an equal split between non-divided and divided or one-way streets.
- There was about an equal split between two-lane and multiple-lane roads.
- Ninety-one percent of the collisions occurred on straight roads.
- Sixty-three percent (with unknowns equally distributed) occurred on level roads.
- Seventy percent of the rear-end accidents occurred on dry roads with 24% occurring on wet roads.
- Sixty percent occurred with no traffic control device present and 26% occurred with a stop-and-go light.
- Seventy-five percent occurred under light conditions with 14% under dark-but-lit conditions.
- Seventy-eight percent occurred under no adverse weather conditions and 16% in rain.
- Ninety-nine percent of rear-end collisions did not involve a school bus.
- Sixty-seven percent of rear-end collisions did not involve an injury and 23% had a possible injury.
- Alcohol was not involved in 95% of the rear-end collisions.

3.4 1992 NASS GES

The 1992 NASS GES file was recently made available to the public, and this section presents an analysis to update and augment the previous analysis. The results of the analysis are summarized below. It should be noted that there are some inconsistencies between coding of essentially the same accident parameter in different variables.

- Fifty-nine percent of the lead vehicles were stopped, 24% were slower and 13% were decelerating as coded in the accident type variable.
- In the pre-crash variables, 54% of the lead vehicles were coded as stopped and 54% had no corrective action taken while 68% of the following vehicles were coded as going straight and with no corrective action in 62% of the cases. Striking driver maneuver to avoid was coded as no maneuver in 90% of the cases.
- Eighty percent of the rear-end collisions occurred in clear weather.
- Seventy-six percent occurred in light conditions.
- Seventy-three percent occurred on dry roads.
- Ninety-five percent occurred on straight roads and 76% on level roads.
- Junctions, land use, number of lanes, alcohol, vision obstructions and driver distractions were not factors in the accident.

SECTION4
1991 NASS CDS SUMMARY

This section summarizes the results of the analysis on the 1991 NASS CDS. The details of this work are contained in Volume III of this report and further summary information is in Section 8 of this volume.

A search of the 1991' NASS CDS database found 111 cases of two-vehicle, rear-end collisions that were listed with delta-v calculated. Of these 111 cases, 59 were selected. The hard copy files on the 59 cases were obtained and reviewed for this analysis.

An important classification within the rear-end crash category is the dynamic situation. The dynamic situation further defines the events leading to a rear-end collision. For the purpose of the analysis performed on the 1991 NASS CDS, a dynamic situation is defined as referring to the motion of the two vehicles with respect to each other prior to either driver recognizing a potential collision problem and prior to the critical pre-crash event. This is consistent with defining the dynamic situation as occurring at the same time, relative to the collision, as the pre-event movement.

There were no detailed cases in the 1991 NASS CDS involving either the lead or following vehicle accelerating. A reason for this may be is that collisions involving accelerating vehicles may be occurring at overall lower speeds and as a result neither vehicle is being towed from the scene and the case is not eligible for inclusion in the CDS.

As part of this analysis, a distinction had to be made between lead vehicle stopped and lead vehicle decelerating and stopped. There are no variables in the CDS that allow complete separation of these two dynamic situations. For the 1991 NASS CDS, if a lead vehicle was decelerating to a stop due to a traffic control device or in order to make a turn on a straight roadway, the dynamic situation was coded as lead vehicle decelerating and stopped. This is because it is believed that a forward looking sensor used in a rear-end collision avoidance system would have the lead vehicle within its view. On the other hand, if the same conditions occurred on a curved roadway, it was coded as lead vehicle stopped because it is believed that a forward looking sensor would not have the lead vehicle in its view until the lead vehicle came to a complete stop. Table 4-l shows the breakdown of the 1991 NASS CDS cases reviewed by dynamic situation.

Table 4-l Percent of Rear-End Collisions vs. Dynamic Situations, Weighted&weighted (91 CDS)

Lead Vehicle	Following Vehicle		
	Accelerating	**Constant Velocity**	**Decelerating**
Stopped	0.0% / 0.0%	23.80% / 25.42%	0.0% / 0.0%
Constant Velocity.	0.0% / 0.0%	4.59% / 11.86%	0.0% / 0.0%
Decelerating	0.0% / 0.0%	9.03% / 16.95%	4.59% / 1.69%
Accelerating	0.0% / 0.0%	0.0% / 0.0%	0.0% / 0.0%
Decel & Stopped	0.0% / 0.0%	58.24% / 44.07%	0.0% / 0.0%

In conjunction of the review of the 1991 NASS CDS to determine the dynamic situations, an estimation of the accident causal factor was performed and the results are shown in Table 4-2. The major difference between the findings of this effort and the NHTSA report is that this effort. found a much higher incidence of alcohol involvement. A reason for this may be that accidents involving alcohol are more thoroughly investigated and therefore were more likely to be included in this analysis.

Table 4-2 Percent of Rear-End Collisions vs. Accident Causal Factor (91 CDS)

Accident Causal Factor	Weighted	Unweighted	NHTSA*
Inattention	69.32%	65.52%	66.3%
Inattention/following too closely	20.63%	13.79%	19.4%
Alcohol/Drug Involvement	8.36%	13.79%	2.1%
Poor Judgment	1.37%	3.45%	0.4%
Poor/Degraded Roadways	0.30%	1.72%	2.4%
Encroachment of another vehicle	0.01%	1.72%	1.1%

*Based on the total findings from "Assessment of IVHS Countermeasures for Collision Avoidance REAR-END CRASHES", May 1993 Table 3-1: Rear-End Crash Causal Factor Analysis, pp3-7.

SECTION 5
1992 NASS CDS SUMMARY

This section summarizes the results of the analysis on the 1992 NASS CDS. The details of this work are contained in Volume IV of this report and further summary information is in Section 8 of this volume.

A search of the 1992 NASS CDS database identified 135 cases of two-vehicle, rear-end collisions that were listed with delta-V calculated for each vehicle and an attempted avoidance maneuver coded for both vehicles. A review of these 135 hard copy cases along with the police accident reports was performed at Zimmerman Associates Inc., in Arlington, Virginia. An estimation of the dynamic situations based on the accident type, pre-crash variables, scene diagram and pictures of the accident scene was performed.

Table 5-l shows the breakdown of the 1992 NASS CDS cases reviewed by dynamic situation.

Table 5-l Percent of Rear-End Collisions vs. Dynamic Situations, Weighted/Unweighted (92 CDS)

Lead Vehicle	Following Vehicle		
	Accelerating	**Constant Velocity**	**Decelerating**
Stopped	0.54% / 0.74%	23.72% / 20.74%	0.69% / 1.48%
Constant Velocity	0.74% / 2.22%	2.80% / 7.41%	0.0% / 0.0%
Decelerating	0.0% / 0.0%	14.71% / 14.81%	4.59% / 1.69%
Accelerating	0.0% / 0.0%	2.07% / 3.70%	0.0% / 0.0%
Decel & Stopped	0.11% / 0.74%	50.05% / 45.93%	4.57% / 2.22%

In conjunction of the review of the 1992 NASS CDS to determine the dynamic situations, an estimation of the accident causal factor was performed and the results are shown in Table 5-2. As in the 1991 NASS CDS analysis, the major difference between the findings of this report and the NHTSA report, is that this report found a much higher incidence of alcohol involvement. A reason for this may be that accidents involving alcohol are more thoroughly investigated and therefore were more likely to be included in this analysis

Table 5-2 Percent of Rear-End Collisions vs. Accident Causal Factor (92 CDS)

Accident Causal Factor	Weighted	Unweighted	NHTSA*
Inattention	44.01%	42.22%	40.5%
Alcohol/Drug Involvement	16.55%	17.04%	2.1%
Inattention/following too close	11.55%	12.59%	26.5%
External Distraction	8.62%	5.19%	13.9%
Poor Judgment	7.63%	8.15%	0.4%
Driver's Vision Obscured	4.70%	2.22%	0.1%
Too fast for conditions	2.04%	2.22%	2.3%
Internal Distraction	1.94%	3.70%	10.2%
Encroachment of another vehicle	1.34%	2.22%	1.1%
Disability	0.95%	1.48%	1.7%
Inattention/too fast for conditions	0.67%	2.96%	N/A

*Based on the total findings from "Assessment of IVHS Countermeasures for Collision Avoidance: REAR-END CRASHES", May 1993.

Table 3-1: Rear-End Crash Causal Factor Analysis, pp3-7.

SECTION 6
1985 NASS SUMMARY

This section summarizes the results of the analysis on the 1985 NASS . The details of this work are contained in Volume V of this report and further summary information is in Section 8 of this volume.

A search of the 1985 NASS database found 134 cases of two-vehicle, rear-end collisions that were listed with delta-v calculated. It was determined that the computer database was adequate and a review of the hard copy cases was not required. The 1985 NASS was selected to provide additional insight into roadway variables, such as profiles, surface types, etc., that are no longer available in the 1991 or 1992 NASS CDS.

Most rear-end collisions were coded as occurring on level roadways. Hillcrest and sag were rarely coded. Rear-end collisions occurring on grades happened about one-third the time. The 1985 NASS has a much higher percentage of rear-end collisions occurring on grades than does the 1991 or 1992 NASS GES, but for a rear-end collision avoidance system, it is not the grade but the change-in-grade that may affect system performance. For a rear-end collision avoidance system to function properly, it must be able to sense the vehicle in front and not other objects. Depending on the type of system, the amount of returned energy from roadway objects such as signposts and the road itself can cause problems. This returned energy is usually denoted as clutter. It is undesirable and very difficult to eliminate. Changes-in-grade may increase the amount of clutter seen by a rear-end collision avoidance system.

The most co&on roadway surface types are asphalt (bituminous) and concrete. All other surface types occur in such a small percentage that they could be ignored for all practical purposes. The surface type may affect the amount of clutter seen by a rear-end collision avoidance system. Surface type is also useful in establishing coefficients of friction for various surface conditions.

Most rear-end collisions were coded as occurring on straight roadways. No definition of a straight roadway was found for the NASS coding. For a rear-end collision avoidance system, the roadway should be straight within the beam or scan width of the sensor to the maximum detection distance of the sensor, or at a minimum to the distance that will allow the system to warn the driver in time to avoid the collision. At some point the roadway curvature may become too great for the rear-end collision avoidance system to be effective. Also roadway curvature introduces additional roadway features that may be sources for clutter and false alarms. For a rear-end collision avoidance system to be effective, it must operate on curved roadways. The amount of curvature allowable versus system effectiveness is being established in the simulation effort in Task 4.

It is necessary for a rear-end collision avoidance system to operate at various speeds of both the lead and following vehicles. Examining the data from the 1985 NASS the upper boundary on estimated travel speed appears to be 70 mph. This places the relative speed between the two vehicles within the range of 5-70 mph.

A rear-end collision avoidance system is likely to encounter differing types of roadway surface conditions. Most collisions are coded as occurring on dry roadways. Wet roadways occur approximately twenty-five percent of the time according to the 1985 NASS. Accidents that occur on roadways other than dry or wet happen less than five percent of the time.

SECTION 7
HUMAN FACTORS STUDIES

The human factors report reviews and examines the applicable literature on the driver/human factors issues that contribute to rear-end collisions. In addition to a review of the literature, a detailed rear-end crash scenario is discussed. By understanding the complex driver/human factors of the rear-end collision and how these factors affect the timeline of an impending crash, more effective collision avoidance systems can be designed. The details of the human factors studies are contained in Volume VI of this report.

The purpose of the human factors report is to build a framework for evaluating and describing all driver/human factors issues involved in rear-end collisions. In order to make recommendations for system specification, all issues relating to rear-end crashes must be understood. This review describes only literature and findings relevant to the rear-end crash scenario and discusses each related factor in detail. An annotated bibliography is included as an addendum to Volume VI to provide the reader with a source for more detailed information.

The human factors report examines the literature on driver/human factors, relevant behavioral research, and previous research on collision intervention systems. The report also describes the type of collision intervention systems that have been or are being considered in driving research. The systems described are based on definitions provided by NHTSA. The report reviews past and present collision intervention systems found in the literature. Systems which display a warning to the driver are discussed along with intervention systems that provide automated avoidance countermeasures. The report also describes previous rear-end collision models, display issues, and the framework for a future rear-end collision prediction model. Different driver interface factors that contribute to the design of collision intervention systems is also investigated. False and nuisance alarms and warning frequency are reviewed, as well as display modality, following the discussion of prediction models. Elimination of variables from models that have little useful prediction value are discussed. A framework for new prediction models for rear-end collisions is presented.

SECTION 8
SUMMARY

8.1 INTRODUCTION

As previously stated, the primary objective of this program is to develop practical performance specifications for rear-end collision avoidance systems. Section 2 presented a preliminary framework to be used to develop a performance specification for rear-end collision avoidance systems. The framework should not be considered all-inclusive, but it reflects knowledge and information gathered to this point in the program. The list is essentially technology independent, and the items within the list are not broken down by the type of system (i.e., headway maintenance system, driver warning system or automatic control system). As a result, not all items are applicable to all three system types. A final performance specification may be unique to the type of system. This section ties the data from the six volumes of this report to the framework presented in Section 2.

8.2 ACCIDENT CHARACTERISTICS

8.2.1 Dynamic Situations

As previously defined, a dynamic situation refers to the motion of the two vehicles prior to either driver recognizing the potential for a collision. Table 8.2.1-1 shows the best estimate of occurrence of dynamic situations and is primarily based on the clinical analysis performed on the 1991 and 1992 NASS CDS.

Table 8.2. l-l Rear-End Collisions versus Estimated Dynamic Situation, (91 and 92 CDS)

Lead Vehicle	Following Vehicle		
	Accelerating	**Constant Velocity**	**Decelerating**
Stopped	1%	18%	1%
Constant Velocity	2%	7%	0
Decelerating	0	14%	3%
Accelerating	0	2%	0
Decel & Stopped	1%	50%	1%

It was discovered that most rear-end collisions occur with the following vehicle traveling at a constant velocity, and under that category, with the lead vehicle decelerating and stopped.

Whether a particular accident should be classified as lead vehicle stopped or lead vehicle decelerating and stopped was based on judgment in many cases. The basis of this judgment assumes certain roadway features that would affect a rear-end collision avoidance system.

8.2.2 Accident Type

The accident type is useful in determining the dynamic situation from the mass database files. The accident type is not necessarily a specification issue since all presented accident types must be addressed for a rear-end collision avoidance system to be effective. The accident type statistics tend to correlate between databases and are useful for determining statistical meaning for small accident sample sizes.

8.2.3 Lead Vehicle Moving Versus Lead Vehicle Stationarv

Rear-end crashes can be classified into two major categories that vary with respect to causal circumstances: lead vehicle stationary (LVS) and lead vehicle moving (LVM). It was found that approximately 70% of rear-end collisions were LVS and 30% were LVM. This parameter is not particularly useful in the development of a specification except to point out the fact that stationary vehicles must be detected. A rear-end collision avoidance system may be greatly simplified by only requiring moving vehicles to be detected.

8.2.4 Travel Speed

There were three travel speed matrices presented, one for each of the clinical analysis performed. The maximum velocity typically encountered was 70 mph and the minimum velocity encountered was 5 mph. This places the relative velocity between the two vehicles within the range of 5-70 mph. These relative velocities are useful for the simulation effort in Task 4.

8.2.5 Striking Vehicle Pre-Crash Variables

The five pre-crash variables are new for the 1992 NASS CDS and GES except for "'Attempted Avoidance Maneuver". As part of the analysis, the other four pre-crash variables were estimated for the 1991 NASS CDS. The most commonly coded striking vehicle pre-event movement (GV64) was "going straight". Over ninety percent of the cases reviewed in the 1992 NASS CDS and the 1991 NASS CDS were coded or estimated this way. "Slowing or stopping in traffic lane" was coded about five percent of the time. Other codmgs occurred in a small enough percentage that they could be ignored. The most commonly coded striking vehicle critical pre-crash event (GV65) was “other vehicle in lane stopped”. Over eighty percent of the cases reviewed in the 1991 NASS CDS were estimated this way and over sixty percent of the cases reviewed in the 1992 NASS CDS were coded this way. “Other vehicle in lane with slower speed” was coded or estimated about twenty percent of the time in both the 1991 and 1992 NASS CDS. “This vehicle traveling too fast for conditions” was coded about eighteen percent of the time in the 1992 NASS CDS. The most commonly coded striking vehicle attempted avoidance maneuver (GV14) was “Braking”. Fifty-six percent of the cases reviewed in the 1991NASS CDS were coded this way and sixty percent of the cases reviewed in the 1992 NASS CDS were coded this way. "No avoidance actions” was only coded as happening twenty percent of the time. This contradicts the data presented in the 1992 NASS GES that codes corrective action attempted (V27) as typically "No corrective action attempted”. Over sixty percent of the accidents in the 1992 NASS GES are coded this way. Only twelve percent of the accidents in the 1992 NASS GES are coded with a corrective action as “braked/slowed”. The most commonly coded striking vehicle pre-crash stability after avoidance maneuver (GV66) are “skidding longitudinally” (52%), “tracking” (33%) and “‘no avoidance actions” (13%) in the 1992 NASS CDS cases reviewed. The most commonly coded striking vehicle pre-crash directional consequences of avoidance maneuver (GV67) are “vehicle stayed in travel lane” (76%) and “no avoidance maneuver” (13%) in the 1992 NASS CDS cases reviewed. The pre-crash variables along with the accident type were useful in determining the dynamic situation from the 1991 and 1992 NASS CDS cases reviewed. However, numerous errors or inconsistencies were found in the coding of the new pre-crash variables in both the CDS and GES.

8.2.6 Struck Vehicle Pre-Crash Variables

The most commonly coded struck vehicle pre-event movement (GV64) was “stopped in traffic lane”. Over eighty percent of the cases reviewed in the 1991 NASS CDS were estimated this way and over sixty-six percent of the cases reviewed in the 1992 NASS CDS were coded this way. ‘Slowing or stopping in traffic lane” was coded about fifteen percent of the time. The most commonly coded striking vehicle critical pre-crash event (GV65) was “other vehicle in lane traveling in same direction with higher speed”. Over ninety-six percent of the cases reviewed in the 1991 NASS CDS and the 1992 NASS CDS were coded or estimated this way. The most commonly coded striking vehicle attempted avoidance maneuver (GV14) was “no avoidance actions”. ninety percent of the cases reviewed in the 1991 NASS CDS and the 1992 NASS CDS were coded or estimated this way. The most commonly coded striking vehicle pre-crash stability after avoidance maneuver (GV66) is “no avoidance maneuver”. Over ninety percent of the cases reviewed in the 1991 NASS CDS and the 1992 NASS CDS were coded or estimated this way. The most commonly coded striking vehicle pre-crash directional consequences of avoidance maneuver (GV67) is also "no avoidance maneuver". Again over ninety percent of the cases reviewed were coded this way. The pre-crash variables along with the accident type were useful in determining the dynamic situation from the 1991 and 1992 NASS CDS cases reviewed. However, numerous errors or inconsistencies were found in the coding of the new pre-crash variables in both the CDS and GES.

8.3 ENVIRONMENTAL CONDITIONS

8.3.1 Atmospheric Condition

According to an unweighted estimate from the 1992 NASS GES, eighty percent of all rear-end collisions occur during clear weather. Seventeen percent occur during rain, about two percent during snow and all other atmospheric conditions occur in the remaining one percent. All systems will be somewhat affected by atmospheric conditions. For a collision avoidance system to be effective it must, at a minimum, operate during clear weather conditions. A robust system would operate during rain, but the amount of ram that a rear-end collision avoidance system must operate in must be determined. Most rear-end collision avoidance system designers should design for a specified amount of rain and then test their system to determine the actual system degradation due to rain.

8.3.2 Light Condition

According to an unweighted estimate from the 1992 NASS GES, seventy-six percent of all rear-end collisions occur during daylight conditions. Fourteen percent occur during dark-but lit conditions, about six percent during dark conditions and about four percent occur during dawn/dusk conditions. The light condition may be important for a system that works in the visible spectrum of light and may be susceptible to degradation from very dark conditions or very bright conditions.

8.4 ROADWAY CHARACTERISTICS

8.4.1 Roadway Surface Conditions

According to an unweighted estimate from the 1992 NASS GES, seventy-three percent of all rear-end collisions occur during dry roadway surface conditions. Twenty-four percent occur during wet roadway surface conditions, about two percent during icy roadway surface conditions and about one percent occur during snowy or slushy roadway surface conditions.

At a minimum a rear-end collision avoidance system needs to work during dry roadway surface conditions. A more robust system would also operate with wet roadway surface conditions and this would eliminate approximately ninety seven percent of the collisions. The remaining roadway surface types, snow, ice, etc., occur with such infrequency that they could be ignored. Wet roadway surface imposes additional requirements on a rear-end collision avoidance system. First it is likely that in traffic conditions the water on the roadway surface would become airborne as vehicles passed over the surface. This water spray may affect the system like rain would under atmospheric conditions. Also a wet roadway surface will affect the stopping distance required by a vehicle and this may require a rear-end collision avoidance system to adjust the desired headway to the vehicle in front to provide additional stopping distance.

8.4.2 Roadway Surface Type

According to the 1985 NASS, eighty-eight percent of the roadway surface types on which rear-end collisions occur are asphalt (bituminous). Twelve percent of the rear-end collisions occur on concrete. All other surface types are involved in such a small percentage that they can be ignored.

8.4.3 Roadway Coefficient of Friction

The roadway coefficient of friction has been related to vehicle deceleration measured in g's for the purpose of the analysis and simulation effort in Task 4. The following vehicle deceleration is modeled as a constant value starting at brake application and ending when the following vehicle speed drops to zero. The deceleration is random and uniformly distributed over the limits listed in Table 8.4.3-l for the four road conditions. These values are based on models described by Knipling et.al. (previously cited) and by Gillespie in "Fundamentals of Vehicle Dynamics", Society of Automotive Engineers. The limits set on vehicle deceleration tend to be conservative when compared with actual testing that has occurred on vehicles.

Table 8.4.3-l Deceleration vs. Roadway Condition

Road Condition	**Deceleration in G's**
Dry	**0.50 to 0.85**
Wet	**0.26 to 0.36**
Snow	0.15 to 0.25
Ice	0.05 to 0.14

8.4.4 Roadway Alignment (Horizontal)

The roadway's horizontal alignment refers to whether the roadway is straight, curved right or curved left. Most accidents, approximately ninety-five percent according to an unweighted sample of the 1992 NASS GES, are coded as occurring on straight roadways. This "straightness" of a roadway may be over-represented, especially to a rear-end collision avoidance system. For a rear-end collision avoidance system the roadway must be straight within the beam or scan width of the radiated energy to the maximum detection distance of the sensor or at a minimum to the dice that will allow the system to warn the driver in time to avoid the collision. After performing a clinical analysis on 135 cases of the 1992 NASS CDS, only seventy-eight percent of the roads would probably be considered straight to a rear-end collision avoidance system. Twenty percent would be considered curved right and two percent would be considered curved left. As part of the analysis and simulation effort in Task 4, a determination of system effectiveness versus roadway curvature is being performed.

8.4.5 Roadway Profile

The roadway's vertical alignment refers to whether the roadway is level, has a grade, hillcrest, other or unknown. According to an unweighted sample from the 1992 NASS GES, seventy-six percent of all rear-end collisions happen on level roadways. Hillcrest and sag are coded so infrequently that they can be ignored. Twenty-three percent of rear-end collisions are coded as occurring on grades. The 1985 NASS has a higher occurrence of rear-end collisions happening on grades than the 1992 NASS GES. After performing a clinical analysis on 135 cases of the 1992 NASS CDS, fifty-five percent of the roadways may be considered by the rear-end collision avoidance system ad having a grade. Forty-three percent would be considered level and two percent would be considered a hillcrest. The "grade" of a roadway would not be any different to a rear-end collision avoidance system than a "level" roadway. The difficulty to a rear-end collision avoidance system involves points in roadways where a change-in-grade occurs. This could cause the vehicle in front to not be detected by the sensor or could cause system degradation due to large amounts of returned energy from the roadway surface.

8.4.6 Lane Width

The lane width relates to the physical width of the travel lane. Typical lane widths vary from eleven to thirteen feet. For the purpose of analysis and simulation, twelve feet is a good rule of thumb. To verify this rule of thumb, a search of the 1985 NASS was performed and the highest percentage (14%) of the recorded lane widths for rear-end collisions was found to be twelve feet. The lane width is important in specifying beam width for the sensor and possibly scan width for scanned systems. The lane width may also require a system to handle multiple vehicles simultaneously at longer ranges.

8.5 VEHICLE CHARACTERISTICS

8.5.1 Striking Vehicle Body Type

By knowing the type of vehicle that the rear-end collision avoidance system is installed upon, a more accurate determination of the braking, steering and acceleration dynamics can be made.

8.5.2 Struck Vehicle Body Type

The range of body types that the sensor will be viewing is useful in possibly categorizing the vehicle cross section.

8.5.3 Struck Vehicle Cross Section

The struck vehicle cross section, usually in square meters, gives a general indication of the amount of reflected energy from the vehicle in the forward path. This is important in the detection of the lead vehicle. The struck vehicle cross section will vary depending on the type of sensor technology used.

8.5.4 Vehicle Braking Dynamics

A good source of braking distances for various new vehicles is Motortrend magazine. The braking distances are specified in stopping distance in feet from 60 mph to 0 mph. The deceleration characteristics currently being used for the analysis and simulation effort were presented in Section 8.4.3, roadway coefficient of friction.

8.5.5 Vehicle Steering; Dynamics

Steering dynamics are necessary for systems that would take evasive action to avoid a collision by steering away from the impending collision. It is believed that for a rear-end collision avoidance system to steer away from a potential hazardous condition that the system would have to work in conjunction with a side looking system.

8.5.6 Vehicle Acceleration Dynamics

Acceleration dynamics may be important to systems that provide autonomous intelligent cruise control and/or cooperative intelligent cruise control. Acceleration dynamics were not studied in association with the Task 1 interim report.

8.6 DRIVER CHARACTERISTICS

8.6.1 Driver Reaction Time

Numerous research has been performed to quantify driver reaction time. The current best estimate will be utilized in developing the specification. The response of the driver to the system interface is currently being modeled as a time delay of 0.3 seconds. The driver response is being modeled as a random time delay which is Log normal distributed with a mean value of 1.14 seconds and a standard deviation of 0.32 seconds. This is a widely accepted model described by Toaka in "Brake Reaction Times of Unalerted Drivers", ITE Journal, March 1989.

8.7 SYSTEM CHARACTERISTICS

System characteristics are those items that are unique to the rear-end collision avoidance system. It was not the purpose of this Task 1 interim report to determine system characteristics. Consequently, no attempt is made within this report to summarize or draw conclusions regarding system characteristics.

8.8 REAR-END COLLISION CAUSAL FACTORS

As part of the analysis on the 1991 NASS CDS and the 1992 NASS CDS, a determination of the accident causal factor was performed. The accident causal factor was selected from the following list:

- Inattention
- Alcohol/Drug Involvement
- Inattention/following too closely
- External Distraction
- Poor Judgment
- Driver's Vision Obscured
- Too fast for conditions

- Internal Distraction
- Encroachment of another vehicle
- Disability
- Inattention/too fast for conditions

Other accident causal factors may exist, but were not used as part of this analysis.

As part of the analysis, vehicular failure was eliminated as a cause.This was done because it is believed that accidents caused by vehicular failure of the striking (following) vehicle were unavoidable. Accidents involving vehicular failure of the struck (lead) vehicle, such as disabled in travel lane, were considered valid avoidable accidents.

The category "Too fast for conditions" was used to replace the "Poor/Degraded Roadways" category. This is because accidents caused by wet, slippery, etc. roadways are not due to poor or degraded roadways but due to the driver's inability to recognize the degraded road surface and adjust driving habits accordingly.

Table 8.8-l shows the distribution of the two analyses performed compared with the work from the NHTSA report.

Table 8.8-l Accident Causal Factors

Accident Causal Factor	1991 NASS CDS	1992 NASS CDS	NHTSA*
Inattention	69.32%	44.01%	40.5%
Alcohol/Drug Involvement	8.36%	16.55%	2.1%
Inattention/following too close	20.63%	11.55%	26.5%
External Distraction	N/A	8.62%	13.9%
Poor Judgment	1.37%	7.63%	0.40%
Driver's Vision Obscured	N/A	4.70%	0.1%
Too fast for conditions	0.30%	2.04%	2.3%
Internal Distraction	N/A	1.94%	10.2%
Encroachment of another vehicle	0.01%	1.34%	1.1%
Disability	N/A	0.95%	1.7%
Inattention/too fast for conditions	N/A	0.67%	N/A

*Based on the total findings from "Assessment of IVHS Countermeasures for Collision Avoidance: REAR-END CRASHES", May 1993.

Table 3-1: Rear-End Crash Causal Factor Analysis, pp3-7.

The analysis performed with the 1992 NASS CDS included a review of the police accident reports. The analysis performed with the 1991 NASS CDS only used the hard copy data files for review purposes. One major difference from the NHTSA report is the higher instance of alcohol involvement. This higher instance of alcohol involvement may be due to more thorough investigation of cases involving alcohol and a consequently greater likeliness of review under this analysis.

Accidents involving disabilities or encroachment of another vehicle may be unavoidable even when using a rear-end collision avoidance system. Accidents involving alcohol/drug involvement, poor judgment, or driver's vision obscured should be mitigated or avoidable by using a rear-end collision avoidance system. All other accidents should be avoidable through proper use of a rear-end collision avoidance system.

8.9 FOLLOWING WORK

The Task 1 interim report establishes a baseline for generating a set of performance specifications for a rear-end collision countermeasures systems. Most of the information presented within this report will be used to stimulate the simulation and analysis phase (Task 4) of this contract. The information required for the specification has also been used to define the testing of existing systems in Task 3. The information presented within this report will be used to develop the functional goals as part of Task 2.

Functional goals, as defined in Task 2, are a qualitative description of the data processing algorithms which will drive the processing function. Functional goals can also be defined as changes to the situation that would help to eliminate or mitigate the severity of rear-end collisions. Functional goals will possibly be unique to each category of system and each dynamic situation.

To derive the functional goals in Task 2, a taxonomy of collision subsets and crash-related events will be developed. The taxonomy will be a three dimensional matrix that serves to order the functional goals by system type, dynamic situation and situation modifiers (such as environmental conditions, etc.).

Task 4 will be followed by Tasks 5 through 7 where a rear-end collision countermeasures system will constructed/acquired whose performance goal is to meet the preliminary performance specifications identified in Task 4. Testing of this system will take place in Task 8, leading to the generation of a final performance specification in Task 9.